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DIE DESIGN HANDBOOK

A PRACTICAL REFERENCE BOOK ON PROCESS ANALYSIS, PRODUCT DESIGN, METAL MOVEMENTS, MATERIALS, AND PROVED DIE DESIGNS FOR EVERY CLASS OF SHEET-METAL PRESSWORKING

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DIE DESIGN HANDBOOK

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PREFACE

The planned objective of the "Die Design Handbook" has been to provide die designers and users with rapid access to the distinctive design details of hundreds of dies that have proved superior in cold metal-pressworking operations.

Characteristically, the data are intended to serve the men who already know how to design dies, but have some specific design problem and hope to avoid the delays of costly development by learning how someone else has already conquered the difficulty.

The Handbook planners have insisted that die design cannot stand alone in a really useful handbook, but must be related in an orderly way to the design of the part to be produced, to the properties of die and stampings materials, to the optimum processing available, to the components that can better be purchased, and to the available pressroom facilities.

Space considerations have prevented discussion of the hot working of metal, because of the extensive data that would be required due to the fundamental differences in metallurgy, product and tooling design, and equipment and operations, as compared to cold pressworking. Nor has space permitted entering further into pressroom practice than to give brief criteria for selecting presses, lubricants, and handling equipment, and to set and try out the die. Either subject would deserve a separate handbook for adequate coverage.

Because of the all-member and all-industry cooperation received, acknowledgements must be general, but nonetheless sincere and cordial:

To the hundreds of members who replied in detail to advance surveys designed to find out what topics should be covered.

To the scores of companies and individuals who made the raw material available, often with request that there be no identified recognition.

To the Society's editorial staff, for their valiant labors in skill and patience.

To the official industrial reviewers, for conscientious work that has augmented the book's accuracy and practicality.

To the ASTE National Book Committee, not only for their skill in plan and policy, but also for cheerful readiness to examine material, review manuscript, and, in fact, to do anything that needed doing.

To National Officers of the Society, for patient awareness that designing and building a primary reference book takes much time and means.

FRANK W. WILSON

CONTENTS

SECTION 1

PRESSWORKING TERMINOLOGY*,†

Accumulator, hydraulic: A device employed in hydraulic machinery for storing energy.

Air cushion: An air-actuated die cushion.

Air draw: A draw operation performed in a single-action press with the blankholder pressure supplied by an air cushion.

Air-hardening steel: An alloy steel, also called self-hardening steel, that will harden by cooling in still air from a temperature higher than the transformation range.

Allowance, metal: The area of excess metal needed to complete any subsequent processing.

bend: (See Bend allowance.)

Alloy: A substance that has metallic properties and is composed of two or more chemical elements of which at least one is a metal.

Annealing: A process involving the heating and cooling of a metal, commonly used to induce softening. The term refers to treatments intended to alter mechanical or physical properties or to produce a definite microstructure.

Bead: A narrow ridge in a sheet-metal workpiece or part, commonly formed for reinforcement.

draw: (a) A bead used for controlling metal flow; (b) riblike projections on draw-ring or hold-down surfaces for controlling metal flow.

Bed, adjustable: A press bed which can be raised or lowered.

Bed, press: The stationary and usually horizontal part of a press that serves as a table to which a bolster plate or lower die assembly is mounted.

Bend allowance: The developed arc length along the neutral axis of bent metal.

Bend angle: The angle through which a bending operation is performed.

Bending: The straining of material, usually flat sheet or strip metal, by moving it around a straight axis which lies in the neutral plane. Metal flow takes place within the plastic range of the metal, so that the bent part retains a permanent set after removal of the applied stress. The cross section of the bend inward from the neutral plane is in compression; the rest of the bend is in tension.

Bend radius: (a) The inside radius at the bend in the work; (b) the corresponding radius on the punch or on the die.

Bevel (angle): Ninety degrees minus the bend angle of a flange. For bend angles of less than 90° the bevel (angle) is termed an "open bevel"; for bend angles over 90°, the bevel (angle) is termed a "closed bevel."

Blank: A pressed metal shape, ready for a subsequent press operation.

Blank development: (a) The technique of determining the size and shape of a blank; (b) the resultant flat pattern.

Blankholder: The part of a drawing or forming die which holds the workpiece against the draw ring to control metal flow.

* Reviewed by E. E. Charlton, Division Supervisor, W. N. Collier, Foreman, and A. E. Lehman, Designer, Punching, Tool and Die Division, General Electric Co.

† Certain of the definitions are taken or adapted from the volumes listed in the references at the end of this section.

Blanking: The operation of cutting or shearing a piece out of stock to a predetermined contour.

Block, heel: (*See* Heel block.)

Bolster plate: A plate secured to the press bed for locating and supporting the die assembly.

Buckling: A bulge, bend, kink, or other wavy condition of the workpiece caused by compressive stresses.

Bulging: The process of expanding the walls of a cup, shell, or tube with an internally expanding segmental punch or a punch composed of air, liquids, or semiliquids, such as waxes or tallow, or of rubber and other elastomers.

Burnishing: The process of smoothing or plastically smearing a metal surface to improve its finish.

Burring: A common term for "deburring" or smoothing the rough cut edges of metal.

Burr side: The side of a punched blank that presents a rough edge around its periphery or around a hole or opening in it. In blanking operations, it is the face or side of the blank that comes in direct contact with the punch. In piercing or perforating operations, it is the face or side of the blank that comes in direct contact with the die.

Bushing, guide-post: A replaceable insert usually fitted in the upper shoe to provide better alignment.

Cam action: A motion at an angle to the direction of an applied force, achieved by a wedge or cam.

Camber: A slight convexity or bulging of sheet, strip, or plate as might appear when looking along the edge.

Capacity, press: The amount of force, in tons, exerted by a press slide near the bottom of its stroke.

Carbonitriding: A process in which a ferrous alloy is casehardened by first being heated in a gaseous atmosphere of such composition that the alloy absorbs carbon and nitrogen simultaneously, and then being cooled at a rate that will produce the properties desired.

Carbon steel: A steel that owes its specific properties chiefly to the presence of carbon, without substantial amounts of other alloying elements; also termed "ordinary steel," "straight carbon steel," or "plain carbon steel."

Carburizing: A process that introduces carbon into a solid ferrous alloy by heating the metal in contact with a carbonaceous material—solid, liquid, or gas—to a temperature above the transformation range and holding it at that temperature.

Case: The surface layer, or case, of a ferrous alloy that has been made substantially harder than the interior or core.

Casehardening: Any process of hardening a ferrous alloy so that the case or surface is substantially harder than the core or interior.

Casting strains: The strains resulting from the cooling of a casting accompanied by residual stresses.

Cerromatrix: The trade name of an alloy of low melting point, used for anchoring punches and die sections.

Chute: A trough in which blanks, workpieces, or parts are fed to or conveyed from a die or press.

Clearance, die: The space, per side, between the punch and die.

Closing in: The process of forming a closed end on a tubular part.

Clutch: A device which connects and disconnects a driven machine member and a driving machine member.

Coil cradle: A stand that supports and allows rotation of coil stock.

Coinage metals: Alloys of gold or silver with nickel or copper, used for minting coins.

Coining: A closed-die squeezing operation in which all surfaces of the work are confined or restrained.

Cold heading: The process of upsetting the ends of bar, wire, or tube stock while cold.

Cold shut: A discontinuity that appears on the surface of cast metal as the result of two metal streams meeting and failing to unite.

Cold working: Working of a metal, such as by bending or drawing, to plastically deform it and produce strain hardening.

Crimping: A forming operation used to set down, or close in, a seam.

Critical temperatures: Established temperatures to which metals must be heated to produce metallurgical changes such as hardening and normalizing; also known as transformation temperatures.

Cup: Any shallow cylindrical part or shell closed at one end.

Cupping: An operation that produces a cup-shaped part.

Curling: Forming an edge of circular cross section along a sheet or at the end of a shell or tube. (*See also* Wiring.)

Cushion, hydraulic: A die cushion actuated by hydraulic pressure. (*See* Die cushion.)

Cut-and-carry method: A method in which the part under fabrication is not entirely detached from the strip, or is pushed back into the strip, for transport to a succeeding station in a progressive die.

Daylight: (See Shut height.)

Deburring: Removing burrs.

Deep drawing: The drawing of deeply recessed parts from sheet material through plastic flow of the material, when the depth of the recess equals or exceeds the minimum part width.

Deflection: The deviation of a body from a straight line or plane when a force is applied to it.

Dial feed: (*a*) A press feed which conveys the work to the dies by a circular motion; (*b*) a mechanism which moves dies under punches by a circular motion and into definite indexed positions.

Die: (*a*) A complete tool consisting of a pair or a combination of pairs of mating members for producing work in presses, including all supporting and actuating parts of the tool; (*b*) the female part of a complete die.

Die, assembling: A die which assembles and fastens parts together by riveting, press fitting, folding, staking, curling, hemming, crimping, seaming, or wiring.

bending: A die which permanently deforms sheet or strip metal along a straight axis.

blanking: A die for cutting blanks by shearing.

brake: A die used in a press brake.

burnishing: A die which improves surface or size by plastically smearing the metal surface of the part.

cam: A die in which the direction of moving elements is at an angle to the direction of forces supplied by a press.

combination: A die in which a cutting operation and a noncutting operation on a part are accomplished in one stroke of the press. The most common type of combination die blanks and draws a part.

compound: A die in which two cutting operations are accomplished in one press stroke. The most common type of compound die blanks and pierces a part.

compound-combination: A die in which a part is blanked, drawn, and pierced in one stroke of the press.

curling: A forming die in which the edge of the work is bent into a loop or circle along a straight or curved axis.

cut-and-carry: (*See* Die, progressive.)

dimpling: A forming die which produces a conical flange (stretch flange) encircling a hole in one or more sheets of metal.

dimpling, ram-coin: A forming die which forms a conical dimple in two sheets, and rivets the sheets together with some coining of a small ringlike area immediately surrounding the hole.

dinking: A die which consists of a press or hand-operated hollow punch with knife-edges for cutting blanks from soft sheet metals and nonmetallic materials.

double-action: A die in which pressure is first applied to a blank through the blank-holder and is then applied to the punch.

embossing: A die set which is relatively heavy and rigid for producing shallow or raised indentations with little or no change in metal thickness.

expanding: A die in which a part is stretched, bulged, or expanded by water, oil, rubber, tallow, or an expanding metal punch.

extrusion: A die in which a punch forces metal to plastically flow through a die orifice so that the metal assumes the contour and cross-sectional area of the orifice.

floating (or punch): A die (or punch) so designed that its mounting provides for a slight amount of motion, usually laterally.

follow: (*See* Die, progressive.)

forming: A die in which the shape of the punch and die is directly reproduced in the metal with little or no metal flow.

gang: A series of dies mounted on a die plate.

heading: (*a*) A die used in a forging machine or press for upsetting the heads of bolts, rivets and similar parts; (*b*) a die used in a horizontal heading machine for upsetting the flanged heads on cartridges and similar shells.

hemming: A die which folds the edge of the part back over on itself; the edge may or may not be completely flattened to form a closed hem.

horn: A die in which a horn, mandrel, or anvil holds the work, usually on a horizontal axis.

inverted: A die in which the conventional positions of the male and female members are reversed.

joggle: A die which forms an offset in a flanged section.

lancing: A die which cuts along a line in the workpiece without producing a separation in the workpiece without yielding a slug.

multiple: A die used for producing two or more identical parts at one press stroke.

perforating: A die in which a number of holes are pierced or punched simultaneously or progressively in a single stroke of the press.

piercing: A die which cuts out a slug (which is usually scrap) in sheet or plate material.

progressive: A die in which two or more sequential operations are performed at two or more stations upon the work, which is moved from station to station.

punching: A term interchangeable with piercing die.

riveting: A die that assembles two or more parts together by riveting.

sectional (segmental): A die, punch, or form block which is made up of pieces, sections, laminations, segments, or sectors.

shaving: A die usually having square cutting edges, negligible punch and die clearance, and no shear on either punch or die.

shimmy (Brehm trimming die): A cam-driven die which cuts laterally through the walls of shells in directions determined by the position of cams.

side-action: A type of die that operates approximately at right angles to the motion of the press slide by means of cams, wedges, or auxiliary press mechanisms.

single-action: A drawing die that has no blankholder action, since it is used with a single-action press without the use of a draw cushion.

swaging: A die in which part of the metal under compression plastically flows into contours of the die; the remaining metal is unconfined and flows generally at an angle to the direction of applied pressure.

tandem: (*See* Die, two-step.)

toggle draw: (*See* Die, double-action.)

trimming: A die that cuts or shears surplus material from stock or workpieces.

triple-action: A die in which a third force is applied to a lower punch in addition to forces applied to the blankholder and the punch fastened to the inner slide.

two-step: A drawing or reducing die in which the reduction is made in two stages or levels, one above the other, in a single stroke of the press.

waffle: A type of flattening die that sets a waffle or crisscross design in the blank or workpiece without deforming it.

wedge-action: A die which has a side motion actuated by a wedge surface. (*See* Die, cam.)

Die block: (*a*) A block or plate out of which the die proper is cut; (*b*) the block or plate to which sections or parts of the die proper are secured.

Die cushion: A press accessory located beneath or within a bolster or die block, to provide an additional motion or pressure for stamping operations; actuated by air, oil, rubber, or springs, or a combination thereof.

Die height (shut height): The distance from the finished top face of the upper shoe to the finished bottom face of the lower shoe, immediately after the die operation and with the work in the die.

Die holder: A plate or block upon which the die block is mounted.

Dieing machine: A high-speed vertical press, the slide of which is actuated by pull rods extending to the drive mechanism below the bed.

Die pad: A movable plate or pad in a female die, usually for part ejection by mechanical means, springs, or fluid cushions.

Die radius: The radius at the edge of a female die over which metal is formed or drawn into the die.

Die set: A standardized unit consisting of a lower shoe, an upper shoe, and guide pins or posts.

Die shoe: A plate or block, upon which a die holder and in which guide posts are mounted.

Die slide: An attachment for sliding the lower part of a die set in and out of the press in synchronization with the press stroke.

Die space: The maximum space within a press bounded by the top of the bed (bolster), the bottom of the slide, and any other press parts.

Die stamping: The general term for a sheet-metal part that is formed, shaped, or cut by a die in one or more press operations.

Dimpling: Localized indent forming of sheet metal, so as to permit the head of a rivet or a bolt to fasten down flush with the surface of the sheet.

Directionality in sheet metal: A property resulting from the rolling process in its fabrication at the mill so that its greatest tensile strength is in the direction of the rolling.

Dishing: Forming a large-radiused concave surface in a part.

Distortion: Any deviation from a desired contour or shape.

Double seaming: The process of joining metal edges, each edge being flanged, curled, and crimped.

Draft: The taper given to a die so as to allow the part to fall through the die or be removed.

Drawability: (a) A measure of the feasible deformation of a blank during a drawing process; (b) percentage of reduction in diameter of a blank when it is drawn to a shell of maximum practical depth.

Drawing: A process in which a punch causes flat metal to flow into a die cavity to assume the shape of a seamless hollow vessel.

Draw marks: Impressions, such as scratches, burnished areas, and similar marks left on workpieces by draw dies.

Drawpiece: Any drawn part.

Draw radius: The radius at the edge of a die or punch over which the work is drawn.

Draw ring: A ring-shaped die part (either the die ring itself or a separate ring), over the inner edge of which the metal is drawn by the punch.

Ductility: The property of a material that permits it to sustain permanent deformation in tension without rupture.

Dwell: The time interval in a press cycle during which there is no movement of a press member.

Earing: The formation of ears or scalloped edges around the top edge of a drawn shell due to directional differences in the plastic-working properties of rolled sheet metal.

Eccentric: A machine element that converts rotary motion to straight-line motion.

Ejecting: The removal of a part from a die by an air blast or mechanical means.

Elasticity: The property of a material which renders it capable of some return to its former size and shape after any deformation.

Elastic limit: The maximum stress to which a material can be subjected, and yet return to its original shape and dimensions on removal of the stress.

Embossing: A process that produces relatively shallow indentations or raised designs with theoretically no change in metal thickness.

Energy: The capacity of a body for doing work, measured in terms of force and distance.

Extrusion: The plastic flow of a metal through a die orifice.

Eyelet machine: A multiple-slide press, usually employing a cut-and-carry or a transfer feed for sequential operations in successive stations.

False wiring: Curling the edge of a sheet, shell, or tube without inserting a wire or rod inside the curl.

Feed: A device that moves or delivers stock or workpieces to a die.

Feed, roll: A die feed operated from the press slide or crankshaft, in which the stock is moved by gripping rollers.

drum: A feed in which the station dies are located on the periphery of a drum horizontally mounted in the die space.

grip (slide, hitch): A type of feed mechanism employing a set of jaws to grip strip stock and feed it to the die.

hopper: A bin designed to hold parts and with a mechanism which selects and automatically feeds individual parts into a chute.

indexing: A feed that rotates blanks and parts for various operations, usually visually indicating the position of the blank or part.

magazine: The combination of a magazine and a mechanism for holding of parts and feeding one unit of the work at a time.

Flaring: (*a*) The process of forming an outward flange on a tubular part; (*b*) forming a flange on a head.

Flash (fin): The excess metal attached to a part after a forming operation.

Flattening: The truing of metal surfaces by the use of restrike dies, or other methods.

Fluting: The forming of longitudinal recesses in a cylindrical part.

Flying cutoff device: A cutting die, saw, or wheel that cuts work to length while it is moving.

Form block: A punch or die used in the rubber-pad process to form materials.

mechanical: A special die used in rubber-pad forming to perform operations which cannot be made with the simpler, regular form blocks.

Forming: Making any change in the shape of a metal piece which does not intentionally reduce the metal thickness.

Form radius: (*See* Radius, die.)

Fouling (*pickup*): The adherence of particles of a part to a punch or die.

Gag: A metal spacer to be inserted so as to render a floating tool or punch inoperative.

Gage: A device used to position work in a die accurately.

finger: A manually operated device to limit the linear travel of material.

Galling: The friction-induced roughness of two metal surfaces in direct sliding contact.

Geneva motion (*star wheel motion*): An intermittent motion, sometimes used in dial and drum feeds, in which a part of the driving shaft's motion is transmitted to a driven shaft.

Gibs, adjustable: Guides or shoes designed to ensure the proper sliding fit between two machine parts.

Guerin process: A forming method in which a pliable rubber pad attached to the press slide is forced by pressure to become a mating die for a punch or punches which have been placed on the press bed.

Guide posts (*guide pins; leader pins*): Pins or posts usually fixed in the lower shoe and accurately fitted to bushings in the upper shoe to ensure precise alignment of the two members of a die set.

Guide, stock: A device used to direct strip or sheet material to the die.

Head block (*head*): The top member or crown of a hydraulic press, usually containing the cylinder.

Hitch feeds: (See Feed, grip.)
Hole flanging: Turning up or drawing out a flange around a hole; also called "extruding."
Horn: A cantilever block or post which acts as a die, or to which the die is fastened.
Hydropress: A single-action hydraulic press, equipped with a rubber pad.
Inching: A control process in which the motion of the working members is precisely controlled in short increments.
Indenting (pocketing): The forming of depressions of appreciable size and with fairly square walls, e.g., the indenting of the primer hole in a shell case.
Indexing: Rotating a part angularly and sequentially performing a press operation.
Inside-out redrawing: (See Reverse drawing.)
Interlock: A device mutually interacting with another device to govern succeeding operations in the same or allied devices.
Ironing: An operation in which the thickness of the shell wall is reduced and its surface smoothed.
JIC: Joint Industry Conference.
Jog (jogging): (See Inching.)
Joggle: An offset surface consisting of two adjacent, continuous or nearly continuous short-radius bends of opposite curvature.
Kirksite: Trade name of a zinc-base alloy used principally in low-production dies.
Knee: (See Bed, adjustable.)
Knife-edge cutters: (See Die, clicking.)
Knockout: A mechanism for ejecting blanks or other work from a die. Commonly located on the slide, but may be located under the bolster. (See Liftout.)
Lancing: Cutting along a line in the workpiece without producing a detached slug from the workpiece.
Leader pins: (See Guide posts.)
Lifters: (See Vacuum-cup lifters.)
Liftout (bottom knockout): A mechanism located on the bolster or press bed for ejecting a part from the die, or raising it to a level for advancing to another station as in progressive dies.
Lightening hole: A hole punched in a part for the purpose of saving weight.
Limit switch: A type of electric switch used to control the operations of a machine automatically.
Load (press): Amount of force exerted in a given operation.
Loading: (See Pickup.)
Lubricant: Any substance which has the specific property of reducing friction between two surfaces in contact.
Lüders' lines: Depressed elongated markings parallel to the direction of maximum shear stress, or elevated elongated markings appearing on the surface of some materials, particularly on iron and low-carbon steel, when deformation is beyond the yield point in tension or compression, respectively.
Magazine: A chutelike bin in which parts are uniformly positioned for feeding.
Meehanite: The trade name for nodular cast irons having high compressive strengths; commonly cast into large dies, punches, and other die elements.
Mild steel: Usually SAE 1010 to 1020 steel.
Mill finish: A surface finish produced on sheet and plate, characteristic of the ground finish on the rolls used in fabrication.
Motion diagram: A graph showing the relative motions of the moving members of a machine.
Necking (necking in): Reducing the diameter of a portion of the length of a cylindrical shell.
Nest: (a) To stack like parts within one another to occupy a minimum space; (b) a plate having an opening to conform to the contour of a part, used to locate the part in a die; (c) to lay out a blank so that the outlines of parts produced will interlock

Normalizing: A process in which a ferrous alloy is heated to a suitable temperature above the critical range and then cooled in air at room temperature.

Nosing: Forming a curved portion, with reduced diameters, at the end of a tubular part.

Notch brittleness: The inherent brittleness in areas containing a groove, scratch, sharp fillet, or notch.

Notching: The cutting out of various shapes from the edge of a strip, blank, or part.

Oil canning (canning): The distortion of a flat or nearly flat surface by finger pressure, and its reversion to normal.

Olsen ductility test: A test for indicating the ductility of sheet metals by forcing a hemispherical-shaped punch or hardened ball into the metal and measuring the depth at which fracture occurs.

Overbending: Bending metal a greater amount than that called for in the finished piece, so as to compensate for spring-back.

Overload relief bed: A press bed with a built-in cushion, usually of the hydropneumatic type, which depresses at a predetermined overload.

Pad: The general term used for that part of a die which delivers holding pressure to the metal being worked.

Parting: An operation usually performed to produce two or more parts from one common stamping.

Perforating: The piercing or punching of many holes, usually identical and arranged in a regular pattern.

Pickoff: An automatic device for removing the finished part from a die, after it has been stripped, or released from the die.

Pickup: The adherence of particles of metal to a die surface in contact with the metal being worked.

Piercing: The process of die-cutting holes in sheet or plate material.

Pilot: A pin or projection provided for locating work in subsequent operations from a previously punched or drilled hole.

Planchet: A metal disk with edges milled ready for coining.

Planishing: A hammering operation in which parts are given a dense smooth surface finish by a rapid succession of blows delivered by highly polished dies or by a planishing hammer.

Plastic flow: The phenomenon which takes place when a substance is deformed permanently without rupture.

Plasticity: The property of a substance that permits it to undergo a permanent change in shape without rupture.

Plastic working: The processing of a substance by causing a permanent change in its shape without rupture.

Platen: The sliding member or ram of a power press.

Pneumatic die cushion: (*See* Die cushion.)

Pneumatic toggle links: Main links of a toggle press which are equipped with pneumatic cushions to give air-pressure-controlled flexibility.

Prefill valve: A pressure-actuated valve required for controlling the prefilling (or exhausting) of oil during fast traverse operation of hydraulic press ram cylinder.

Preformed part: A partially formed part which will be subjected to one or more subsequent operations.

Preheating: A general term used to describe heating applied as a preliminary to some further thermal or mechanical treatment.

Press: A machine having a stationary bed or anvil, and a slide (ram or hammer) which has a controlled reciprocating motion toward and away from the bed surface and at right angles to it, the slide being guided in the frame of the machine to give a definite path of motion.

arbor: A press originally developed for forcing arbors or mandrels into holes and similar assembling.

arch type: A type of press having its columns arched outward to permit a wider bed and slide flange, left to right, between the columns.

automatic: A press whose action is synchronized with mechanically fed work.
cam: A press in which one or more of the slides are cam-actuated.
C-frame: A press having uprights or housing resembling the form of the letter C.
crank: A crankshaft-actuated mechanical press.
double-action, mechanical: A press having one slide within the other, the outer slide usually being toggle- or cam-operated, resulting in independent parallel slide movements.
double-crank: A mechanical single-action press in which two cranks on the same shaft operate the slide.
eccentric: A mechanical press in which an eccentric is used to move the slide instead of a crankshaft.
enclosed: A press having most of its working parts enclosed.
end-wheel: A mechanical press with flywheel at back and shaft running front to back.
flywheel: A mechanical press which has the flywheel mounted directly on the main or crankshaft.
foot: A type of press powered entirely by foot pressure.
four-point suspension: A press whose slide is actuated by four connections.
front-to-back shaft: A press having its main shaft running front to back.
gap (overhanging): (See Press, C-frame.)
geared: A press whose main crank or eccentric shaft is connected to the drive shaft or flywheel shaft by one or more sets of gears.
horizontal: A press in which the ram or slide movement is horizontal.
horn (horning): A press equipped with or arranged for a horn.
hydraulic: A press actuated by a hydraulic cylinder and piston.
inclinable: A press whose main frame may be tilted backward, usually up to 45°, to facilitate ejection of parts by gravity through an open back.
inclined: A press built so that it is permanently inclined to a fixed nonvertical position.
knuckle-joint: A heavy powerful short-stroke press in which the slide is actuated by a toggle (knuckle) joint.
mechanical: A press having a slide (or slides) actuated by mechanical means.
multiple-slide: (1) A press having individual slides built into the main slide, or (2) a press of more than one slide in which each slide has its own connections to the main shaft.
notching: A mechanical press used for notching internal and external circumferences and also for notching along a straight line. These presses are equipped with automatic feeds, since only one notch is made per stroke.
OBI: (See Press, open-back inclinable.)
one-piece frame: A press whose bed, uprights, and crown are composed of a single casting or weldment.
one-point: A mechanical press in which the slide is operated by one connection to the shaft. It is usually a single-crank type or a single eccentric press of the enclosed type.
open-back: A gap press designed to facilitate feeding from front to back and ejection from the back.
open-back inclinable: An inclinable press in which the opening at the back between the uprights is usually slightly more than the left-to-right dimension of the slide flange. (See also Press, inclinable.)
open-rod: A hydraulic press with vertical rods instead of uprights to guide the slide.
oscillating-die: A press in which a reciprocating and/or rotary motion of the die and punch is synchronized with the feed.
overhanging: A gap press in which the frame overhangs the bed.
pillar: A small press with straight sides, commonly used for subpress work.
punch: (1) Most commonly, an end-wheel gap press of the fixed-bed type; (2) a name loosely used to designate any mechanical press.
rack-and-pinion reducing: A long-stroke reducing press actuated by a rack and pinion.

reducing: A long-stroke, single-crank press used for redrawing (reducing) operations.
rubber-pad: Any single-action hydraulic press with its slide equipped with a rubber pad for rubber pad forming.
side-wheel: Any press with a flywheel at the side and with a left-to-right crankshaft.
single-action: Any press with a single slide; usually considered to be without any other motion or pressure device.
single-piece frame: (*See* Press, one-piece-frame.)
solid frame: (*See* Press, one-piece-frame.)
straight-side: An upright press open at front and back with the columns (uprights) at the ends of the bed.
tapering: A press designed to permit placing a blank in a die without the need for a slide plate, and to deliver an exceptionally long stroke.
tie-rod: A type of press in which four steel tie rods hold the bed, uprights, and crown together under a predetermined compressive load.
toggle: (*a*) Any mechanical press in which a slide, or slides, are actuated by one or more toggle joints; (*b*) a term applied to double- and triple-action presses.
toggle drawing: A press in which the outer or blankholder slide is actuated by a series of toggle joints and the inner slide by the crankshaft or eccentrics.
trimming: A special-purpose mechanical press in which shearing and trimming operations are usually done on forgings.
triple-action: A press having three slides with three motions synchronized for such operations as drawing, redrawing, and forming, where the third action is opposite in direction to the first two.
tryout (*spotting*): A press used in the final finishing of dies to locate inaccuracies of mating parts.
twin-drive: A press having two main gears on the crankshaft meshing with two main pinions on the first intermediate shaft.
two-point: A mechanical press in which the slide is operated by two connections to the crankshaft.
underdrive: A press in which the driving mechanism is located within or under the bed or below the floor line.
watch (*watchmaker's bench press*): A small end-wheel gap press having a comparatively high die space to allow the use of subpresses.
wiring: Any press of several types used for wiring operations.

Press-brake (*bending brake*): An open-frame press for bending, cutting, and forming; usually handling relatively long work in strips.

Press tonnage: (*See* Capacity, press).

Pressure attachment: (*See* Die cushion.)

Pressure switch: An electrical switch operated at a predetermined pressure.

Puckering: A wavy condition in the walls of a deep drawn part.

Pull feed: (*See* Feed, grip.)

Punch: (*a*) The male die part, usually the upper member and mounted on the slide; (*b*) to die-cut a hole in sheet or plate material (*see* Piercing); (*c*) a general term for the press operation of producing holes of various sizes in sheets, plates, or rolled shapes.

Punch holder: The plate or part of the die which holds the punch.

Quick-return motion (*drag-link motion*): A motion used on crank presses to provide fast upward slide travel.

Quill-type punch: A frail or small-sized punch mounted in a shouldered sleeve or quill.

Rabbit ear: A recess in a die corner to allow for wrinkling or folding of the blank.

Rack-and-pinion drive: A drive incorporating a rack and pinion and commonly used to actuate roll feeds.

Ram: (*See* Plunger, Platen, Slide.)

Recovery: The removal of residual stresses caused by localized plastic flow in cold-worked metals by annealing without substantially altering the grain structure or strength. (*See* Stress relieving.)

Redrawing: Second and following drawing operations in which cuplike shells are deepened and reduced in cross-sectional dimensions.

Reducing: Any operation that decreases the cross-sectional dimensions of a shell or tubular part; includes drawing, ironing, necking, tapering, and redrawing.

Reductions: (a) A general term for any forming operation, or specifically referring to some dimensions; (b) the measure, in percentage, of the decrease of some dimension of a part. The term is commonly applied in multiple-operation draw work to express the decrease in diameter with each redraw operation.

Reeding: The serrations (ridges and grooves) around the edge of a coin.

Reel: A spool or hub for handling and feeding wire and strip material.

Refining temperature: A temperature usually just higher than the transformation range, employed to refine the grain size.

Relief (undercut or back-off): Clearance obtained by removing metal, either behind or beyond the cutting edge of a punch or die.

Residual stress: Stresses left within a metal as the result of nonuniform plastic deformation or by drastic gradients of temperature from quenching or welding.

Restriking: A sizing operation in which compressive strains are introduced in the stamping to counteract tensile strains set up by previous operations.

Reverse redrawing (inside-out redrawing): A second or subsequent redrawing operation, performed in the opposite direction to the original drawing.

Ring riser: A one-piece riser block. (See Riser block.)

Riser block: A plate inserted between the top of the bed and the bolster to decrease the height of the die space.

Roll straightener: A mechanism equipped with rolls to straighten sheet or strip stock, usually used with a feed mechanism for pressworking.

Rubber pad (blanket): A flat piece of rubber used as an auxiliary tool for rubber forming.

Rubber pad forming: (See Guerin process.)

Rubber platen: A container filled with rubber and attached to the slide of a hydraulic press for rubber-pad forming.

Scoring: (a) The scratching of a part as it slides over a die; (b) reducing the thickness of a material along a line to weaken it purposely along that line.

Scrap: Pieces or parts not normally usable.

Scrap cutter: A shear or cutter operated by the press or built into a die for cutting scrap into sizes for convenient removal from the die or disposal.

Seam: (a) The fold or ridge formed at the juncture of two pieces of sheet material; (b) on the surface of a metal, a crack that has been closed but not welded; usually produced by some defect either in casting or in working, such as blowholes that have become oxidized, or folds and laps that have formed during working.

Seaming: The process of joining two edges of sheet metal by multiple bending.

Seizing: Welding of metal from the workpiece to a die member under the combined action of pressure and sliding friction.

Setback: The distance from the intersection of two corresponding mold lines to the bend line.

Shank, punch-holder: The stem or projection from the upper shoe which enters the slide flange recess and is clamped to the slide.

Shaving: A secondary shearing or cutting operation in which the surface of a previously cut edge is finished or smoothed.

Shear: (a) A tool for cutting metal and other material by the closing motion of two sharp, closely adjoining edges; (b) to cut by shearing dies or blades; (c) an inclination between two cutting edges.

Shedder: A pin, rod, ring, or plate, operated by mechanical means, air, or a rubber cushion, that either ejects blanks, parts, or adhering scrap from a die, or releases them from punch, die, or pad surfaces.

Sheet: Metal having a thickness up to ¼ in.

Sheet-metal gage: Refers to standard identification of sheet-metal thicknesses.

Shoe: (*a*) A metal block used in bending processes to form or support the part being processed; (*b*) the upper or lower component of a die set.

Shut height of a press: The distance from the top of the bed to the bottom of the slide with the stroke down and adjustment up. In general, the shut height of a press is the maximum die height that can be accommodated for normal operation, taking the bolster into consideration.

Sizing: A secondary pressworking operation to obtain dimensional accuracy by metal flow.

Slide: The main reciprocating press member; also called the ram, the plunger, or the platen.

Slitting: Cutting or shearing along single lines; used either to cut strips from a sheet or to cut along lines of a given length or contour in a sheet or part.

Slug: A small piece of material, usually scrap, produced in piercing or punching holes in sheet material.

Spacer block: (*See* Riser block.)

Spalling: The breaking off of flakelike metal particles from a metal surface.

Spotting: The fitting of one part of a die to another, by applying an oil color to the surface of the finished part and bringing it against the surface of the intended mating part, the high spots being marked by the transferred color.

Spring-back: The extent to which metal tends to return to its original shape or position after undergoing a forming operation.

Spring cushion: (*See* Die cushion.)

Staking: The process of permanently fastening two parts together by recessing one part within the other and then causing plastic flow of the material at the joint.

Stamp: (*a*) The general term to denote all pressworking; (*b*) to impress lettering or designs by pressure into the surface of a material.

Stock oiler: A device, generally consisting of felt-wick wipers or rolls, which spreads oil over the faces of sheet or strip stock.

Stop, automatic: (*a*) A device for positioning stock in a die; (*b*) a mechanism that initiates the stopping action of a press after its complete cycle; (*c*) a device for initiating the stopping action of a press at the start of operating troubles, such as misfeeding, buckling of strip stock, or nondischarge of blanks, for the protection of the die or the operator.

Stop pin: A device for positioning stock or parts in a die.

Straightener rolls: (*See* Roll straightener.)

Strain: The deformation, or change in size or shape of a body, produced by stress in that body. Unit strain is the amount of deformation (usually in inches) per unit length (usually in inches).

Strain hardening: The increase in hardness and strength in a metal caused by plastic deformation at temperatures lower than the recrystallization range.

Stress: The internal force or forces set up within a body by outside applied forces or loads. Unit stress is the amount of load per unit area.

Stress cracking: The cracking of parts which have retained residual stresses from cold forming, heat treating, or rapid cooling.

Stress relief (relieving): A heat treatment which is done primarily for reducing residual stresses.

Stretch (stretcher) forming: The shaping or forming of a sheet by stretching it over a formed shape.

Stretch (stretcher) leveling: A stretching process producing a slight plastic flow to obtain flat surfaces on sheet metal.

Stretcher strains: (*See* Lüders' lines.)

Striking: A general term for making a quick and forceful (hitting) contact between a punch and the work.

Stripper: A device for removing the workpiece or part from the punch.

Stripper plate: A plate (solid or movable) used to strip the workpiece or part from the punch; it may also guide the stock.

Stripping: The operation of removing the workpiece or part from the punch.

Stroke of a press: The reciprocating motion of a press slide, specified as the number of inches between the terminal points of the motion.

Subpress: A small cylindrical die set in which the upper and lower members are incorporated in a self-contained unit so arranged as always to hold the die members in alignment.

Swaging: A squeezing operation in which part of the metal under compression plastically flows into contours of the die; the remaining metal is unconfined and flows generally at an angle to the direction of applied pressure.

Table: Sometimes called a "knee." (*See* Bed, adjustable.)

Table feed: A device and expression for feeding rubber-pad presses, consisting of tables upon which the dies, form blocks, and blanks are mounted, which are then rolled into place under the rubber platen.

Tapering: A swaging or reducing operation, in which the metal is elongated in compression, for producing conical surfaces on tubular parts.

Tempering (drawing): A heat-treating process for removing internal stresses in metal at temperatures above those for stress relieving, but in no case above the lower critical temperature.

Tensile strength: The ultimate strength of a material, measured in pounds per square inch in tension on the original cross section tested, which, if exceeded, causes sectional deformation leading to ultimate rupture.

Tension: The internal force or forces set up within a body, and causing or tending to cause extension or stretching.

Three-point bending: A bending operation in which the blank is placed on two supports and force is applied between the supports.

Throat (gap): The open space in a gap-frame press behind the slide center line.

Throw: In crank and eccentric presses, a distance equal to one-half the stroke.

Tin plate: Sheet steel coated with tin from 0.0003 to 0.002 in. thick, applied by the hot-dipping process.

Toggle joint: A connecting mechanism consisting of two links freely pinned together at one end and connected by free pins to other machine parts at their other, or outer, ends.

Tonnage, press: (*See* Capacity, press.)

Top stop: An automatic device for stopping a press at the top of a stroke, *i.e.*, after each cycle.

Torque: Any twisting effort which produces or tends to produce rotation.

Torsion: The internal resistance of a body to a torque acting upon that body.

Trimmer, flat-edge: A machine in which a cam-driven lower die moves horizontally to cut or notch drawn shells.

Trimming: Trimming is the term applied to the operation of cutting scrap off a partially or fully shaped part to an established trim line.

pinch: Trimming the edge of a tubular part by pinching or pushing the flange or lip of the part over the cutting edge of a draw or stationary punch.

Triple action: Any operation on sheet metal in which three separate motions are required.

Tripping mechanism: Any auxiliary mechanism, either manually, mechanically, or automatically operated, which stops, starts, or otherwise controls the operation of the primary mechanism.

Ultimate strength: The maximum stress which a material can withstand before or at rupture.

Undercut: (*See* Relief.)

Uniform stroke motion: A type of motion obtainable with a drag-link mechanism, in which a fairly uniform speed of slide is obtained during a large portion of the working stroke.

Upsetting: A squeezing or compressing operation in which a larger cross section is formed on the part by gathering material in such a way as to reduce the length.

Vacuum-cup lifter: A mechanism for lifting or moving blanks or strips from a stack by means of rubber suction cups attached to lifting or feeding arms.

Vent: A small hole in a punch or die for admitting air to avoid suction holding, or to relieve pockets of trapped air which would prevent proper die closure or action.

Wiper block: A metal block used to exert pressure during the wiper forming of sections.

Wiper forming (wiping): A method of curving work over a form block or die in which the form block is rotated relative to a wiper or slide block.

Wiring: The curling or forming of a curled edge of a sheet or tube with a wire or rod inserted within the curled edge.

Work: Any material part or piece that is being processed or handled to or from a processing operation.

Wrap forming: (*See* Stretcher forming.)

Wrinkling: A wavy condition on metal parts, due to buckling under compressive stresses.

Yield point: The stress at which a pronounced increase in strain is shown without an increase in stress.

References

1. "Bliss Power Press Handbook," E. W. Bliss Co., Toledo, Ohio, 1950.
2. "Metals Handbook," 1948 ed., American Society for Metals, Cleveland, Ohio.

SECTION 2

STAMPINGS DESIGN*

No stamping-design work can be considered optimum until, in the judgment of the pressworking department or custom stamper, it holds out the strong probability of achieving the following:

1. A die, or set of dies, that combines maximum production and least maintenance with lowest feasible life cost
2. Maximum utilization of the least expensive stamping material that will serve satisfactorily
3. Most efficient pressworking practices
4. A stamped product that consistently meets sales and service requirements of shape, dimensions, strength, finish, style, and utility

Design alteration, except to meet changed product or press requirements, or to utilize existing dies with reasonable modifications, is to be avoided as being expensive and time-wasting. Therefore, even preliminary die sketches should be examined in the light of the following data.

GENERAL DESIGN PROCEDURE

The design planning of a new stamped part or assembly should take into account the following steps:

1. Determine exactly what the product is to accomplish in its application.
2. Convert or reduce any vague or generalized specifications to specific descriptions of materials, mechanical units, and dimensions.
3. See that all dimensions have the broadest permissible tolerances, and that initial allowances are made for overtravel, temperature and pressure variations, and other physical factors encountered in product service.
4. Set overall size limits with references to mounting upon an attachment to a machine, a control, or other cooperating parts. These limits may indicate the need of slotted holes, spacers, or similar devices.
5. Are weight limits imposed by the conditions of service? If so, consider reduction of the weight by such means as punching out unneeded material, or by resort to lighter or thinner-gage material strengthened by stiffening ribs or bosses.
6. Check all critical points, such as bearing points, where high mechanical stresses or excessive wear may occur. Are parts as designed able to resist deformation during ejection from dies, tote-box handling, tumbling, or heat treatment?
7. If very high and fast stamping production is in view, see to what extent the physical proportions, the appearance, or the finish can be altered or compromised to achieve such production.
8. Find out whether there are any unavoidable limitations in available press equipment, fabrication and assembly facilities, or other production factors, and alter stampings design as far as possible to meet the limitations.

* Reviewed by J. A. Barth, General Manager, Barth Corp., and J. W. Gulliksen, General Superintendent, Worcester Pressed Steel Co.

REDESIGN OF EXISTING PRODUCTS

When a stamped part or assembly has been in production for some time, it may become feasible or necessary to redesign the product, because of market demands of appearance, functioning, or cost factors. It is especially desirable to consider product redesign if the worn press tools or stamping operations have proved unsatisfactory. The following are good examples of integrated product and die redesign.

Television-tube Electron Gun. The redesign of four electron-gun components shown in Fig. 2-1 resulted in 60 to 75 per cent reduction in manufacturing costs. Top views show original parts design; lower views show them redesigned.

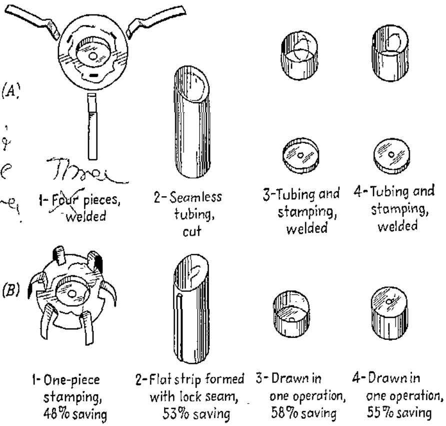


FIG. 2-1. Components of television-tube electron gun: (*A*) original design; (*B*) redesign. (*John Volkert Metal Stampings, Inc.*)

The anode (No. 2) was previously made from stainless-steel tubing cut to shape; in redesign it is formed from flat coil stock and lock-seamed in a Multislide machine. The grids (Nos. 3 and 4) were also made from tubing, to which separately blanked and formed lens caps were welded; in redesign they are drawn in one piece from flat stock. The flange spacer or spider (No. 1) was originally fabricated from four pieces welded together; in redesign it is now stamped at the rate of 75 per minute in a six-station progressive die (Fig. 2-2) from automatically fed coil stock. The spacer was improved in redesign by doubling the number of arms. The steps used in producing the flange spacer from stainless-steel strip are (1) pretrimming to permit flow of material in subsequent operations; (2) cupping for the center hub; (3) finish drawing the center hub; (4) finish trimming the six arms and piercing for the center hole; (5) finish sizing and squaring at the hub; (6) cutoff and finish forming.

Elimination of welding on the grids and flange spacer avoided possible loss of accuracy.

Perforated Bulkhead. The original design of a bulkhead (*A*, Fig. 2-3) used a conventional geometric layout of holes to provide air flow. Holes had to be kept small in size to minimize distortion in subsequent forming as shown in view C. In this design, the shearing load of the many small perforating punches was heavy, and the limited capacity of available presses required the perforating and the circumferential blanking to be done in separate operations.

When the die had to be rebuilt, the number of holes was reduced to approximately one-half and made larger to provide equivalent flow area (*B*, Fig. 2-3), and the hole layout was so arranged as to avoid the ribs and highly stressed areas involved in subsequent drawing.

The larger hole size reduced the total perimeter of holes by 33 per cent. The reduced shear load enabled piercing and blanking to be combined in a single two-station die, with the piercing and blanking punches so stepped that the cutting loads at the two stations were not in full action at the same instant.

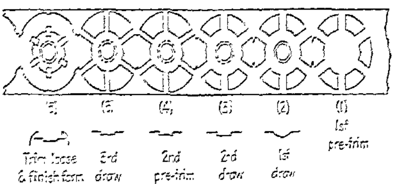


FIG. 2-2. Six-station progressive die strip development for producing electron-gun flange spacer from ½ hard fine-grain stainless-steel strip (0.010 by $2\frac{3}{8}$ in.). (*John Volkert Metal Stampings, Inc.*)

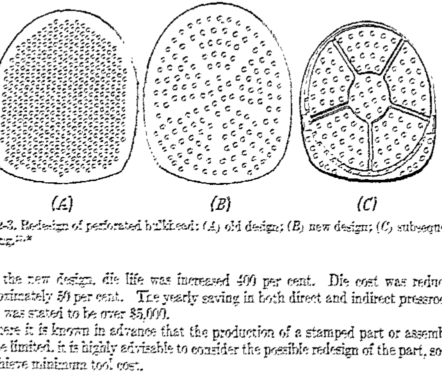


FIG. 2-3. Redesign of perforated bulkhead: (*A*) old design; (*B*) new design; (*C*) subsequent forming.[23]*

In the new design, die life was increased 400 per cent. Die cost was reduced approximately 50 per cent. The yearly saving in both direct and indirect pressroom labor was stated to be over $5,000.

Where it is known in advance that the production of a stamped part or assembly will be limited, it is highly advisable to consider the possible redesign of the part, so as to achieve minimum tool cost.

In Fig. 2-4, part *A* (of unimportant overall detail) is a hinged key. The hinge is of conventional curved design, and the hinge section would require two or more operations. In redesigned part *B*, the only significant change was to move the hinge pinhole as far as possible from the bent section at *A*. Part *B* was produced in two operations at about half the tooling cost for part *A*.

Also shown in Fig. 2-4 is part *C*, a simple clevis in five design variations. Part C_1 is a casting, heavy and rather high in machining cost. C_2 is milled from bar stock and welded to a stamping; design is better, but the drilling and welding operations increase

* Superior numbers relate to References at the end of this section.

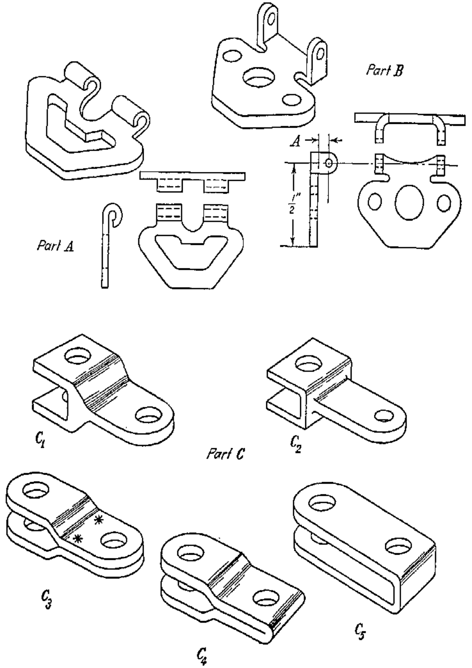


Fig. 2-4. Examples of piece part redesign.[16]

the cost. C_3 is a good design of two symmetrical stampings welded together. C_4 is a one-piece stamping involving simple operations and assuring uniform hole alignment. C_5 is probably the ultimate in simplicity of design and economy in tooling and production.

DESIGN FOR EFFICIENT STOCK UTILIZATION

Use of Standard Mill Stock.* The size, shape, appearance, and intended use of a stamped product will generally dictate the stampings-materials specifications. However, applied knowledge of the grades, qualities, gages, sizes, physical forms, and finishes available in standard mill stamping stock will frequently assist in securing best die design and stamping efficiency.

Maximum Volume for Given Area of Material. The calcular principle of maxima and minima can be used to determine the least amount of sheet metal required to form

* See Secs. 26 and 27, covering stamping materials.

an open-top square-bottomed box of given volumetric capacity. For the box shown in Fig. 2-5, formed from a blank of width a and length a, the volume would be $(x)(a-2x)^2$, and would be a maximum when

$$x = \frac{a}{6} \qquad (1A)$$

The four corners of x^2 area each, whether cut out or folded in, would be minimum waste under such conditions.

By the same principles, the minimum amount of metal in a plain cylindrical can of given volumetric capacity, closed at one end, and making allowance for waste in blanking the circular end, but none for crimping the end to the shell, is determined by the formula

$$H = \frac{D}{2} \qquad (1B)$$

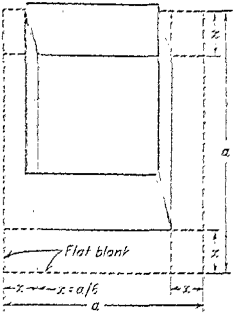


FIG. 2-5. Relation of flat blank to formed box of maximum volumetric capacity.

Utilizing Grain Structure. In designing parts to have formed sections, such as lugs or ears, plan if at all possible to form such sections at right angles to the direction of grain in the metal (Fig. 2-6C); otherwise they may crack in forming. Generally, it is preferred practice to design formed sections parallel to each other, as at A and C, or at an angle to each other not exceeding 45°. Where sections must be formed at right angles to one another, blanking

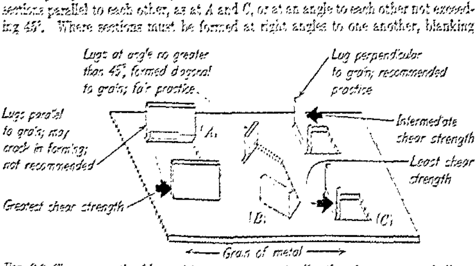


FIG. 2-6. Shear strength of lugs with reference to grain direction; heavy arrows indicate direction of applied force.

them diagonally in the strip, as in view B, will provide some continuous grain running through such sections.

Where the face of a right-angled lug or ear must receive a large thrust load, the part should be so designed that the thrust will be in the direction that induces shear (lug tends to bend in same direction as formed, upper lug, Fig. 2-6C), rather than in the direction that would bend the lug back into the original flat (lower lug, Fig. 2-6C), with danger of cracking. The shear strength of a formed lug is greatest along its narrow edge (view A).

Product Design for Minimum Scrap. Stock layout is one of the most important phases of die engineering, and one of the first steps to be taken.

However, cases frequently occur where a slight to moderate change in product design, while in no way impeding the functioning of the part, will save appreciable materials and tooling expense.

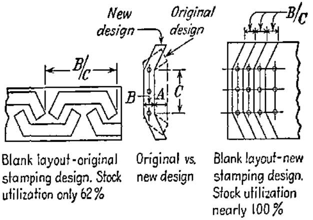


FIG. 2-7A

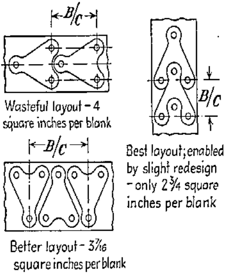


FIG. 2-7B

FIG. 2-7. Stock layout for minimum scrap. (*Hinman.*[1])

The simple hook-ended flat blank in Fig. 2-7*A* in conventional layout utilized only 62 per cent of the strip; no other nesting was more efficient. Consultation between the product designer and die designers revealed that the only mandatory dimensions in the piece were *A*, *B*, and *C*. When the piece was redesigned, a new strip layout was possible which utilized nearly 100 per cent of the material.

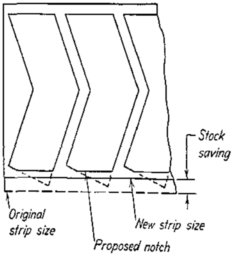


FIG. 2-8. Unnecessary corners cut off to permit use of narrower strip stock.[2]

In the case of the part shown in Fig. 2-7*B*, a 14 per cent materials saving was made just in changing strip layout from single in-line to an alternating double-row arrangement. Further investigation showed that about one-third of each piece could be cut from the piece ahead without changing the utility of the part, and resulting in a 32 per cent savings in material, compared with the original layout.

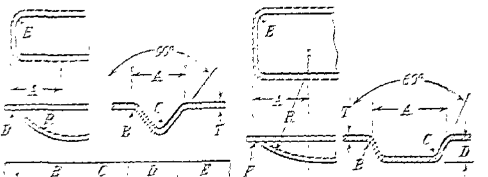
It is good practice to examine the product design for any corners or flanges projecting at the top, bottom, or sides which can be cut off without detriment to strength or necessary welding surface. This practice, as shown in Fig. 2-8, permitted a considerably narrower strip to be used.

Study of some product designs may show that the part can be made in two pieces to reduce scrap.

Aside from the width and length savings in materials, referred to above, savings through use of a thinner stock can commonly be realized through judicious use of beads, ribs, embosses, and flanges.

DESIGN TO INCREASE STRENGTH OF STAMPINGS

Beads, ribs, and flanges may often be used to impart rigidity to stampings which might otherwise be too flexible and weak. Their judicious use may reduce required material thickness by as much as one-half.



A	B Radius	C Radius	D Radius	E Radius
[illegible]	T	[illegible]	[illegible]	4T
[illegible]	T	T	[illegible]	4T
[illegible]	T	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	4T	[illegible]	[illegible]	4T
[illegible]	4T	[illegible]	[illegible]	4T
Maximum radius as determined by "T" and multiples of "T," is not to exceed 0.25 of an inch				

A	B Radius	C Radius	D	E Radius	F Radius
[illegible]	2T	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	2T	[illegible]	[illegible]	[illegible]	[illegible]
Maximum radius as determined by "T" and multiples of "T," is not to exceed 0.75 of an inch					

Fig. 2-9. Maximum radii on V-type and flat-type ribs.

Beads and Ribs. The ribs specified in Figs. 2-9 and 2-10 have been so designed that the angle of the sides will normally allow their use, not only on flat surfaces, but also on curved and angular surfaces without producing back draft.

In a right-angle bent sheet, the bend is usually a weak point. By the use of stiffening ribs (A-A, Fig. 2-10), overall rigidity is increased by 100 to 200 per cent. Overall height of ribs can be about twice stock thickness; if possible, inside radius of rib should equal stock thickness.

If the hole in the part is functional (not just a lightening hole), a rib such as at B-B may be formed midway between the hole circumference and the edge of the part. Since the blank contour is made first, the holes second, and the ribbing last, ribbing should be as far away from the pierced hole as possible, to minimize distortion of the finished part, and avoid trimming.

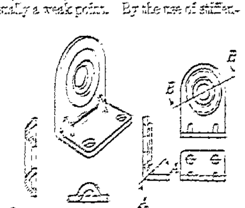


Fig. 2-10. Reinforcing ribs on stampings.[11]

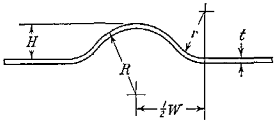
A limitation to bead depths may arise from inability to form stretched recesses, such as beads, to the desired depth, since the maximum obtainable depth is a function of the minimum bottom depth R.

$$R = \frac{2TS}{F} \text{ for circular recesses} \tag{2}$$

$$R = \frac{TS}{F} \text{ for elongated recesses} \tag{3}$$

where R = bottom radius, in.
T = stock thickness, in.
S = tensile strength, psi
p = forming pressure, psi

Locked-in beads (those terminating short of the edge of the sheet) have their proportions given in Fig. 2-11. If these proportions are maintained, either intermediate or larger sizes can be rubber-formed in most of the wrought aluminum stamping grades, annealed steels, and all magnesium alloys formed at 300 to 400°F. The minimum radius at the end of the bead is shown in the tabulation as R_e, but it is not shown on the drawing. The function of this radius is to fair the end of the bead from



Bead No.	H	$\frac{1}{2}W$	R	r	R_e	Suitable gages
−1	0.050	1/8	7/64	0.070	1/2	0.020
−2	0.100	1/4	7/32	0.140	1	0.020–0.025
−3	0.150	3/8	21/64	0.210	1½	0.020–0.032
−4	0.200	1/2	7/16	0.280	2	0.020–0.040
−5	0.250	5/8	35/64	0.350	2½	0.020–0.051
−6	0.300	3/4	21/32	0.420	3	0.020–0.064
−7	0.350	7/8	49/64	0.490	3½	0.020–0.064
−8	0.400	1	7/8	0.560	4	0.020–0.064

FIG. 2-11. Allowable sizes of locked-in aluminum beads. (*Schulze.*[3])

its full depth to the surface of the part. Figure 2-12 shows sundry other general design suggestions for the use of strengthening ribs and beads.

Internal Beads. In rubber forming of internal beads, the platen contacts the whole web simultaneously and, as pressure builds up, it tends to clamp the sheet in place. As pressure continues to increase, the metal stretches into the bead depression while the metal around the depression is more tightly locked. Most of the deformation is therefore confined within the bead itself, and distortion of adjacent metal is minimized. Because the length subjected to stretching is short, the depth of an internal bead is sharply limited.

Company practices vary widely. The maximum possible internal bead depth a depends primarily upon the bead width A, standard beads commonly having the ratio A/a between 5 and 6. In general, 24SO internal beads are specified only up to 0.064-in. material thickness; some difficulties are likely in raising beads in metal thinner than 0.32 in. For thicknesses over 0.080 in., bead width must be at least 1.375 in., and at least 1.625 in. for thicknesses over 0.090 in.

Parallel internal beads can be spaced close together; the joining crest, however, should have a radius of at least $4T$ to avoid cracking. Beads parallel to an edge should be no less than 0.5 in. from the edge. The bead end may extend to the bend lines of a flange, or stop 0.25 to 0.5 in. short.

External Beads. In rubber-formed external beads, the highest point of stamping pressure is on the crown of the forming strip. Metal is locked at this point and, with

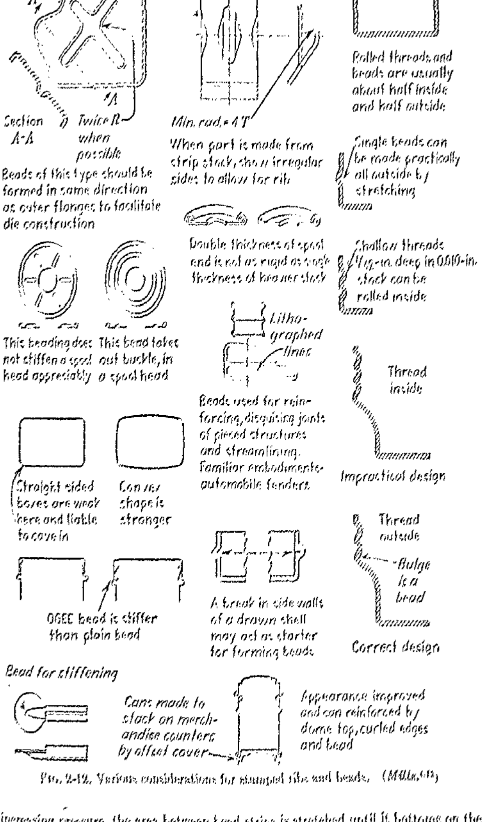


FIG. 2-12. Various considerations for stamped ribs and beads. (Mills.[43])

increasing pressure, the area between bead strips is stretched until it bottoms on the form block. Deformation being thus spread progressively over a large area, an external bead can be formed considerably deeper than an internal bead of the same curvature. Somewhat offsetting this advantage, a rather large edge radius is required. Because of the sharper resulting contours, external beads are more efficient stiffeners than internal beads.

Die-formed external beads are formed by metal movement very similar to that for rubber forming of internal beads. However, a very deep external bead designed for rubber forming cannot be produced in a single die operation.

Figure 2-13A gives the minimum recommended center-line distances of external beads parallel to the edge of the sheet and the minimum recommended distance for the end of the bead to the edge of the sheet, using an A/a ratio range between 4 and 6.

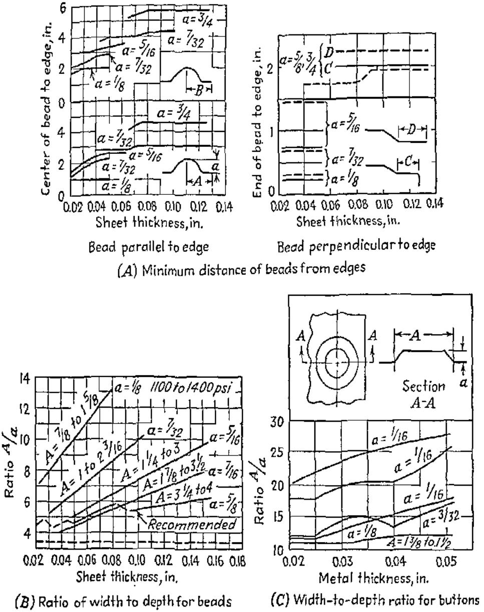


Fig. 2-13. Bead and button considerations.[10]

Dimensions A and C refer to parts with flanges, while B and D refer to parts without flanges.

Figure 2-13B shows the ratio of width A to depth a for beads which can be formed using the usual rubber pressure of between 1,100 and 1,400 psi.

Buttons or Bosses. These are flat-bottomed circular depressions or elevations in thin sheet (Fig. 2-13C), used to increase buckling resistance of unstiffened area, and where drawing of the material must be held to a minimum. Distance from center of button to a flanged edge should exceed 60 to 80 per cent of the button diameter, and 70 to 100 per cent to a free edge.

Flanges. A flange as formed on a sheet-metal part is the result of a simple bending operation, or combinations of bending and compression (shrink flanges), or combinations of bending and elongation (stretch flanges). In Fig. 2-14, these are respectively designated as types *A*, *B*, and *C*. Type *D* flange is a combination of types *A*, *B*, and *C*.

Sundry good general flange-design considerations include use of standard bend radii relative to the gage and condition of metal, use of a 90° or open-bevel flange wherever possible, and use of standard bend relief for intersecting flanges (*A*, Fig. 2-15).

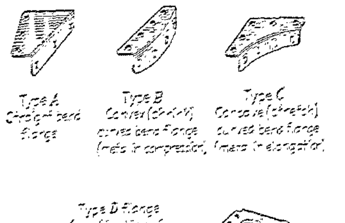


FIG. 2-14. Types of stamped flanges.

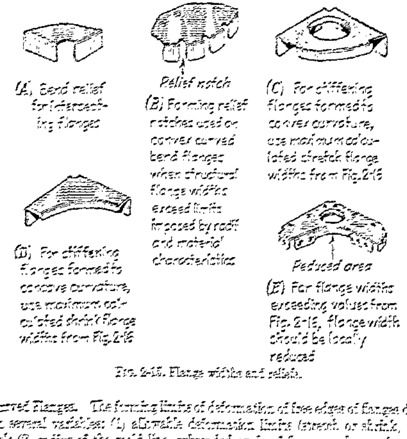


FIG. 2-15. Flange widths and reliefs.

Curved Flanges. The forming limits of deformation of free edges of flanges depend upon several variables: (1) allowable deformation limits (stretch or shrink) of the metal; (2) radius of the mold line, subtended angle of flange, and restraints at the extremities (tangents) of the curved sections of the flanges; (3) cross-sectional flange dimensions (width and angle); and (4) method of forming.

The limits of stretch depend upon type, gage, and condition of the metal, and the method of forming. The mold-line radius, and the flange width and/or the angle must be adjusted to meet design requirements and still be within deformation limits of the metal. For limits of allowable deformation, see Table 2-1.

TABLE 2-1. PERMISSIBLE FORMING LIMITS FOR CURVED FLANGES

Metal or alloy	% elongation (stretch)		% compression (shrink)	
	Rubber forming	Die forming	Rubber forming	Die forming
Aluminum:				
2SO	25	30	6	40
2S-½H	5	8	3	12
3SO	23	30	6	40
3S-½H	5	8	3	12
52SO	20	25	6	35
52S-½H	5	8	3	12
61SO	21	22	8	35
61SW	12	20	8	20
61ST	5	10	2	10
24SO and 24SO clad	14	20	6	30
24ST and 24ST clad	6	18	0.5	9
24SRT and 24SRT clad	0	0	0	0
R301-O and 14SO	14	20	4	30
R301-T and 14ST	5	6	0	0
75SO	13	18	3	30
75ST	0	0	0	0
Magnesium:				
AM350 and Ma	10	15	6	16
AM3SH and Mh	0	0	4	12
AM-C52SO and FS-1a	0	0	5	16
AM-G52SH and FS-1h	0	0	3	6
AM-C57SO and J-1a	0	0	4	12
AM-C57SH and J-1h	0	0	0	0
Steel:				
SAE 1010	..	38	...	10
SAE 1020	..	22	...	10
SAE 8630	..	17	...	8
S.S.302 annealed	..	40	...	10
S.S.302-½H	..	15	...	10
S.S.321	..	40	...	10
S.S.347	..	40	...	10

Data supplied by Curtiss-Wright Corp.

Above allowable deformations are satisfactory for flanges formed in stock, 0.040 in. or thicker. Values can be slightly reduced for the lighter gages, particularly for shrink flanges.

Values for compression (shrink) rubber forming may be exceeded by use of notches, controlled wrinkling, special form blocks to compensate for bow effect, etc. Elongation values may be increased for some alloys by polishing edge of the blank.

The approximate deformation of the free edge of the flange is given by

$$D = 100\left(\frac{R_2}{R_1} - 1\right) \qquad (4)$$

where D = deformation, per cent

R_1 = edge radius, in., before forming (flat pattern radius)

R_2 = edge radius after forming

Positive values of D indicate elongation (stretch); negative values indicate compression (shrink).

Flange Calculations. The relationships of the various dimensional elements for stretch and shrink flanges are shown in Fig. 2-16.

The amount of setback, for all flanges, can be determined from Fig. 2-17.

The amount of setback for all flanges can be determined from Fig. 2-17 by connecting the radius scale at the value of R to the thickness scale at the value of T with a straight line. The setback value J is read at the point where this line intersects the horizontal line representing the bevel of the bend.

Dimensions for 90° flanges can be determined from Fig. 2-18, as can be the percentage of elongation (stretch), or compression (shrink), in the metal of a given flange. The use of the chart for determining percentage of elongation is illustrated in Example

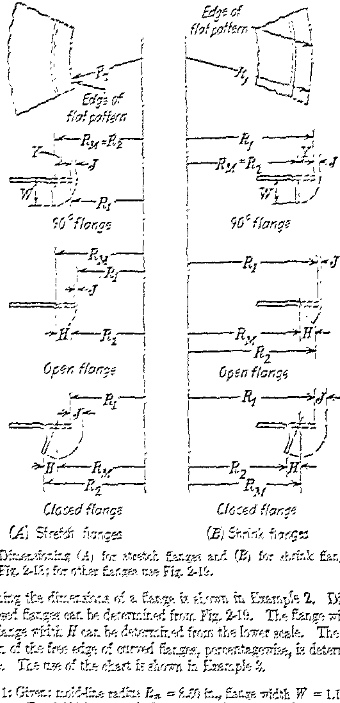


FIG. 2-16. Dimensioning (A) for stretch flanges and (B) for shrink flanges. For 90° flanges use Fig. 2-18; for other flanges use Fig. 2-19.

1; determining the dimensions of a flange is shown in Example 2. Dimensions for open or closed flanges can be determined from Fig. 2-19. The flange width W or the projected flange width H can be determined from the lower scale. The approximate deformation of the free edge of curved flanges, percentagewise, is determined on the upper scale. The use of the chart is shown in Example 3.

Example 1: Given: mold-line radius $R_m = 2.50$ in., flange width $W = 1.16$, 90° stretch flange thickness $T = 0.064$ in. Required: per cent deformation and permissible materials.

Assuming a safe value of $2T$, bend radius $R = 0.12$ and, from Fig. 2-17, setback

$$J = 0.13 \text{ in.}$$

Flat pattern flange width $Y = W - J = 1.03$ in. From Fig. 2-18,

$$\text{elongation} = 13 \text{ per cent}$$

select materials from Table 2-1 which have 13 per cent or greater elongation.

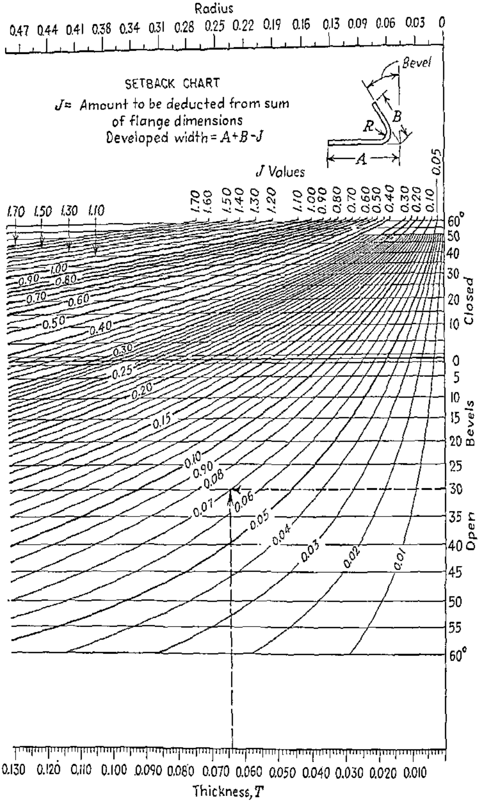


Fig. 2-17. Setback chart.

Example 2: Given: mold-line radius R_m = 10.00 in.; 0.040-in.-thick 24ST aluminum, 90° stretch flange, to be rubber-formed. Required: maximum flange width W. Using a value of $3T$ (Table 2-7), bend radius R = 0.12. From Fig. 2-17, setback J = 0.11 in. From Table 2-1, elongation E = 6 per cent. From Fig. 2-18, Y = 0.57. Then, maximum flange width W = 0.57 + 0.11 = 0.68 in.

Example 3: Given: mold-line radius R_m = 6.00 in., flange width W = 1.20 in., flange

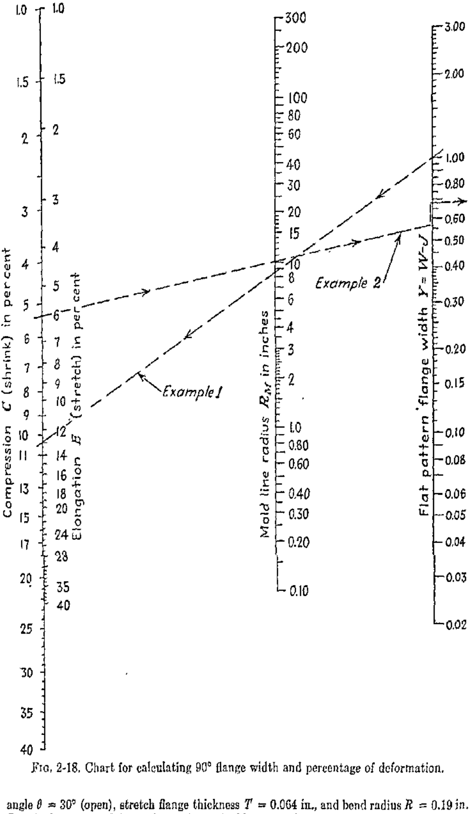


FIG. 2-18. Chart for calculating 90° flange width and percentage of deformation.

angle θ = 30° (open), stretch flange thickness T = 0.064 in., and bend radius R = 0.19 in. Required: per cent deformation and permissible materials.

From Fig. 2-17, J = 0.06 in., and R_1 (Fig. 2-19) = 6.00 − 1.20 + 0.06 = 4.86. From Fig. 2-19 (lower graph) projected flange width H = 0.60 in., and

$$R_2 = 6.00 - 0.60 = 5.40 \text{ in.}$$

per cent elongation = 11 per cent (upper graph). Consult Table 2-1 for materials possessing 11 per cent or greater elongation.

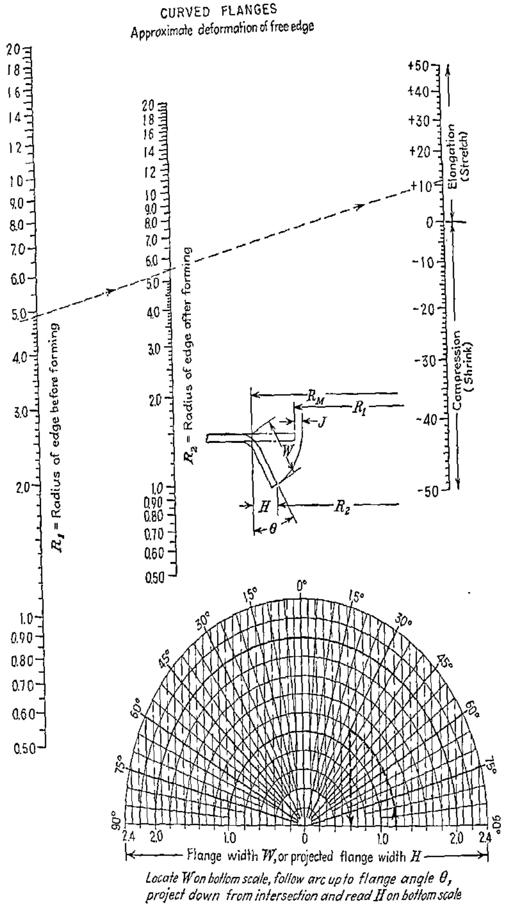


FIG. 2-19. Chart for calculating widths of open or closed flanges.

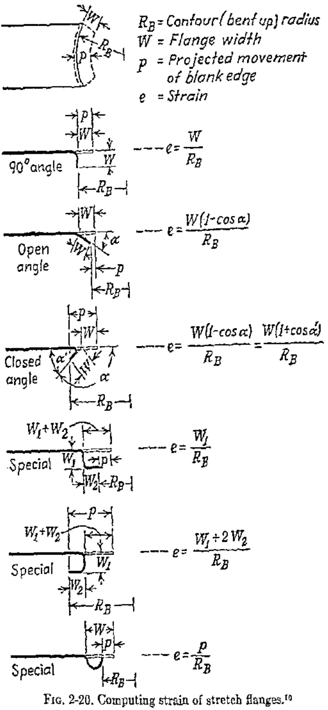


FIG. 2-20. Computing strain of stretch flanges.[10]

Permissible Strain in Stretch Flanges. These values, which depend upon edge condition of the metal, the flange width (see Fig. 2-20), and method of forming strain for *right-angle flanges*, may be approximately computed by the formula

$$e = \frac{W}{R_B} \tag{5}$$

where e = elongation (strain) factor at free edge of flange
W = flange width, in.
R_B = contour (bent-up) radius of flange, in.

For 24ST and 24SO aluminum 90° flanges, 0.10 is a safe value for e where edges are smooth; 0.06 is a safe value for shear edges. A larger degree of stretch occurs where contour radius R_B is small, or where the stretch flange is adjacent to a shrink flange.

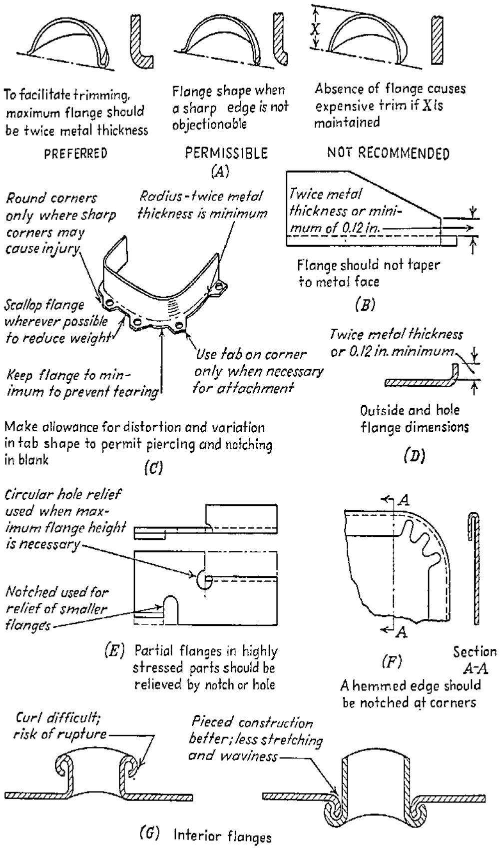


Fig. 2-21. Details of stamped flanged design.[2]

Air Force specifications indicate that there is danger of cracking when elongation exceeds 12 per cent in 2 in. Therefore, for safety, $\epsilon = 0.12$, and

$$\frac{R_E - W}{R_E} = 0.88 \tag{6}$$

For open flanges (angles less than 90°; see Fig. 2-20),

$$\epsilon = \frac{W(1 - \cos \alpha)}{R_E} \tag{7}$$

For $\epsilon = 0.12$, Eq. (7) gives the following values for various open flange angles:

$$\alpha = 30°: W = 0.472R_E$$
$$\alpha = 45°: W = 0.290R_E$$
$$\alpha = 60°: W = 0.194R_E$$
$$\alpha = 75°: W = 0.139R_E$$

For ϵ values for closed angles, and some special angles, see Fig. 2-20.

Permissible Strains in Shrink Flanges. Equation (5) for 90° stretch flanges also applies to 90° shrink flanges. Here, however, the metal is in compression, and the sheet must be supported against buckling or wrinkling. With rubber forming, there is practically no support against buckling, and only slight shrinking can be accomplished, so that rubber forming is limited to very large flange radii or very narrow widths. For 24SO aluminum, without subsequent rework, shrink is limited to not over 2 or 3 per cent, and 0.5 per cent for 24ST.

Figure 2-21 illustrates various elements of flange design.

TOLERANCES ON STAMPINGS

Dimensional Tolerances. Tolerances are restrictions in specifications and should be made only as close as may be essential or critical in the functioning of the stamped part. Unnecessarily close tolerances will increase tool and production costs and lower the die life, and may make up to 100 per cent inspection mandatory.

TABLE 2-2. BLANKING AND PIERCING TOLERANCES, INCHES*

Material thickness, in.	Size of blanked or pierced opening		
	Up to 3 in. wide	Over 3, up to 8 in. wide	Over 8, up to 24 in. wide
0.025	0.003	0.005	0.008
0.030	0.003	0.006	0.010
0.050	0.004	0.008	0.012
0.064	0.005	0.009	0.014
0.125	0.006	0.010	0.016
0.187	0.010	0.016	0.025
0.250	0.015	0.020	0.035

* All tolerances are plus for blanking, and minus for piercing.

Blanking and Piercing Tolerances. Table 2-2 gives blanking and piercing tolerances which can ordinarily be maintained on steel, brass, copper, or aluminum parts. Greater tolerances are usually required on fiber, rubber, and softer materials.

It should be noted that blanking tolerances are indicated as *plus*; this is because the die opening determines the blank size and, as the die is resharpened, the size of the opening increases. Conversely, piercing punches decrease in diameter with wear, and the pierced holes become smaller (minus tolerance).

Hole tolerances for solid rivets should be plus 0.015 in., minus 0.000; for draw rivets they should be plus or minus 0.005 in.[6]

Bending and Form Contour Tolerances. Figure 2-22 suggests allowable tolerances on bent parts.

It may sometimes be inadvisable to specify tolerance on each dimension of a contoured shape, because of a possible objectionable accumulation of these tolerances.

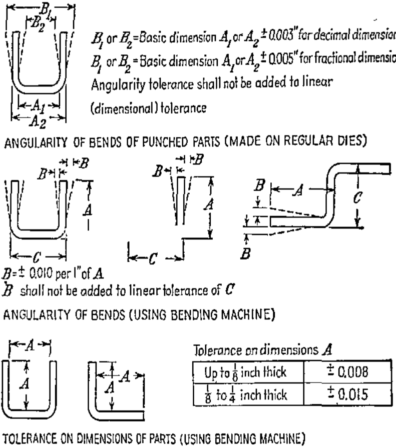


FIG. 2-22. Tolerances for bent parts. (*Neilsen.*[5])

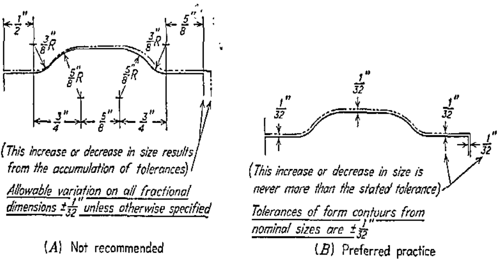


FIG. 2-23. Indication of form contour tolerances.[6]

In such cases, notation should be clearly made on the drawings, as suggested in Fig. 2-23.

Flatness Tolerances. Parts should be so designed (Fig. 2-24) that straight edges can be maintained on the flat blanks of formed parts wherever possible. This results in economy and ease of production, since the blank can be sheared from flat blanks with relatively inexpensive dies.

Tolerances of 0.005 in. per inch of length are usual for flatness of punched parts. Where the design will permit use of a stripping die, flatness tolerance of 0.001 in. can be maintained. For bronze parts thinner than 0.042 in., tolerance of 0.010 in. is allowable.

Squareness and Eccentricity Tolerances. For squareness of sheared parts, a tolerance of ±0.003 in. is allowable for parts dimensions given in decimals and ±0.010 in. on fractional dimensions for each inch of the surface length. This tolerance is for squareness only and is not to be added to the linear tolerance.[5]

The tolerance for eccentricity between hole and OD of washers punched with stock dies is 0.004 in. on 1 in. OD or less and 0.008 in. on OD greater than 1 in.[5]

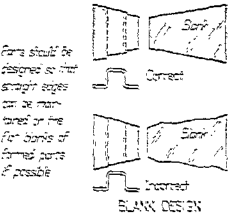


Fig. 2-24. Design for use of flat stock.

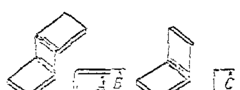


Fig. 2-25. Effect of variation in stock thickness on overall tolerance.[14]

Tolerances on Stock Thickness. For standard commercial mill tolerances on stamping strip, sheet, and coil stock, see Secs. 26 and 27.

If high accuracy is necessary in the bending or forming of sheet metal, the overall tolerance on stock thickness must be considered. Cold-rolled strip steel has about 50 per cent closer thickness tolerance than cold-rolled sheet steel. Should the sheet metal vary 0.002 in. in thickness, dimension A (Fig. 2-25) would be both a small cumulative error in the bending operation, and an overall variation in the stock thickness.

On the other hand, if dimension B is taken from the outside of the offset bend, the variation would be twice that of A, plus the required bending or forming tolerance.

PRODUCT DESIGN FOR BLANKING AND PIERCING HOLES

In designing stampings with punched holes, it should be remembered that only about one-third the thickness of the metal is sheared cleanly to the size of the punch. The remainder fails in shear by the pressure on the sheared slug, producing a rough hole tapering outward from the diameter of the punch to the diameter of the die (Fig. 2-26). This fact is

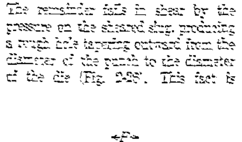


Fig. 2-26. Schematic section of punch in producing a hole.

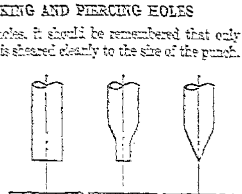


Fig. 2-27. Basic methods of producing holes in stampings.

	PUNCH PRESS		
R_1	0.16 preferred or $2T$		
R_2	$2T$ min		
D_1 or D_2	T	Non-ferrous	Ferrous
	Thru 0.062	0.12	0.12
	0.063-0.38	0.12 or $1.5T$ whichever is greater	$2T$
D_3	$1.0T$ or 0.098 min except 0.120 min for alloy steels etc.		
D_4 or D_5	T	Width	
	Thru 0.032	0.06	
	0.033-0.125	$2T$	
	0.126-0.38	$2.5T$	

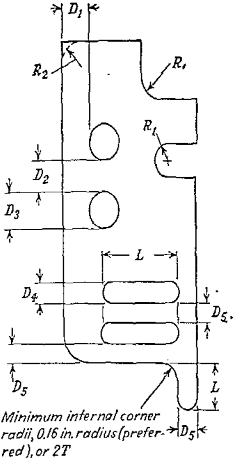


FIG. 2-28. Minimum practical punching and blanking dimensions. (*A. H. Petersen.*)

especially important when the periphery of the hole is intended to act as a bearing surface

Holes in stamped parts are produced by one of three methods: punching, extruding, or piercing (Fig. 2-27).

Punched Holes. Figure 2-28 presents general guides for punched-hole diameters, center-to-center distances, and distance from edge of blanked part. Tolerances on punched holes are given in Table 2-3.

When holes are to be punched in stampings, for later use in assembling with bolts or screws, minimum edge distances should be so calculated as to utilize the full shear or bearing strength of the bolts or screws (Table 2-4).

TABLE 2-3. MAXIMUM PUNCHED-HOLE TOLERANCES FOR ALUMINUM AND STEEL SHEET

Decimal nominal diam., in., incl.	Equivalent drill size, incl.	Sheet thickness, in.				
		0.025 through 0.042	0.050 through 0.072	0.078 through 0.093	0.102 through 0.156	0.187 through 0.250
0.125-0.141	1/8-9/64	*	+0.006; -0.001	+0.008; -0.002	+0.011; -0.003	
0.144-0.228	27-1	*				
0.234-0.413	15/64-Z	*				
0.422-0.688	27/64-11/16	*				+0.021; -0.003
0.703-0.984	45/64-63/64	*	*			
1.000 and up	1 and up	*	*	*		

Data courtesy of A. H. Petersen.

* Use same tolerances as for drilled holes. (See "Tool Engineers Handbook.")

TABLE 2-4. RECOMMENDED DISTANCES, CENTER OF SCREW OR BOLTHOLE TO NEAREST EDGE OF PART

Connection	Material in which the bolt or screw bears	
	24 ST, 24 SRT, 75 ST, 14 ST, 17 ST, 195-T6, 356-T4 and T6, 220-T4, 8630, corrosion-resistant steel	61 SW, Mg alloy, die-cast materials
Bolts and nonflush screws	1.7 diam. + 0.03 in.	2.0 diam. + 0.03 in.
Flush screws	2.0 diam. + 0.03 in.	2.4 diam. + 0.03 in.

Data courtesy of A. W. Petersen.
Above values allow a manufacturing tolerance of 0.03 in.

Extruded Holes. An extruded hole is usually formed in a single operation by a punch which clean punches a smaller hole, and then follows through to flange the sides. Sometimes a hole flange is specified which is wider than can be formed in one operation. This necessitates drawing metal in from outside the hole by first drawing an embossment much larger than the hole, then by successive steps forming the flange and finally punching out the hole. It is a more expensive method, and its use can be limited by keeping the specified flange width to an absolute minimum.

If the extruded hole is to be tapped, the maximum height H (Fig. 2-29) of the extrusion should not exceed one-fifth of the body size of the tap. In view *A*, with an

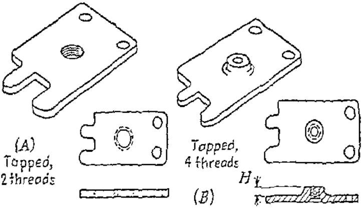


FIG. 2-29. Extruded holes for tapping.[16]

8-32 thread, only two threads could be produced. In view *B*, 3½ to 4 threads would be possible. If permissible, a 10-32 thread in place of the 8-32 would increase the hole size and therefore the height *H*.

In addition to extruding so as to provide a boss for tapping, tapped holes deeper than the sheet thickness can be built up by means of clinch-on nuts, or by use of a nut *spot-welded in line with the punched hole.*

Pierced Holes. A pierced hole is made by a sharp-pointed punch which follows through to flange the sides, forming a hole with torn or irregular edges.

Relation of Holes to Right-angle Bends. Because of variations in stock thickness and temper, the relation of right-angle bends to given hole locations is somewhat difficult to maintain.

The most desirable location of a hole adjacent to a right-angle bend is shown in view *A2*, Fig. 2-30, the edge of the hole being *not closer to the bend than dimension* $X = 1\frac{1}{2}T$ *plus R.* Where a hole must be located as close as possible to the bend (but not actually in the bend), as in view *A1*, the addition of a crescent slot allows the part *to be die-cut, blanked, and pierced, with enough flat material around the hole to avoid distortion.*

When a hole must be located actually in a right-angle bend, unless piercing is done after bending, hole distortion would be considerable if design were as shown in *B1*.

particularly if stock thickness exceeded 0.015 in. Redesign, as in *B*2, permits normal sequence of stamping operations.

Holes in a right-angle-bent stamping must sometimes hold close relationship in assembly with a separate base or part. Thus, the gear-train plate in *C*1 must assemble with another plate on a common base *X*, with dimensions *C* and *D* closely held so that the bearing holes will be in alignment in final assembly. With the design as in *C*1, slight variations in stock thickness or temper could throw the alignment out.

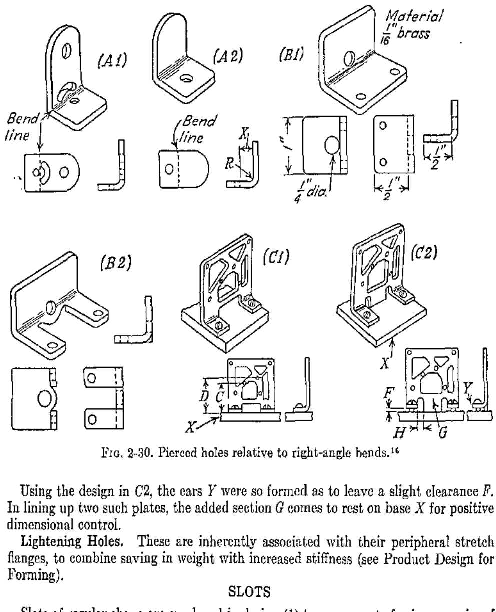


FIG. 2-30. Pierced holes relative to right-angle bends.[16]

Using the design in *C*2, the ears *Y* were so formed as to leave a slight clearance *F*. In lining up two such plates, the added section *G* comes to rest on base *X* for positive dimensional control.

Lightening Holes. These are inherently associated with their peripheral stretch flanges, to combine saving in weight with increased stiffness (see Product Design for Forming).

SLOTS

Slots of regular shape are employed in design (1) to compensate for inaccuracies of manufacture, or (2) to provide dimensional adjustment. Their basic dimensional considerations are indicated in Fig. 2-28.

NOTCHES; PERFORATIONS

There are two general groups of notches: (1) notches that are part of the product design, and provided for clearance, locating, or attaching; (2) notches added to flanges to facilitate forming of the part.

Notches in highly stressed parts should never be specified with a sharp V at the vertex because it would provide the starting point of a tear. Instead, it should if at all permissible be rounded (*A*, Fig. 2-31), the minimum radius preferably being 2*T*. This type of notch is usually added in the blank; allowance should therefore be made for distortion in any subsequent forming operation.

A sharp vertex in notches is allowable on parts bearing lower stresses, and may aid in lowering diemaking and maintenance costs. If sharp notches are used, allowance for distortion should be made so that the notch can be added in the blank.

If design includes well-defined notches or side-wall perforations (*B*, Fig. 2-31) in a drawn part, they must be made after drawing; otherwise the openings would tend to close up under compressive force.

Relief Notches for Right-angle Bends. If the exterior surface of an unrelieved bend is parallel with the profile of the blank, some tearing or fracturing will occur

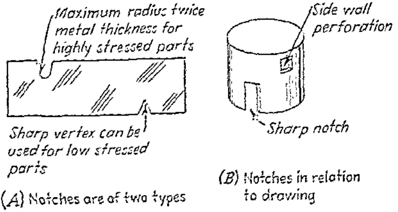


Fig. 2-31. Basic notch considerations.

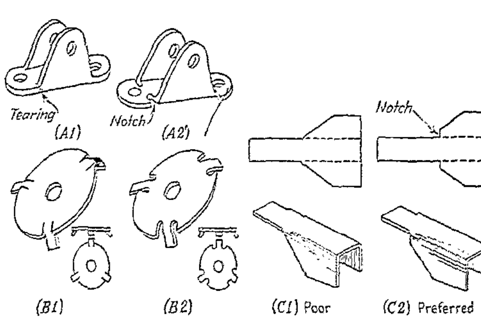


Fig. 2-32. Relief notches for right-angle bends.[16]

because of bending (*A*1, Fig. 2-32); the amount of tearing decreases with increase in peripheral radius of the finished formed part. To avoid such tearing or fracture, relief notches can be made in the flat blank, as at *A*2, and should if possible be at least twice stock thickness in both width and depth. This design will bend better and have a more rigid section.

Such designs as at *B*1 should be avoided for small-lot or pilot runs, since the lancing tool not only has to lance the three ears loose, but must also form and set them. With relief notches used as at *B*2, the forming tools merely form and set the ears at almost any desired angle. The radius at which the ears meet the major blank can be readily varied.

When one surface of right-angle-bent stamping meets an adjacent surface at a taper or slant (*C*1, Fig. 2-32), some buckling may result. It is better practice to notch as at *C*2 in order to have work contours meet at 90°.

Figure 2-33 shows some basic considerations in shearing edges of strip stock.

TABLE 2-7. APPROXIMATE RADII FOR 90° COLD BENDS IN ALUMINUM ALLOYS[7]

Alloy and temper*	Sheet thickness, in.					
	0.016	0.032	0.064	0.128	0.182	0.258
2SO, 3SO	0	0	0	0	0	0
2S-H12, 2S-H14, 3S-H12, 24SO, 52SO, 61SO	0	0	0	0	0T–1T	0T–1T
3S-H14, 52-H32	0	0	0	0T–1T	0T–1T	½T–1½T
2S-H16, 52-H34, 75SO	0	0	0T–1T	½T–1½T	1T–2T	1½T–3T
3S-H16, 61ST4	0T–1T	0T–1T	½T–1½T	1T–2T	1½T–3T	2T–4T
2S-H18, 52-H36, 61ST6	0T–1T	½T–1½T	1T–2T	1½T–3T	2T–4T	2T–4T
3S-H18, 52-H38	½T–1½T	1T–2T	1½T–3T	2T–4T	3T–5T	4T–6T
24ST3	1½T–3T	2T–4T	3T–5T	4T–6T	4T–6T	5T–7T
24ST36, 75ST6	2T–4T	3T–5T	3T–5T	4T–6T	5T–7T	6T–10T

* 0 = annealed
H12 = ¼ hard
H14 = ½ hard
H16 = ¾ hard
H18 = full hard
H32 = ¼ hard and stabilized
H34 = ½ hard and stabilized
H36 = ¾ hard and stabilized
H38 = full hard and stabilized
T3, T4 = room temperature, aged
T6 = elevated temperature, aged
T36 = aged and rolled

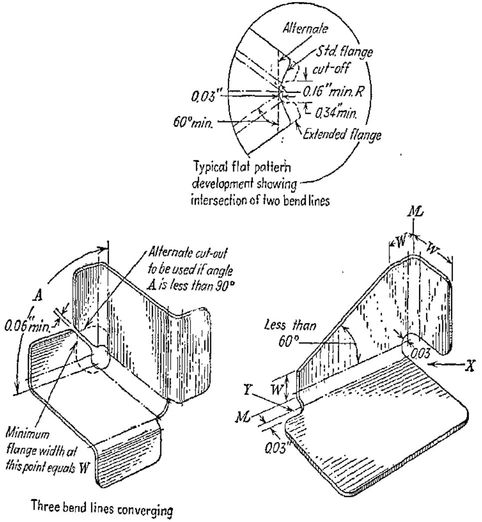


FIG. 2-35. Bend relief cutouts.

TABLE 2-8. MINIMUM BEND RADII, INCHES, FOR MISCELLANEOUS MATERIALS
All bends across the grain; 90° bend max

Low-leaded Brass (64.5–67.5% Cu; 0.30% Pb Max; 0.05% Fe Max; Balance, Zinc)

Temper	Thickness, in.	Radius	Temper	Thickness, in.	Radius
½ H..............	*0.005–0.091*	Sharp	Hard..............	0.005–0.051	Sharp
			Hard..............	0.057	0.0156
¼ H..............	0.005–0.057	Sharp	Hard..............	0.064–0.081	0.0312
¾ H..............	0.064–0.091	0.0156	Hard..............	0.091	0.0937
			Hard..............	0.102–0.114	0.250

Phosphor Bronze

Temper	*Grade A* (5% tin)	*Grade B* (8% tin)	*Grade D* (10% tin)
Hard..............	Sharp	Sharp	0.0312 in.
Spring..............	0.0156 in.	0.0312 in.	0.0625 in.

Beryllium copper up to 0.040 in. thick:
Solution-treated and ¼ hard: sharp radius
½ hard: 4.0*T* without orange peel; sharp radius without cracking
Hard: 7.5*T* without orange peel; 3.0*T* radius without cracking

Magnesium

ASTM grade	Forming temperature, deg F				
	70	200	400	500	600
M1 annealed..............	5*T*	4*T*	3*T*	2*T*	1*T*
M1 cold worked..............	11*T*	8.5*T*	6.5*T*	4.5*T*	
M31X annealed..............	3.5*T*	2*T*	1.5*T*	1*T*	
M31X cold worked..............	7.5*T*	3*T*			

Titanium RC-70 and RC-130A: 3*T* min.
Zirconium: Annealed and hot-rolled sheet can be bent 180° on a 3*T* radius. 10% cold work increases radius to 8*T*; 20% cold work increases radius to 12–16*T*

account, however, that this method makes the part weaker, work-hardens the metal excessively, and makes any subsequent forming operations difficult.

Significance of Bend Length. Because of failure in cracking at the convex surface, bending limits are determined by the *amount of stretch a metal can undergo under* the particular stress conditions.

The bend length (axial line of the bend) directly affects these stresses. For a part of very narrow bend length, the tension S_1 on the convex surface is only circumferential. In addition, where the bend length is finite, there is also present a transverse tension S_2 along the axis of the bend. The ratio S_2/S_1, which defines the stress condition at the critical location, increases with an increasing ratio of bend length L to metal thickness T. The ratio S_2/S_1 varies almost linearly with the ratio L/T until, for bend lengths greater than about eight times the thickness ($L/T = 8$), the stress ratio remains practically constant.

Bend Relief Cutouts. Where two or more bend lines intersect (X, Fig. 2-35), or where the bend intersects an edge of the piece at an angle less than 60°, the use of bend

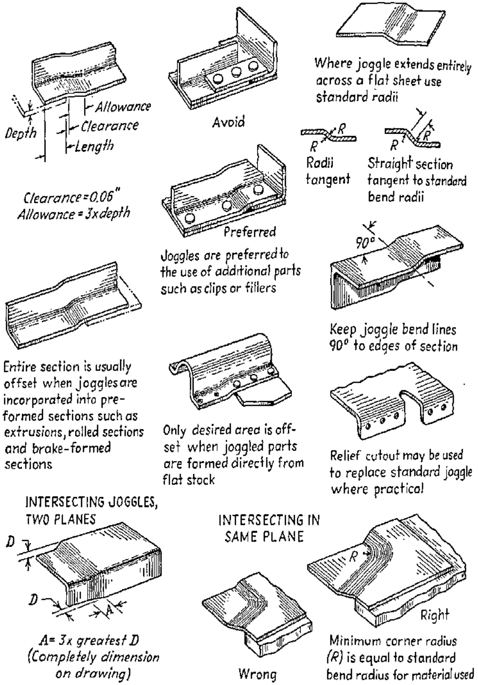


FIG. 2-36. Design of joggles.

relief notches or cutouts is indicated, to prevent distortion due to the proximity of the flanges. The cutout should be so shaped that all portions of the metal are removed which would otherwise have curvature in more than one direction.

The cutout should be extended from 0.3 to 0.6 in. past the critical bend tangent line or intersection of bend tangent lines. Internal radii should be a minimum of 0.16 in.

W in Fig. 2-35 represents minimum flange width for the composition, heat-treat condition, and thickness of the metal. For rubber forming without auxiliary devices, some practical minimum flange widths are:[8]

24SO (75SO) aluminum	$\frac{1}{16}$ in. + $2.5T$
24ST aluminum	$\frac{1}{8}$ in. + $4.0T$
Annealed stainless steels	$\frac{3}{16}$ in. + $4.5T$
$\frac{1}{4}$H stainless steels	$\frac{5}{8}$ in.

Nonferrous parts having narrow projecting tabs, small cutouts to reduce air leakage, or slots narrower than 0.75 in. may have relief radii smaller than 0.16 in. For parts

0.040 in. thick or less, minimum radius may be 0.06 in. For parts thicker than 0.040 in., minimum radius must be 1½T.

Ferrous parts must have a minimum radius of 1½T on both inside and outside corners of the blank.

Joggles. A joggle is an offset bent or formed on a part to provide clearance for adjoining parts. It is generally used in sheet-metal assemblies when a member must be fitted to two parallel surfaces not in the same plane. The decision to joggle will depend on relative stiffness of parts, flushness desired, and the cost compared with alternative provisions for assembly.

Joggles may be provided for surface differences as small as 0.010 in. Some aircraft designers set arbitrary height minima at 0.020 to 0.025 in. for smooth exteriors and 0.030 to 0.040 in. for interior structures.

Figure 2-46 illustrates some practical joggle-design considerations.

PRODUCT DESIGN FOR FORMING

The term "forming" can generally embrace all nonshearing stamping operations. It is here limited to metalworking operations in which characteristically the shape of the punch and die is directly reproduced in the metal, with little or no plastic flow of the metal.

Such limitation cannot be rigidly followed, since the stress characteristics of metal under deep recessing or cupping approach the stress conditions for pure drawing, where the side-wall metal is subjected to combined circumferential compressive stresses and radial tensions. In the following analysis of formed-products design, drawn types are therefore also discussed (see also Product Design for Drawing).

ANALYSIS OF FORMED-PARTS DESIGN

Figure 2-47 shows 22 classes of formed parts, classified as to shape and also, from top to bottom, according to the relative severity of tooling and process requirements. This classification generally applies to all readily formed metals, though especially devised to cover aluminum alloys.

Part types (i.e., shrink flange), whose stamping limitations are chiefly set by compression-type failures, can be produced in many metals to approximately the same limits. However, where a product design makes it inherently liable to tension-type failures (i.e., height of a stretch flange), the processing limits will depend closely upon the work material.

The basis of this classification is the contour of the stamped part, this contour being defined by a number of sections through the part.

Many particular shapes will seem to fall almost equally well into two or more classifications. Sometimes different part types will appear to be similar. In such cases, it is frequently possible by slight design changes to shift the part type from one difficult to form, to one relatively easy to produce.

Again, redesign may permit assembling a single complex product from several simple, easily produced parts.

The following design criteria are specific to the parts types classified in Fig. 2-47.

TYPE 1. SINGLY CURVED PARTS

Class 1-A. Straight Sections. Design considerations essentially the same as for class 1-B.

Class 1-B. Straight Flanged Sections. See Bend Radii above. Minimum flange widths depend on the forming method. Shorter flanges can be produced by trimming or, in rubber forming, by a wiper-type form block. Flange end cuts should be designed at least 60° to the mold line to avoid pronounced bulging at that point.

Class 1-C. Smoothly Contoured Sections. Because of the large radii of curvature common to these parts, spring-back is greater than normal, and minimum bends will depend chiefly on the type of forming equipment that can or must be used. Practical radii would be 1½ to 2 in. on rolls, 1 in. by stretch forming, and ½ in. with caged rubber die in a power brake.

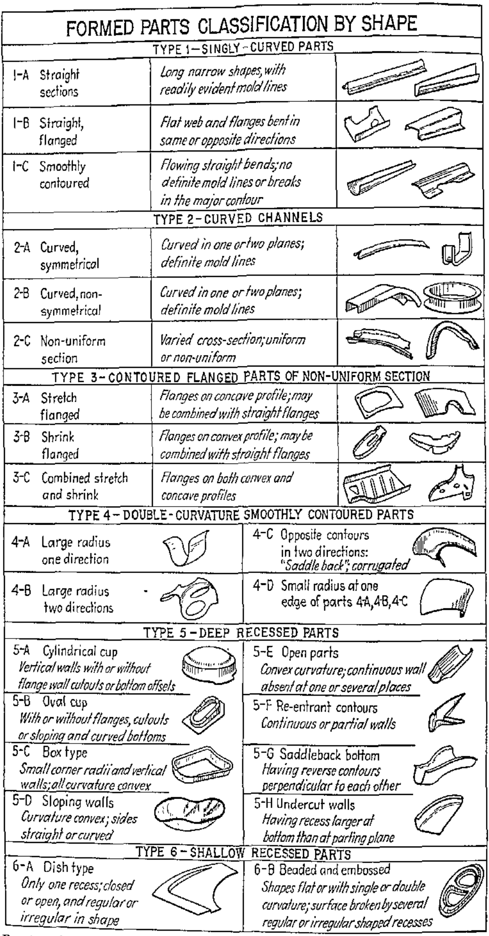


FIG. 2-37. Formed shapes classified in order of increasing severity of operations; class 1, easiest; class 6, most difficult.

TYPE 2. CURVED CHANNELS

Class 2-A. Symmetrical Sections. The preferred section, wherever possible to use. Elongation in outer fibers must not exceed the material's limits. One operation contour bending of preformed sections can be done up to about 20 per cent stretch for 24SO aluminum; *for rubber press forming, it is limited to about 12 per cent.* Tensile bending strains can be reduced by designing the section so that the neutral axis is close to the outer surface of curvature.

If long, thin-gage parts are required, they should be made of hard or non-heat-treatable material, to resist distortion in heat treatment. Cross sections should have

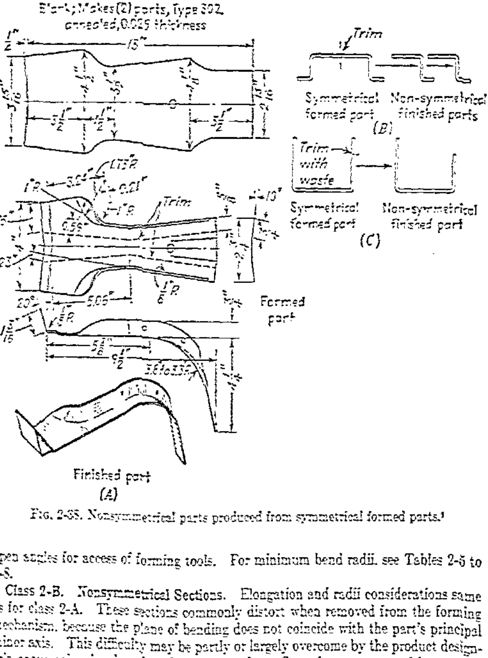


FIG. 2-38. Nonsymmetrical parts produced from symmetrical formed parts.[1]

open angles for access of forming tools. For minimum bend radii, see Tables 2-5 to 2-8.

Class 2-B. Nonsymmetrical Sections. Elongation and radii considerations same as for class 2-A. These sections commonly distort when removed from the forming mechanism, because the plane of bending does not coincide with the part's principal minor axis. This difficulty may be partly or largely overcome by the product designer's cooperation in changing the cross section. Sometimes, a part with nonsymmetrical cross section can be made symmetrical during forming, either (1) by combining two parts (identical, or right- and left-handed) into a single blank to be trimmed apart after forming (Fig. 2-38*A* and *B*), or (2) by adding excess metal and trimming it off after forming (Fig. 2-38*C*).

Class 2-C. Nonuniform Sections. Elongation and radii considerations same as for class 2-A. The cross section should be symmetrical wherever possible. For satisfactory stretch forming, change in cross-sectional shape must be gradual.

TYPE 3. CONTOURED FLANGED PARTS OF NONUNIFORM SECTION

Class 3-A. Stretch-flanged Sections. See Table 2-1 on permissible forming limits; also, accompanying text on dimensional calculations for, and permissible strain in both stretch and shrink flanges. For bend radii, see Tables 2-5 to 2-8. The designer should remember that stretch increases with increasing flange width, increasing flange-edge movement (increasing bend angle), and decreasing contour radius. Any cutouts made to bring the stretch within rubber-forming limits must extend over the full length of the stretch area.

Class 3-B. Shrink-flanged Sections. Flange widths, bend radii, and forming limits are same as for class 3-A. For rubber forming, high shrink (compressive) strains must be relieved by providing short flange segments with free edges. Hard stock and thin gages do not shrink readily.

Class 3-C. Combined Stretch-and-shrink flanged Sections. Flange widths, bend radii, and permissible strains are generally the same as for classes 3-A and 3-B except that strains in adjacent stretch-and-shrink portions are complex and cannot yet be properly evaluated.

A flange having adjacent stretch-and-shrink areas can be formed to a severe contour if the contour radii and/or the segment angles are small (under 4 in. and 60°, respectively) since the stretch-and-shrink strains may largely compensate each other. Total strains may be considered as consisting of two components: (1) strains resulting from the contouring of the flanges, and (2) strains created by curving the web. The latter strains are caused by deviations from a flat web.

Shrink areas on reverse-contour rubber-formed parts are always critical, and thin gages or strong, hard stock should be avoided where possible.

It has been observed[10] that stretch portions of reverse-contoured flanges of deep-drawn boxes can be made very high in comparison with their contour radii, without cracking. Such cracking was encountered, however, in a severe-stretch flange adjacent to a shrink flange, which latter developed wrinkles. The mutual relief of strains in adjacent shrink-and-severe-stretch flanges of formed boxes is commonly provided, either by closing the box or by adding short portions of convex contour which are trimmed off after forming.

TYPE 4. DOUBLE-CURVATURE SMOOTHLY CONTOURED PARTS

Class 4-A Parts. Large Radius in One Direction. The majority of the parts covered by class 4 are especially suited for stretch forming, permitting the use of hard stock and thus avoiding heat-treat distortion. Suitable materials include 24ST and 61SW aluminum, and quarter-hard or annealed austenitic stainless steel, for parts formed in one operation; and as-quenched 52SO and 24S aluminum for parts requiring two or more operations.

A practical limit for *longitudinal* stretching may be set at a minimum of twice the maximum transverse extension; broader parts are preferably stretched longitudinally. Approximate limits of elongation (per cent in 42 in.) for certain 0.064-gage aluminum alloys are:

	Sheared edges, %	Polished edges, %
24SO	8.4	10.8
24ST	5.0	7.3
61SW	5.8	12.5
52SO	10.5	11.6

Minimum bend radii should approximate ½ in. for double-action die forming, and 1 in. for stretch forming. Parts that taper longitudinally are suited for stretching, but greater flash will result because more metal is needed to make the blank symmetrical for forming.

Class 4-B Parts. Large Radii in Two Directions. Data on type of material, bend radii, and maximum stretch are same as for class 4-A. Parts deviating only slightly from flat sheet are difficult to form accurately because of high friction around the edge of the die; also because buckles tend to form along the center of the blank parallel to the direction of stretching. Proper die development can usually correct this buckling tendency.

Class 4-C Parts. Opposite Contours in Two Directions. Suitable materials and forming limits are same as for class 4-A. However, if the maximum contour is at the edge of the part, edge effect will reduce the formability.

The "saddleback" characteristic of this class has contours concave on opposite sides of the sheet. It can be stretch-formed over a block if the one contour is not reversed (curves throughout in one direction); the other contour may be with or without a number of reversals. The direction of stretching must be along the unreversed contour.

To prevent wrinkling, the saddle should be shallow, not exceeding a 0.09 maximum depth-chord ratio. If the part is corrugated (several reversals of contour) the depth-chord ratio of such reversals should not exceed 0.22.

Class 4-D Parts (A,B,C Parts with Small Radii). This class should be designed only for ductile materials. The sharp radius (generally formed in a second operation) should be so proportioned that shrink does not exceed 4 to 6 per cent. If the sharp radius produces a stretch flange, maximum width can be one-twentieth of the profile radius of the part periphery, where the flange is turned through 180°.

Any sharp contour which does not coincide either with the directions of stretching or perpendicular to it requires a separate operation.

TYPE 5. DEEP RECESSED PARTS; TYPE 6. SHALLOW RECESSED PARTS

These two types are here included for classification purposes only (see Product Design for Drawing).

OTHER DESIGN CONSIDERATIONS FOR FORMED PARTS

Lightening Holes in Flanges. Flange design proper has been covered under Design to Increase Strength of Stampings. Lightening holes can be flanged in annealed aluminum alloys up to 0.125 in. thick, and in heat-treated 24ST up to 0.064 in. thick. Austenitic stainless steel up to 0.060 in. can be formed with external hole flanges and up to 0.050 in. thick, with internal flanges. The quarter-hard stainless steels up to 0.04 in. thick can be externally flanged, and internally flanged up to 0.030 in. thick.

Rubber-sheared lightening-hole minimum diameters, in relation to aluminum alloy thicknesses, are shown in Table 2-9.

Sheet-metal Box Design. Box constructions shown in Fig. 2-39 represent successful designs in widespread applications.

Lock-seam corners (view *A*) are excellent for metal 0.018 in. or thinner. Manufacturing cost is moderate where tooling cost is justified by the estimated quantity. Lithographing can be done in the flat sheet before forming. Height of box sides is usually less than 3 in., because of press-stroke limitations.

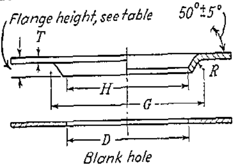
The can-type lock-seam construction (View *B*) is economical to manufacture but is limited to lightweight stock and round corners. The bottom not being flush with the seamed edge, the construction is not suited for heavy contents but, with double seam, holds powdered products well. This design would require sealing compound for leakproofing.

When design calls for small boxes of fairly stiff metal a blanked dovetail-fastening construction (view *G*) will permit the shape to be retained without seaming or welding.

Where simple leakproof design is wanted, a box with ends folded on the outside (view *H*) may be considered. Ends folded on the inside (view *J*) make for improved appearance but are not leakproof.

A construction using split corners with tabs (view *M*) is low in cost, and in widespread use where appearance is not important.

TABLE 2-9. LIGHTENING HOLES FOR 55° FLANGE[1]



D, in.	H, in.	G, in.	T, in.	R, in.
		1/8-in. Flange Height		
0.445	0.812	1.223	0.020–0.040	3/16
0.400		1.212	0.051–0.072	1/4
0.570	0.938	1.348	0.020–0.040	3/16
0.525		1.337	0.051–0.072	1/4
0.695	1.062	1.473	0.020–0.040	3/16
0.650		1.462	0.051–0.072	1/4
0.820	1.188	1.598	0.020–0.040	3/16
0.775		1.587	0.051–0.072	1/4
		5/32-in. Flange Height		
0.900	1.312	1.800	0.020–0.040	3/16
0.852		1.791	0.051–0.072	1/4
1.150	1.562	2.050	0.020–0.040	3/16
1.082		2.041	0.051–0.072	1/4
1.276	1.688	2.175	0.020–0.040	3/16
1.208		2.166	0.051–0.072	1/4
1.400	1.812	2.300	0.020–0.040	3/16
1.332		2.294	0.051–0.072	1/4
		3/16-in. Flange Height		
1.606	2.062	2.625	0.020–0.040	3/16
1.543		2.617	0.051–0.072	1/4
1.490		2.611	0.081–0.102	5/16
1.856		2.875	0.020–0.040	3/16
1.793	2.312	2.867	0.051–0.072	1/4
1.740		2.861	0.081–0.102	5/16
1.982		3.000	0.020–0.040	3/16
1.919	2.438	2.992	0.051–0.072	1/4
1.866		2.987	0.081–0.102	5/16
2.106		3.125	0.020–0.040	3/16
2.043	2.562	3.117	0.051–0.072	1/4
1.990		3.111	0.081–0.102	5/16
2.356		3.375	0.020–0.040	3/16
2.293	2.812	3.367	0.051–0.072	1/4
2.240		3.361	0.081–0.102	5/16
2.606		3.625	0.020–0.040	3/16
2.543	3.062	3.617	0.051–0.072	1/4
2.490		3.611	0.081–0.102	5/16
2.856		3.875	0.020–0.040	3/16
2.793	3.312	3.867	0.051–0.072	1/4
2.740		3.861	0.081–0.102	5/16
3.106		4.125	0.020–0.040	3/16
3.043	3.562	4.117	0.051–0.072	1/4
2.990		4.111	0.081–0.102	5/16
3.356		4.375	0.020–0.040	3/16
3.293	3.812	4.367	0.051–0.072	1/4
3.240		4.361	0.081–0.102	5/16
3.606		4.625	0.020–0.040	3/16
3.542	4.062	4.617	0.051–0.072	1/4
3.490		4.611	0.081–0.102	5/16
3.856		4.875	0.020–0.040	3/16
3.793	4.312	4.867	0.051–0.072	1/4
3.740		4.861	0.081–0.102	5/16

These lightening holes may be formed in 52S-H32, 61ST, 24ST, 14ST, R-301-T, and 75ST aluminum alloy and AMC52SO and FS-Ia magnesium alloy or any softer condition of any of these alloys.

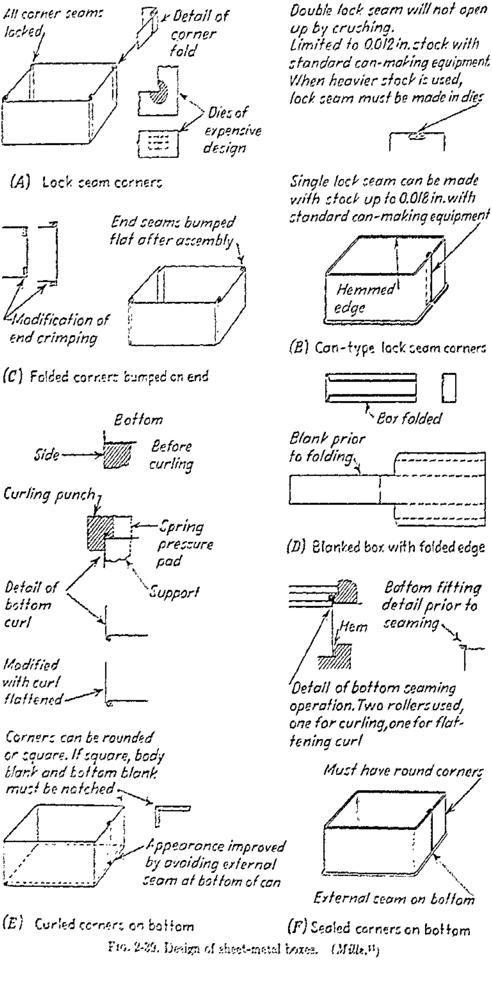


FIG. 2-39. Design of sheet-metal boxes. (Mills.[11])

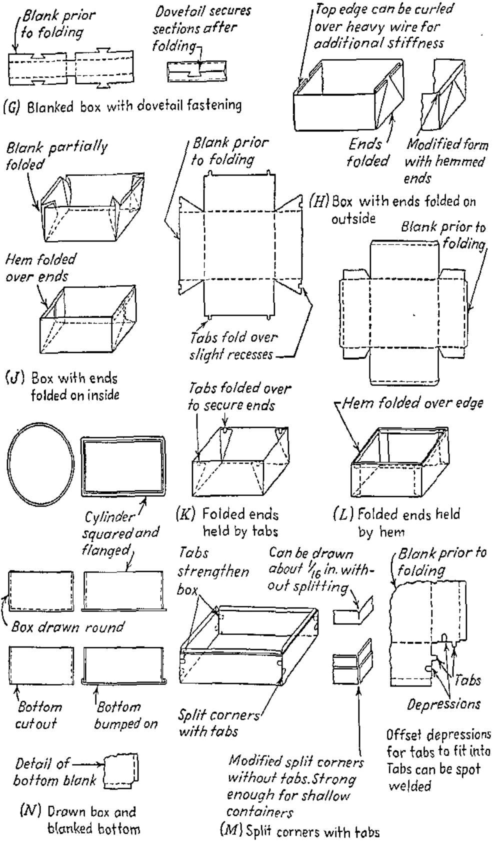


FIG. 2-39. (*Continued.*)

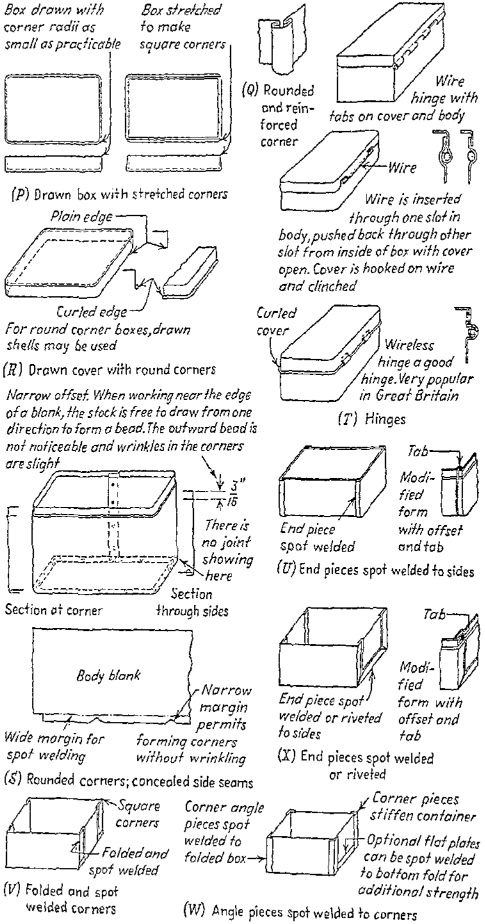


Fig. 2-39. (*Continued.*)

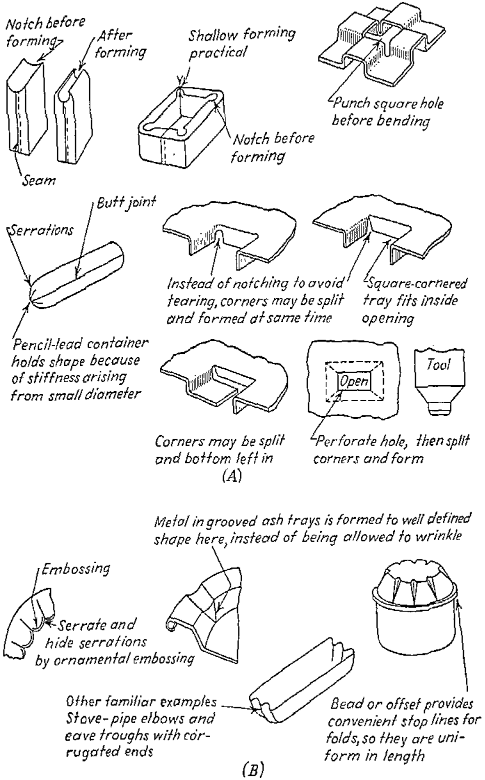


FIG. 2-40. Forming design for surplus stock control. (*Mills.*[4])

The construction shown in view *S* presents very attractive appearance, with all corners round and no joint showing on the side where the bottom is connected.

Various welded-box constructions are shown in views *U*, *V*, *W*, and *X*. Unlike folded designs, spot welding requires spraying or retouching after welding to prevent rusting.

Control of Surplus Stock in Formed Parts. In many parts formed from plain blanks, wrinkling or folding occurs. Sometimes this is not objectionable; more often it is. A common provision is to cut away the surplus stock (*A*, Fig. 2-40). Another

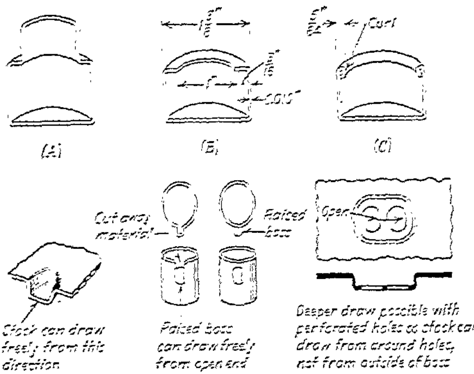


Fig. 2-41. Controlling surplus stock in roll and die forming.[1]

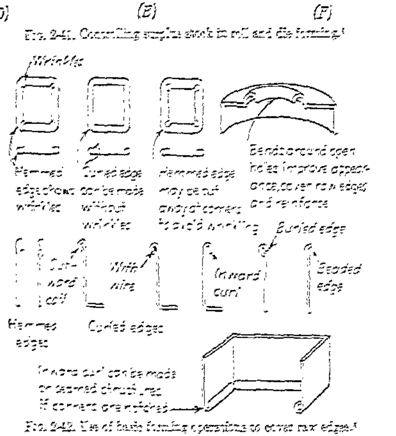


Fig. 2-42. Use of basic forming operations to cover raw edges.[1]

good practice, where feasible, is to form the surplus stock into an intentional and controlled shape, either functionally or for styling (B, Fig. 2-40).

Figure 2-41 shows several formed-parts designs, and appropriate stock control. At A, surplus stock would gather at the smaller of the two diameters, under roll or die forming. By reducing the smaller diameter, in several operations, a slight reduction can be made. Die forming a shell edge, as at B, would cause the flange to wrinkle, unless the flange is rolled in from the outside in three stages: 30, 60, and 90°. Where design and function permit, curl forming of the shell edge (as at C) is a practical method.

Views *D*, *E*, and *F* suggest good product designs wherein forming near an edge, from which the metal can draw freely, tends to less tearing of stock than may result from forming in the interior surface.

Covering of Raw Edges. The design of a part to be formed can often, without requiring extra operations, utilize functional hemming, curling, or beading to eliminate raw edges (Fig. 2-42).

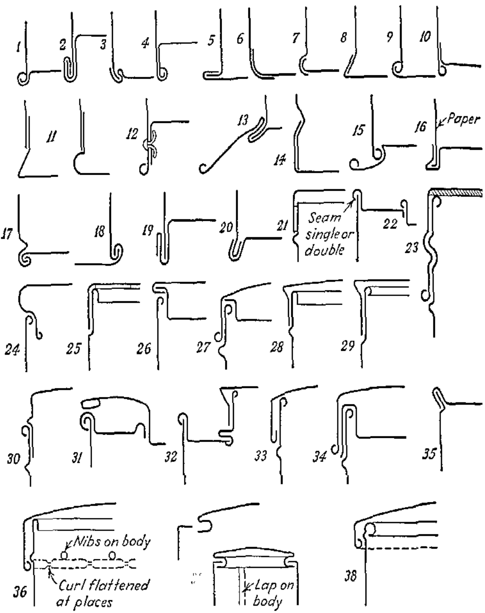


FIG. 2-43. Attachment of tops and bottoms to sheet-metal container. (*Mills*.[15])

Container Top and Bottom Attachment. Figure 2-43 illustrates some common methods of attaching tops and bottoms on sheet-metal containers. A majority of the applications involve the use of interlocking seams; in some cases, snap or press fits are quite satisfactory. Although the designs shown are generally produced in special automatic machines, a number of the designs can be stamped in adapted dies of certain types described in the sections Forming Dies and Assembling Dies.

Container-lid Nibs and Catches. Figure 2-44 shows a variety of detent designs for removable lids on sheet-metal boxes, cans, and cabinets. Catches are commonly made by forming nibs or small projections in both the container and the lid.

A listing of the various types of construction for attachments is as follows (item numbers correspond to those in Fig. 2-43):

1. Single-seam bottom (rapidly produced; no inside support required)
2. Double-seam bottom (for liquid or heavy contents; rapidly produced)
3. Bumped-on bottom (inside support required)
4. Curled-on bottom
5. Flanged bottom
6. Floating bottom
7. Snapped-on bottom
8. Clinched bottom
9. Outside-curled bottom
10. Curled floating bottom
11. Pressed-in bottom
12. Removable bottom
13. Tobacco-can bottom
14. Rolled clinch bottom
15. Snap-fit bottom
16. Seamed-metal bottom
17. Flour-sifter bottom
18. Flat-seam bottom (for teapots, wash boilers, etc.; must be formed over a solid plug; slower production than for single or double seam)
19. False-seam bottom
20. Squeezed and soldered seam for rectangular cans
21. Slip cover
22. Friction plug
23. Screw cover
24. Slip plug
25. Offset slip cover
26. Two-piece plug
27. Slip cover and friction plug
28. Beaded slip cover
29. Offset beaded slip cover
30. Inside slip cover
31. Friction plug
32. Necked with beaded slip cover
33. Hemmed slip cover
34. Two-piece inside-fit cover
35. Rolled seam
36. Lock cover
37. Tea-can cover
38. Snap-on cover

Product Design for Drawing. Under Analysis of Formed-parts Design, in a preceding section, a classification for all formed parts was described and illustrated (Fig. 2-37). It was there stated that classes 5 and 6 more properly relate to drawing operations.

TYPE 5. DEEP RECESSED PARTS

Type 5-A. Cylindrical Cups. Characterized by having vertical walls, with or without cutouts in walls of flanges or offsets at the bottom. For deep drawing with double-action dies, the material strength should not exceed 30,000 psi. For higher-strength materials of the same gage, the maximum single depth of draw must be reduced. The diameter and height of a part should be such that the ratio of punch diameter to blank diameter will be at least 0.5 for double-action dies. The ratio of height to radius should be at least 0.5 for deep-draw 1010 steel and 24SO or 52SO aluminum alloys, and 0.3 for 61SW alloy. Draw radii should be within the range of $5T$ to $10T$, with $8T$ optimum. The maximum depth of draw is equal to the sum of the part depth and the required flange widths, if any.

Type 5-B. Oval Cups. With or without flanges, cutouts, or curved or sloping bottoms. The same general design provisions prevail as for class 5-A.

Type 5-C. Rectangular Box Types. Includes parts with vertical walls and small corner radii; all curvature convex; regular, irregular, or sloping bottom. Draw depth is limited to 7 times any corner radius from ½ to 1 in., or 12 times corner radii of ¼ in. or less. Both the draw and the vertical corner radii must be $5T$ minimum; bottom radii can range from $2\frac{1}{2}T$ to $8T$. For 3SO, 24SO, 52SO, and deep-drawing 1010 steel, the box height-width ratio is about 0.6 for corner radii up to ¾ in., and 0.75 for radii exceeding ½ in. Included corner angles of less than 60° reduce the feasible depth of draw.

Type 5-D. Sloped-wall Parts. Have convex curvature, straight or curved sides, and flat or irregular bottoms. Draw and punch radii requirements similar to those for classes 5-A and 5-B. The punch-blank area ratio is optimum at about 0.33. 3SO, 52SO, 24SO, and other highly ductile materials draw best in this class.

Type 5-E. Open Parts. Characterized by the absence of a continuous wall at one or several locations, and convex curvature. For single draws the draw radius should

Views *D*, *E*, and *F* suggest good product designs wherein forming near an edge, from which the metal can draw freely, tends to less tearing of stock than may result from forming in the interior surface.

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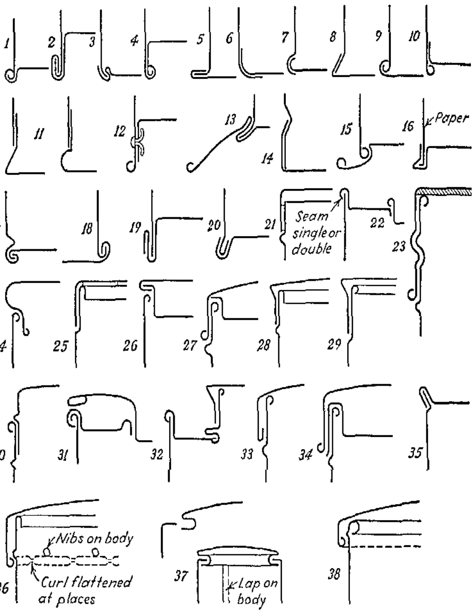

FIG. 2-43. Attachment of tops and bottoms to sheet-metal container. (*Mills.*[13])

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Type 5-E. Open Parts. Characterized by the absence of a continuous wall at one or several locations, and convex curvature. For single draws the draw radius should

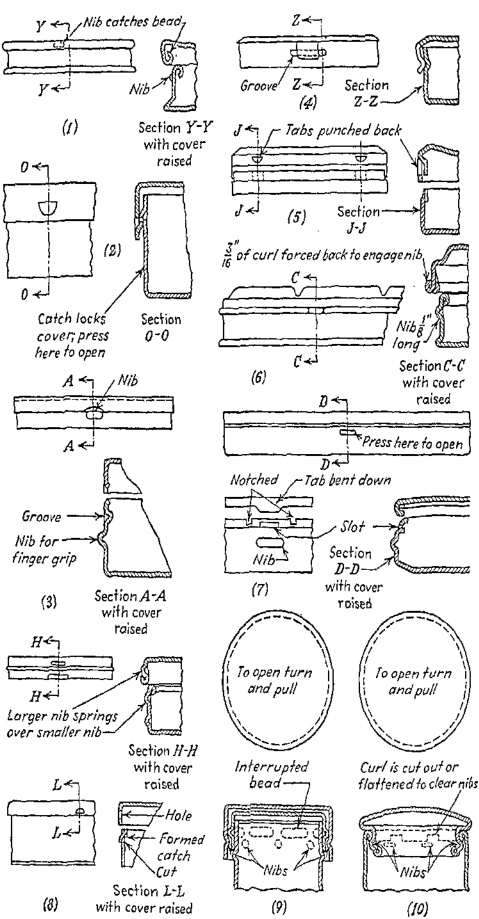

FIG. 2-44. Detent designs for container lids. (Mills.[13])

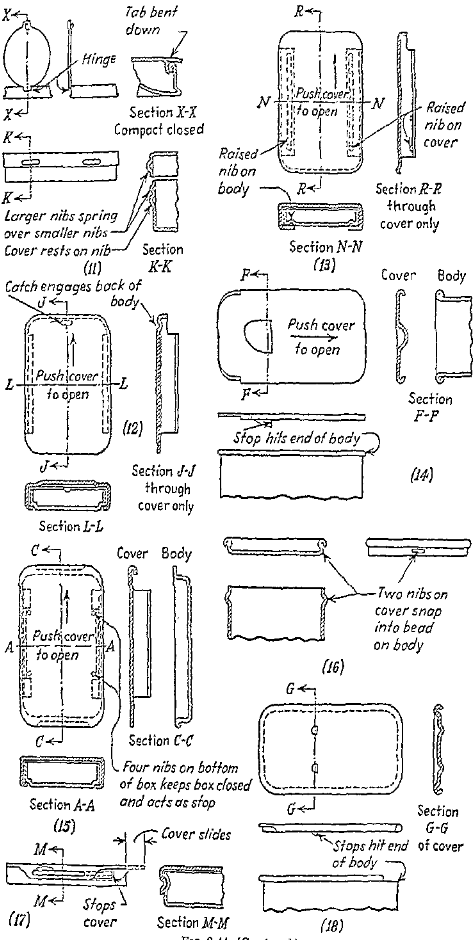

Fig. 2-44. (*Continued.*)

be as large as $10T$ to $12T$, especially where there is an abrupt change in the parting plane. The part should be designed with fairly uniform depth, or else gradual change of depth, to avoid wrinkling. The punch area–blank area ratio should be a minimum of 0.25 for a single draw.

Type 5-F. Reentrant Contour Parts. Whether walls are partial or continuous, the radius of the reentrant area should be not less than the depth of the part, to avoid excessive tool wear and breakage. The punch area–blank area ratio must be not less than 0.30 for 24SO, 52SO, and other ductile materials. Draw radius on the reentrant contour should be ½ in. or greater. Where design permits, sloping walls permit easier forming.

Type 5-G. Saddleback-bottom Parts. Generally, saddlebacks should be avoided because of marked wrinkling tendencies in the saddle center. Such wrinkling is minimized if moderate contours can be held. Draw radii, punch area–blank area ratios, and maximum contours are same as for class 5-E. Saddleback design is best formed in low-yield-strength materials such as 3SO and 24SO.

Type 5-H. Parts with Undercut Walls. Characterized by having a recess that is larger at the bottom than at the parting plane. The part design should permit the undercut to be produced in one operation by tilting the part to permit the access of conventional tooling. Punch area–blank area ratio should be at least 0.30. Draw depth and radius, contour, and materials are same as for classes 5-*A* and 5-*B*.

TYPE 6. SHALLOW RECESSED PARTS

These parts are characterized by having one or more recesses with depth shallow in relation to the major dimensions of the recess. The depth-width ratio must be less than 0.15. Careful parts design, with optimum distribution of recesses, is required to avoid the tendency to buckle in the flat area between recesses. To overcome buckling, beads or other shallow recesses may have to be added to those required by design. Parts of this design can be formed from as-quenched 24S or 24SO; in some cases, 61S can be satisfactorily formed within 8 hr after quenching.

Class 6-A. Dish-type Parts. Typically, have only one recess; shape may be open or closed, and regular or irregular. Since most of these parts are formed by pure *stretch*, all radii should be generous for greatest distribution of strain. Walls of the recess should slope as much as possible.

When the cross section is a circular arc, the following are good values of permissible stretch for the indicated recess depth-width ratios:

Ratio	0.10	0.15	0.20	0.25	0.30
Stretch, %	3	6	10	15	22

Class 6-B. Beaded and Embossed Parts. This class includes a wide variety of shapes, flat or with single or double curvature, having the surface broken by several regular or irregular-shaped recesses. It is essential, when forming 24SO or 52SO, that required stretch limits do not exceed 10 per cent for rubber forming, or 15 per cent for die forming, unless the recess can be located near a free edge where the material can feed into the recess. Hard stock, such as 24ST, can be rubber-formed where most of the part area is covered by closely spaced parallel beads.

Recess mold lines radii should be about 1 in. minimum for properly distributing strains over a large area. Where the part periphery has a surrounding wall, outside corner radius should be at least half the blank radius. Whenever forming is done by pure stretch, the slope at a recess corner should be less than the slope along the sides.

OTHER DESIGN CONSIDERATIONS FOR DRAWN PARTS

Deep-drawn Thin-walled Cylindrical Cups. Drawability in thin-walled cups (blank diameter of $20T$ to $30T$ or larger) is influenced chiefly by the punch and the die radii; the strain properties depend rather little upon the metal thickness. Figure 2-45, valid for brasses and many other ductile materials, shows that an average

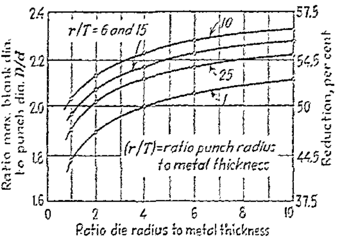

FIG. 2-45. Drawability factors for 63/37 brass sheet, 0.040 in. thick, 1.2 in. punch diameter.

initial-draw reduction of somewhat over 50 per cent, from blank diameter to drawn-shell diameter, can be realized if the die radius is between $5T$ and $10T$, and the punch radius is at least $5T$.

Deep-drawn Thick-walled Cylindrical Cups. The deep drawing of very thick blanks involves interrelated complex limiting factors. The limitations are much more severe for steel than for such ductile metals and alloys as brass. The ironing phase in cup drawing chiefly determines the maximum feasible reduction. A maximum reduction of 65 per cent in cross-sectional area is theoretically possible. Experimentally, wall reductions of 60 per cent of blank thickness, or more, are obtainable, as seen in Fig. 2-46 (for steel blanks of $5T$ to $7T$ diameter).

Deep-drawn Boxes. Where boxes have no flanges, the depth and corner radii are the chief limiting factors. Tests from which Table 2-10 was compiled showed that the corner radius has little effect on maximum depth for the more ductile alloys 2SO, 3SO, and 52SO. For other alloys such as 24SO, 53SW, and 61SW, permissible

TABLE 2-10. DIMENSIONS OF TRIMMED RECTANGULAR ALUMINUM ALLOY BOXES[11]
Drawn from circular blanks in a single operation

Thickness, in. T	Size, in. $W \times L$	Trimmed depth, in. h	Corner radius, in. r	Ratios		
				h/w	h/r	r/w
0.032	2 × 3	1¾	5/32	0.88	11.2	0.078
0.040	4¾ × 6	2	¼	0.42	8.0	0.053
0.051	5¾ × 9	2⅛	5/32	0.37	13.7	0.027
0.051	5⅛ × 6½	2½	3/16	0.51	13.3	0.037
0.051	2 11/16 × 5	2⅜	5/32	0.65	15.2	0.042
0.051	5⅞ × 7½	4	¼	0.68	16.0	0.043
0.051	2 11/16 × 5	2⅞	3/16	0.78	15.3	0.051
0.051	4⅝ × 4⅝	3	¼	0.65	12.0	0.054
0.051	7 × 9¼	2¼	¼	0.38	10.0	0.036
0.064	2 × 4½	1¾	¼	0.88	7.0	0.125
0.064	3 × 3	2	¼	0.67	8.0	0.083
0.064	5 × 5	2½	¼	0.50	10.0	0.050
0.064	5 × 11 5/16	2½	½	0.50	5.0	0.100
0.064	5½ × 6	3	¼	0.55	12.0	0.045
0.064	5½ × 9½	3½	¼	0.64	14.0	0.045
0.064	4 × 7½	3⅝	¼	0.91	14.5	0.063
0.064	5¾ × 9	2⅛	3/16	0.39	11.3	0.034
0.064	5¼ × 5⅝	4	3/16	0.76	21.0	0.037

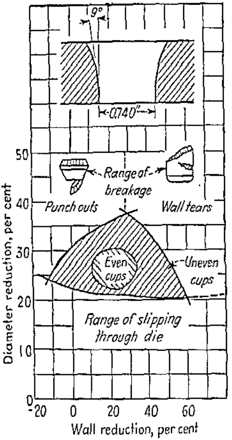

FIG. 2-46. Various types of difficulties in cupping from thick blanks. (*Sachs, Espey, Taub*,[8])

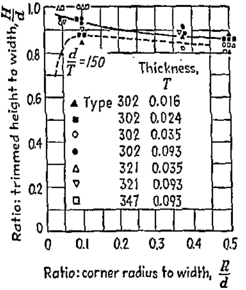

FIG. 2-47. Effects of corner radius and sheet thickness on drawability of stainless steel boxes. (*Lockheed Aircraft Corp.*[8])

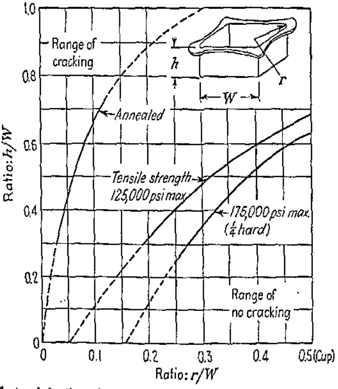

FIG. 2-48. Effects of depth and corner radius on stress-cracking tendency for austenitic stainless steels of various tempers.[9]

depth would be reduced 50 per cent or more if the corner radius is reduced to about 10 per cent of box width.

The limits in cupping box-shaped parts of austenitic stainless steels are indicated in Figs. 2-47 and 2-48. From Fig. 2-47, it is seen that, for a R/d range from 0.03d to 0.5d (cylindrical cup), the maximum box height for stainless (also carbon) steels is greater than 0.8D. Figure 2-48 shows that, in the drawing of stainless steel, the depth and/or the corner radius are also limited by the tendency to stress cracking.

The above considerations do not apply to boxes having reentrant corners, since in such designs the metal is stretched in the corners, and only such metals as have high elongation are suitable.

Drawn Shallow Recessed Parts. These parts (class 6), being produced almost entirely by stretching, the average forming strain (stretch) e involved is given by the equation

$$e = \frac{L_1 - L_0}{L_0} \qquad (8)$$

where L_1 = recessed contour length

L_0 = its developed length in the blank

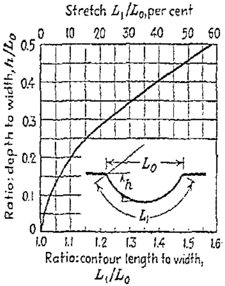

FIG. 2-49. Relation between average stretch and dimensions of a recess of circular contour.

For the most common, circular type of contour recess, average stretch is a function of the ratio between the depth h and the length L_0 of the recess (Fig. 2-49).

PIECED VS. UNIT CONSTRUCTION

Figure 2-50 illustrates a number of good product-design principles involving resort to pieced construction.

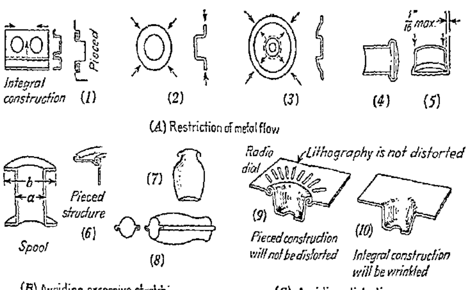

FIG. 2-50. Comparisons of pieced vs. unit construction. (*Mills.*[4])

Restriction of Metal Flow. In a double-cup part of integral construction (view 1), the metal must draw simultaneously over two forming punches and there is strong likelihood of stretching and tearing; pieced construction is preferable in such a case. In a circular shell (view 2), it is well to design the part so that the stock can draw freely from all directions and, preferably, to have the draw near the periphery. Where design permits a center hole (view 3), difficult draws can be made more easily; however, possible tearing limits the amount of draw from inside.

Avoidance of Excessive Stretch. The spool and the jar designs shown in views 6 and 7 are not practical because of risk of tearing. Stretching of the spool from

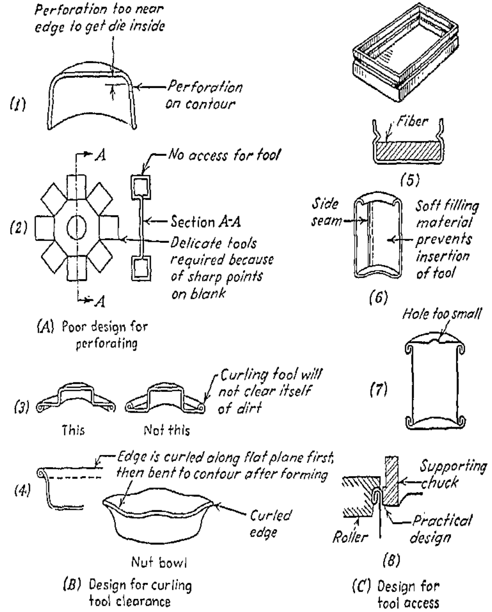

FIG. 2-51. Design considerations for tool access.[4]

diameter a to flange diameter b risks rupture in thin stock; pieced structure avoids this. The jar in view 7 can be formed in thin metal only to a limited extent by bulging with rubber or hydraulic dies; but pieced construction as in view 8 is practical for die forming.

DESIGN FOR STRONG, SIMPLE TOOLING

A little thought and discretion on the part of the product designer frequently can greatly facilitate optimum tool design and operation. In Fig. 2-51A, views 1 and 2 emphasize the need to avoid designs that require tools which are either too fragile or else must be ground to a contour for sharpening.

A product design that does not permit interior access for a forming tool is impractical. View 5 shows a condition where a fiber strip (or other soft material) is to be assembled in a drawn shell, which it is to be held in by an inwardly formed bead.

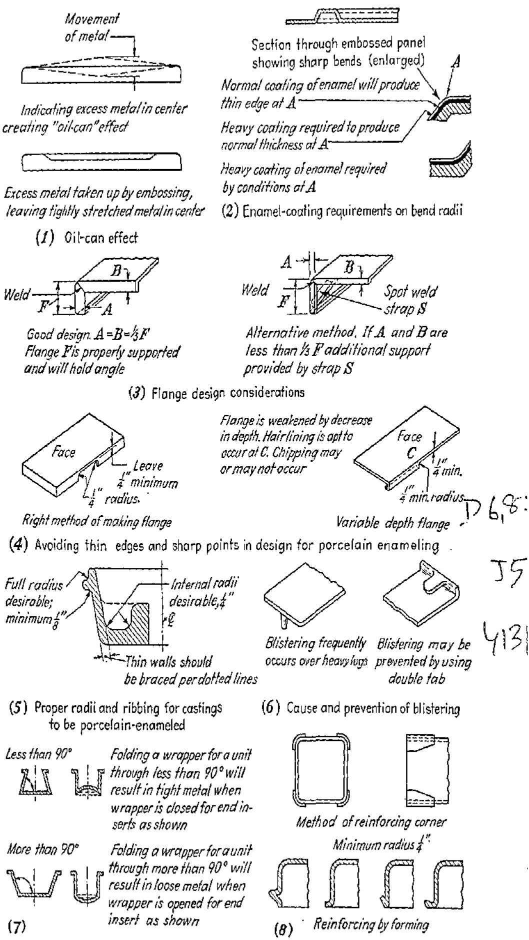

FIG. 2-52. Product-design suggestions for parts to be porcelain-enameled.[15]

Here, product design must permit entry of a hard tool in order to form the sharp groove.

Where a sleeve or tube is designed to be filled with soft material, as in view 6, interior tool access is prevented. The top can be flanged over but, without an interior hard tool to bump against, there will be wrinkling.

Too small an opening, as in view 7, will also prevent insertion of a forming tool, whereas the product design in view 8 does provide interior tool access.

DESIGN OF METAL PARTS FOR PORCELAIN ENAMELING

Gage of Metal. Use of the proper gage of metal is all-important for avoiding such processing defects as chipping, hairlining, warpage, and sagging. It is much better to use somewhat too heavy a stock than one that is too light. Table 2-11 is a safe guide for parts of moderate size, intended to be enameled in white or light colors, and required to have only moderate rigidity and flatness.

The required flatness for large architectural porcelain enamel panels may call for heavier gages than Table 2-11 indicates, going perhaps to 18 or 16 gage. For formed metal plumbing ware, necessary rigidity calls for stock not lighter than 14 gage.

TABLE 2-11. METAL GAGES FOR AVERAGE PORCELAIN ENAMELING REQUIREMENTS[14]

Gage	Width, in.	Total area, sq ft
24	6	0.5
24	12	3.0*
24	18	5.0*
22	6	1.0
22	12	1.5
22	18	6.0*
22	24	8.0*
20	6	1.5
20	12	5.0
20	18	8.0*
20	24	10.0–15.0*

* Should be embossed, flanged, or otherwise suitably reinforced.

Materials. Ordinary stamping grades are not suited as basis metals, because of impurities that may cause blistering or chipping of the coat. Commonly used materials include:

1. "Enameling iron" steel sheets
2. Good grades of drawing steel of 20 per cent carbon or less
3. Non-heat-treatable aluminum alloy sheet
4. Castings: gray iron, malleable iron, aluminum, etc.

Specific design considerations are indicated in Fig. 2-52.

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SECTION 3

PROCESS PLANNING FOR PRESSWORK TOOLING*

PRESSWORKING VS. OTHER MANUFACTURING METHODS

At the outset of process planning, the decision must be reached whether the contemplated product, as designed or with permissible redesign, will be stamped entirely, in part, or not at all. The decision calls for the concerted attention of the design, materials, methods, tooling, manufacturing, and any other functions that may have an interest. Certain practical guiding criteria follow, but the total subject requires reference to extensive literature.[illegible]†

Design factors (see Sec. 2):

1. *Shapes* are limited to those which may be produced by the cutting, bending, forming, or drawing of a piece of sheet metal, or compression operations.

2. *Maximum sizes* are limited chiefly by the types and sizes of available presses. There are few limitations upon minimum size: sections as thin as 0.003 in. are possible, with parts so small that 10,000 may be held in one hand.

3. *Tolerances* are very good. Plus or minus 0.002 in. is common, and closer limits are possible on small and thin parts.

4. The *weight factor* is highly advantageous. Parts formed from sheet metal are lowest in weight, in pounds per square inch of surface.

5. *Surface smoothness* is very good, since surface condition usually is not affected by the forming operation.

6. A *wide choice of materials* is available, including any in sheet form and not so brittle as to break.

7. *Design changes* are usually costly, if required after the original tooling has been completed.

Production factors:

1. *Tooling time*, compared with some other production methods, is adverse, except for temporary or low-production tooling. Die design, tryout, and development may take months.

2. *Production time* is favorably low, since the rate of output is very high; as many as 3,000 pieces per hour have been produced.

Economic factors:

1. *Stamping-materials costs* should be considered low, ranging from 3 to 4 cents per pound for steel, up to 25 cents per pound for aluminum, and higher for some other less used materials. A favorable cost factor is the minimum scrap loss achieved through careful selection of stock and skilled strip layout.

2. *Tool and die costs* are high, usually higher than for tooling for comparable parts that are to be die-cast. Costs are most favorable where large production is in view.

3. *Direct labor costs* depend upon the part size and shape; under normal conditions they are characteristically very low.

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† Superior numbers relate to References at the end of this section.

4. *Presses*, except for the small manual punch presses, are typically more costly than standard machining equipment such as lathes and grinders, and require a higher machine-hour rate.

5. *Finishing costs* are low. Often no other finishing is required than normal painting or plating.

BASIC PROCEDURE IN PRESSWORKING PROCESS PLANNING

From a consideration of all factors, including those listed above, it is assumed that the decision is to produce by means of pressworking.

The pressed-metal process planner now has three major areas of responsibility:

1. Planning the sequence of operations, the specifying of the metalworking equipment, and the gaging necessary to produce good parts economically at a specified production rate.

2. Coordinating the allied processes such as heat treatment, metal finishing, and plating.

3. Integrating the required material handling and operator movement paths.

The second and third responsibilities are executed by specialists and are not here further considered.[2]

The following steps constitute a valid procedure for the planning of a pressed-metal manufacturing process.

1. *Analyze the Part Print.* To aid this step it may be desirable to have enlarged layouts, additional views, experimental samples, models, and limit layouts. It will be helpful to chart assigned responsibility for carrying out the specifications.

a. What Is Wanted? The product designer must establish explicit detailed specifications *for size, shape, material type and condition, and allied processes. The process* planner must be left in no doubt as to all the definite and implied specifications and their interrelationships.

b. List Manufacturing Operations and Allied Processes. A typical listing would be:

1. Pierce hole, *0.501* in., *+0.002/−0.000*
2. Flange 90° ± 2°
3. Buff external surfaces
4. Blank

No attempt should be made, at this point, to list the operations in proper sequence, or to combine the operations, but only to make a preliminary survey of basic operational requirements. Each listed item should be checked off on the part print drawing.

c. Determine Manufacturing Feasibility. Consider the possible die operations that could produce the part with the specified surface relationships. A hole close to a flange, a small radius, a draw requiring annealing, a blank that cannot be economically nested—these and other conditions can frequently be improved by the product designer without affecting the functional requirements (see Sec. 2).

d. Write Recommendations to Product Engineering. Upon completion of part print analysis, recommendations should be written to the product designer. All accepted recommendations call for necessary engineering changes in the part print.

2. Determine Most Economic Processing. For the same part to be stamped, there are usually several alternative production methods. The method selected should be the one which, all factors considered, will result in the lowest overall cost of the part. The cost will include material, tooling, direct and indirect labor, and overhead burden.

Determination of the most economical processing can be accomplished by comparing two or more feasible processes for producing the given pressed-metal part.[1,2] The comparison of unit costs *for each such process, for equal production quantities,* will give a break-even point which is a guide to selecting the most economical tooling. Productive labor costs and burden rates are estimated from past performance, and by the use of standard time data.[3]

A graphical presentation of the break-even point is useful where the spread between processes is small. Where the spread is small, but increased production is a future possibility, it may be preferable to use the higher-cost process.

Unless new pressworking equipment can be amortized over a rather short period, or have future value as standard equipment, it may prove more economical to use existing available equipment even though production costs would be higher.

Likewise, simple dies may be favored over the high-production dies which seem indicated by the anticipated requirements, because of lack of the special skills required to design, construct, and maintain high-production dies. Also, the simpler single-operation dies may permit interchangeability of tooling for different parts which have several common shape and/or size specifications.

3. Plan the Sequence of Operations. Operations planning done only on the basis of past experience can prove costly if seemingly minor details are overlooked.

a. Determine Critical Specifications. Any dimensional specifications which, because of their comparatively close tolerances, or the limitations placed upon the specifications for allied processes, are known as "critical" specifications. Study of the comparative effects of specifications upon surface relationships, with the aid of a limit layout, will reveal the critical specifications from a manufacturing standpoint.

b. Select Critical Areas. Most critical specifications pertain to measurement of surface relations within specified close tolerances. Critical *areas* are those areas or surfaces from which the measurements for all specifications can be taken so as to determine the geometry of the part. Limit layouts serve also to determine the critical areas.

In ideal planning, critical areas should be established first, provided that they are "qualified" as surfaces of registry, in a locating system, for subsequent operations and allied processes (see 3-2-1 System for Locating, and Tests for Qualified Areas in subsequent text).

c. Determine Critical Manufacturing Operations. An operation is designated as "critical" when it is required in order to establish a critical area or an equivalent area, from which subsequent operations or allied processes can be performed. The required degree of control over such stock variations as width thickness, camber, mechanical properties, also control over metal flow characteristics, are basic factors in determining the critical manufacturing operation. The ideal critical manufacturing operation would establish the critical areas in a single operation from the sheet, strip, or coiled stock.

d. Accomplish Critical Manufacturing Operations. This is the major responsibility of the die designer, working to the process plan. However, the process planner must know the basic types of dies (see Secs. 5, 7, 9, 11) and their general applications, and the control of disturbances due to metal flow characteristics which may affect parts accuracy. He must also consider the die designer's problems of deflection, wear control, dirt, and workpiece mutilation.

e. Determine Secondary Manufacturing Operations. These operations are intermediate between the critical manufacturing operations and the finished part. Limitations in these operations are those imposed by the workpiece specification, and by the amount of metal flow and/or movement (see Secs. 4, 6, 8, 10).

Additional secondary operations, such as restrike, may sometimes be necessary to coordinate with an allied process or to reestablish a critical area for subsequent operations.

f. Accomplish Secondary Manufacturing Operations. This follows the same procedural pattern and involves the same responsibilities for the planner as for critical manufacturing operations.

g. Determine Allied Processes. These processes are determined during part print analysis, except as they arise through emergency or necessity. Thus, an annealing operation may become necessary when secondary manufacturing operations have been determined. In some cases, the process planner may avoid annealing by recommending a change in material specifications. All possible elimination of annealing, plating, cleaning, and other allied processes will appreciably reduce total manufacturing costs.

h. Accomplish Allied Processes. These are usually the function of specialists, but the pressed-metal process planner must cooperate by delivering a workpiece in suitable condition for the allied process. The specialist should advise the processor of the effect the allied process will have on the workpiece.

4. Specify the Necessary Gaging. Gaging here includes (1) the gaging of material as-received, and (2) gaging of the workpiece in process. Gaging of material will include width, thickness, and camber for specified tolerances, and mechanical properties. The planning of in-process gaging for use during manufacture follows the same procedure as used to select critical areas, or areas from which measurements can be taken to defend the geometry of the workpiece. The workpiece should not be allowed to continue through the sequence of operations if it is defective from a previous operation.

5. Specify the Necessary Press Equipment. A press should be specified according to the actuation requirements of a die, the type of pressworking operation to be performed, properties of the workpiece material, and the required production accuracy (see Sec. 23).

6. Prepare Routing of Process. The operational machine routings vary in form throughout industry but must meet two common essential requirements: (1) description of the operation must be accurate and complete; (2) the nomenclature used should be according to accepted practice.

A pictorial sketch of the part, shown on the operational machine routing sheet, aids considerably.

3-2-1 SYSTEM FOR LOCATING, AND TESTS FOR QUALIFIED AREAS

Qualified areas are those areas which fulfill the requirements of arithmetical, mechanical, and geometrical tests in order to serve as surfaces of registry.

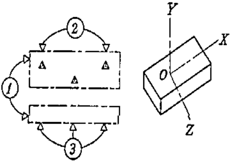

FIG. 3-1. 3-2-1 locating system.

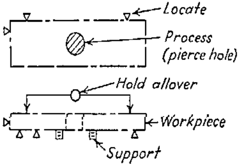

FIG. 3-2. Application of process symbols.

1. Arithmetical Test. The selected surface of registry must not cause a limit stack. If surfaces of registry cannot be selected, they must be qualified, *i.e.*, must be produced to a tolerance closer than those required and specified by the product engineer.

2. Mechanical Test. The size, shape, and finish of the selected surfaces of registry must permit a seat of registry design so each will withstand the operating forces exerted, and also the necessary holding forces.

3. Geometrical Tests. This test pertains to the distribution of the surfaces of registry so that the workpiece will be positionally stable. If surfaces of registry are not thus qualified, the process planner must consider suitable redesign with the product engineer.

In the 3-2-1 locating system (Fig. 3-1), six points are the minimum number of points required to fix a square or rectangular shape in space. Three points establish a plane; two points define a straight line, and one point for a point in space, combined give a total of six points. A small pyramid symbol is used to designate a locating point. In Fig. 3-7, this symbol is used to illustrate a locating system for a rectangular solid. Variations of the illustrated system can be used to fix location of a cylinder, cone, disk, or other geometric shape.

The surface of the device used by the die designer to establish the locating point specified by the process planner is known as a "seat of registry." The corresponding area on the workpiece is known as a "surface of registry."

Process-planning symbols can be used to avoid lengthy writing in the preliminary stages of planning to utilize critical areas for critical and secondary manufacturing operations. Figure 3-2 illustrates use of such symbols.

APPLICATION OF PROCESS PLANNING TO SPECIFIC PRESSED PARTS

Although sound general principles are always of value, their application to pressed parts that have been successfully produced makes them of utmost practical use.

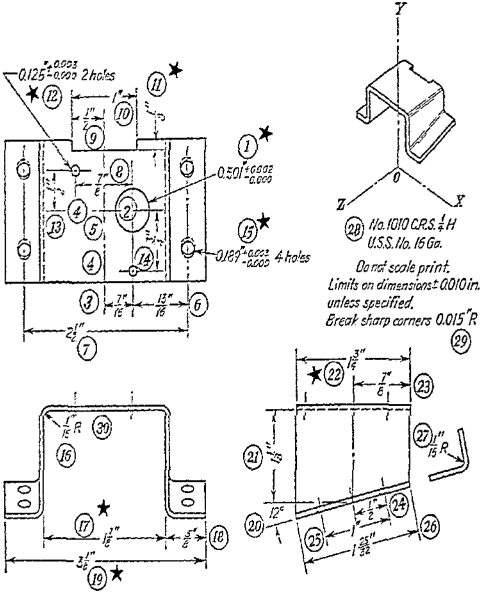

FIG. 3-3. Cross-shaft bracket, analyzed under case 1. Circled numbers refer to separate operations.

Therefore, a number of cases are described. In the first case the process-planning procedure is applied in detail; in the other cases improvement through product and tooling redesign is gained by application of the principles of good planning procedure.

CASE I. CROSS-SHAFT BRACKET

Figure 3-3 is the part print of a cross-shaft bracket, an approved component of an assembly with a forecast production of approximately 100,000 per year.

In some plants the process planner might be expected at the outset to furnish a preliminary routing so that unit costs may be estimated. Such routing might indicate: "(1) blank and pierce," "(2) first flange," "(3) finish flange," and "(4) inspect," together with other normally required information and specifications.

Although such preliminary routing may satisfy estimating needs, it does not always ensure quality parts, economically produced. For such goals, it is essential to apply the accepted planning procedure.

Analyze Part Print. Each specification, dimensional or noted, must be studied to understand exactly what is specified by the product engineer. One method used by the experienced planner is to check off each specification on the print, once it has been interpreted to his satisfaction. For the less experienced planner, a tabular analysis such as that in Fig. 3-4 will prove more effective, because it is a graphical record of information on *all* specifications shown or implied on the part print.

Terms used as column heads, "Material," "Die," and "Processing," in Fig. 3-4 are listed in the following annotation.

"Material" refers to the material of the part to be pressworked, and it should be considered when a surface relationship depends upon a variable of the material. For example, variation in thickness would affect a forming operation.

"Die" refers to the tool which is anticipated for obtaining a required surface relationship. For example, the size of a pierced hole and the obtainable limits depend upon the skill of the diemaker in producing the punch to proper size.

"Processing" refers to the work of the process planner as it affects surface relationships. For example, if two holes were pierced simultaneously, the accuracy of surface relationship would depend upon the die; but if one hole were pierced and the second hole is located from the first, then the accuracy of surface relationship would depend on the skill of the process planner.

This technique in process planning classifies all specifications concerned with surface relationships and reveals whether the relationships depend upon the material, the die, the processing, or some combinations of these factors.

The process planner is primarily concerned with the "Die" and "Processing" columns but, in order to plan an acceptable sequence of operations, the items in the "Remarks" column must be clarified in consultation with the product engineer. The product engineer must also be consulted on any changes in materials specifications which might avoid manufacturing difficulties without affecting the part's functioning requirements. In extreme cases, a study of the materials considerations might show the wisdom or even the necessity of changing to some process other than pressed metalworking. In short, discussions between the process planner and the product engineers should firmly resolve the difference between "What Is Specified" and "What Is Wanted."

Operational Requirements for Case I. The basic pressed-metalworking operations such as cutting, forming, or drawing, which are used to obtain the surface relationships as indicated in the tabular analysis (Fig. 3-4), must be sorted out after all engineering decisions have been made on specifications which were noted in the "Remarks" column.

Operational requirements for the cross-shaft bracket, without regard to final determined sequence,* are indicated by stars in the tabular analysis. The basic operations are:

1. Cut: (1 notch)................ $\frac{1}{8}$ by 1 in.
2. Cut: (1 blank)................ $3\frac{1}{8}$ by $1\frac{3}{4}$ by $1\frac{25}{32}$ in.
3. Cut: (pierce 1 hole)........... $0.501\,^{+0.002}_{-0.000}$ in.
4. Cut: (pierce 2 holes).......... $0.125\,^{+0.003}_{-0.000}$ in.
5. Cut: (pierce 4 holes).......... $0.189\,^{+0.003}_{-0.001}$ in.
6. Form: (2 bends)............. $\frac{1}{16}$ in. radius
7. Form: (2 bends)............. $\frac{1}{16}$ in. radius

* It must be understood that all factors cannot be considered in once-for-all sequence in this stage of planning. In the majority of cases, final decisions can be reached, but they should not be rigidized to preclude refinement as the final plan for the process evolves.

TABULAR ANALYSIS

PART NAME *Cross shaft bracket* DATE *Feb. 1, 1954*

PART NUMBER *P-460 529* PLANNER *E. A. Reed*

No.	SPECIFICATIONS	BETWEEN SURFACES–DEPEND ON: MATERIAL	DIE	PROCESSING	REMARKS	OPERATIONAL REQUIREMENTS
1	$0.501''^{+0.002}_{-0.000}$	√	√		Squareness implied 90°	★
2	℄ Part to ℄ 0.501" hole			√		
3	$\frac{7}{16}''$ to 0.501" ℄ 0.125" holes			√	Possible limit stack with spec. No. 6	
4	℄ to ℄		√		Implied coincident	
5	℄ ⊥ ℄		√		Implied 90°	
6	$\frac{13}{16}''$	√	√	√		
7	$2\frac{1}{2}''$	√	√	√		
8	$\frac{7}{8}''$		√	√		
9	$\frac{1}{2}''$		√	√		
10	1"	√	√		Squareness implied 90° (Nos. 10–11)	★ (Nos. 10–11)
11	$\frac{1}{8}''$	√	√	√		
12	$0.125''^{+0.003}_{-0.000}$ (2) holes	√	√			★
13	$\frac{1}{2}''$ to 0.125" hole		√	√		
14	$\frac{3}{4}''$ to 0.125" hole		√	√		
15	$0.189''^{+0.003}_{-0.001}$ (4) holes	√	√		Squareness implied 90°	★
16	$\frac{1}{16}''$ Radius (2)	√	√		Implied 90° bend	
17	$1\frac{7}{8}''$	√	√			★
18	$\frac{5}{8}''$	√	√		Possible limit stack with spec. No. 17	
19	$3\frac{1}{8}''$	√	√		Implied symmetrical	
20	12°		√	√	No tolerance on ∠	
21	$1\frac{1}{8}''$		√	√	No tolerance on flatness or parallelism	
22	$1\frac{3}{4}''$	√	√	√		★ (Nos. 19–26)
23	℄ to $\frac{7}{8}''$			√		
24	℄ to $\frac{1}{2}''$			√		
25	1"		√	√		
26	$1\frac{25}{32}''$	√	√	√		
27	$\frac{1}{16}''$ Radius (2)	√	√		Implied 90° bend	★
28	1010 C.R.S. $\frac{1}{2}$ H U.S.S. No. 16 Ga.	√			Tolerance on thickness	
29	Break sharp corners 0.015" R	√		√	Question need	Not needed

FIG. 3-4. Tabular analysis of cross-shaft bracket specifications.

A further analysis must now be made of each listed operation, in the light of Feasibility for Manufacturing and Economics of Tooling, previously discussed.

The operational requirements (excluding 1 and 2) will now be examined briefly, in the above-listed order.

3 (pierce one hole, $0.501 {}^{+0.002}_{-0.000}$ in.): No problems are apparent in producing this hole. Tolerance is close, but not impossible with properly maintained tools. The natural break from piercing will provide adequate surface in the hole to meet functional requirements.

4 (pierce two holes, $0.125 {}^{+0.003}_{-0.000}$ in.): No problems are apparent in producing the holes. The natural break from piercing will provide adequate surface in the hole to meet functional requirements.

5 (pierce four holes, $0.189 {}^{+0.003}_{-0.001}$ in.): No problems are apparent in producing the holes. The product engineer objected to the suggestion of keeping all hole axes in the same plane, which might have simplified tooling and processing.

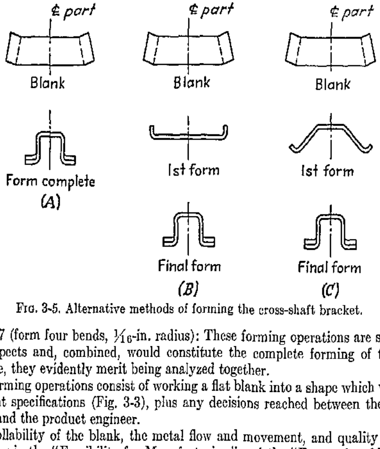

FIG. 3-5. Alternative methods of forming the cross-shaft bracket.

6 and 7 (form four bends, $\frac{1}{16}$-in. radius): These forming operations are similar in some respects and, combined, would constitute the complete forming of the part. Therefore, they evidently merit being analyzed together.

The forming operations consist of working a flat blank into a shape which will meet part print specifications (Fig. 3-3), plus any decisions reached between the process planner and the product engineer.

Controllability of the blank, the metal flow and movement, and quality of finish are factors in the "Feasibility for Manufacturing" and the "Economics of Tooling" for the bracket-forming operations.

Figure 3-5 shows three possible methods of forming the flat blank to obtain the final shape of the cross-shaft bracket.

In the single-operation method shown at *A*, the developed blank would be placed in the die having a suitable locating system. In a single stroke, the metal would be worked over almost the entire surface in forming the blank to shape. In such a method, the surface on the die radius would be subject to excessive wear and, under production conditions, the part might have a mutilated surface. Also, it would be difficult to control spring-back and the part symmetry because of variables of the material, even though the pad would hold the blank securely against the punch face. The 12° flange on the part (Fig. 3-3) would cause a localized flow of material, upon initial closing of the die, which would also distort the part.

In the two-die method shown at B of Fig. 3-5, the developed blank would be flanged on the ends in one die; then the sides would be formed by a single-pad flanging die. Methods A and B both provide fair control of the part, but spring-back control is in both methods difficult when flanges are parallel.

In the method shown at C, using the same blank, a single solid-type die could both form the end flanges and establish the break lines for the sides. In the final forming stage, the sides are flanged in a single-pad die. Blank control would be good, and spring-back in the end flanges could be compensated for by overbending. Since both the break lines are established in the same operation, with minimum metal flow and movement in the die, better dimensional control should be secured in the part.

It therefore appears to the process planner that the method shown in C (Fig. 3-5) would be most satisfactory and would permit combining the blank and pierce operations if hole location tolerances are sufficiently large.

1 and 2 (Blank and notch): The general dimensions of the outline of the part were listed in the tabular analysis (Fig. 3-4). In studying a part print, the process planner will assume, in practically every case, an initial blanking operation to prepare a flat piece of material for the subsequent operations, i.e., a blank must be developed.

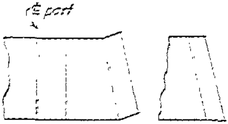

Fig. 3-6. Developed blank for the cross-shaft bracket of case I.

The blank for the crossshaft bracket of case I will be as shown in Fig. 3-6. When the blank has been developed, the process planner must immediately consider utilization of the material, grain direction as related to blank nesting, and any other pertinent factors.

The shape of the ends of the blank requires a skeleton of material between the blanks. However, if the product engineer can be induced to decide that the "optional" blank end, shown in Fig. 3-6, will not affect the part's functional or structural requirements, then both the material and the die costs can be lowered.

Grain direction will not be a problem in this plan, because the specified quarter-hard SAE 1010 cold-rolled steel will form satisfactorily either across or parallel to the grain direction.

The ⅜- by 1-in. notch is, in effect, a portion of the outline of the blank. There being no metal flow or movement in the notch area, the decision will be to include the notch with the blanking operation.

Planning Operations Sequence for Case I. The major decisions on the basic operations for the crossshaft bracket have now been made. The next step is to determine the critical specifications, and so establish the critical areas which can be used as surfaces of registry after they have been accomplished by the proper critical manufacturing operations.

Since close tolerances are an indicator of critical specifications, the process planner will first consider the 0.501 $^{+0.002}_{-0.000}$ hole and the two 0.125 $^{+0.002}_{-0.000}$ holes. (The four 0.156 $^{+0.002}_{-0.001}$ holes might also be considered on the basis of close tolerance, except for the facts that there is metal flow between the planes of the two groups of holes, and that the planes of the 0.501 $^{+0.002}_{-0.000}$ hole were established as common to all flanging operations in the forming of the part.)

Hence, the surfaces of the 0.501-in. and the 0.125-in. holes are decided to be the critical areas from which may be selected the surface of registry which will constitute the locating system required.

Since a minimum of six points or surfaces of registry are required to locate the workpiece, the process planner will consider the inside surface of the top side of the cross-shaft bracket (provides three points), the 0.501-in. hole (provides two points), and the 0.125-in. hole (provides one point).

This system should be checked to determine whether the selected surfaces of registry are qualified (1) arithmetically, (2) mechanically, and (3) geometrically:

1. *Arithmetically*, the selected areas are qualified because of their close tolerances. The holes have a maximum 0.004-in. tolerance, as compared with location dimensions having plus or minus 0.010-in. or 0.020-in. tolerance.

2. *Mechanically*, the surface of the 0.501-in. hole in the *YOZ* and *XOY* planes (Fig. 3-3) qualifies satisfactorily, since ½-in.-diameter pin is known to be structurally adequate for the two seats of registry, one in each plane. The surface of the hole will be only 30 per cent of the thickness of the stock, because of the metal action

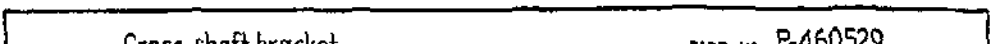

FIG. 3-7*A*. Process picture sheet; basic dimensions for blank development.

in piercing the hole, but this will not disqualify the surface, since only one point in each plane is needed.

The 0.125-in. hole qualifies for the other surface of registry in the *YOZ* plane, except that so small a hole does not permit a structurally adequate locating pin for a seat of registry. Therefore, it is necessary to select some other surface of registry in the *YOZ* plane, such as the edge of the blank. This edge is qualified because it is to be produced in the same die as will produce the holes.

Although the 0.125-in. hole should theoretically be used, it was necessary to move the symbols of the surfaces of registry to the edges. Since a workpiece of this type would be nested, the equivalent of a nest is indicated in the operation diagrams (*C*, *D*, and *E*, Fig. 3-7) by a dashed "Locate" symbol.

3. *Geometrically*, the 0.501-in. hole would be qualified to provide the necessary surfaces of registry to locate the workpiece in the *YOZ* and *XOY* planes, since the inside metal surface in the *ZOX* plane provides the required three points.

The 0.125-in. hole is geometrically qualified in relation to the 0.501-in. hole, because it provides an adequate distance between surfaces of registry for locating purposes. However, it was previously disqualified mechanically because of small size.

Critical manufacturing operations are those required so as to obtain critical areas for secondary operations. The holes could be pierced first, and then used to locate for a blanking operation. However, in case I, it is obviously practical to blank and pierce in the same operation.

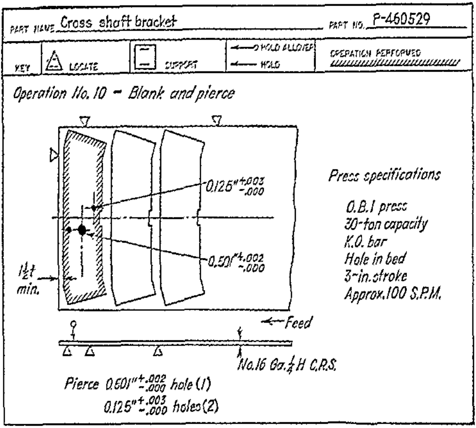

FIG. 3-7B. Process picture sheet; blank and pierce.

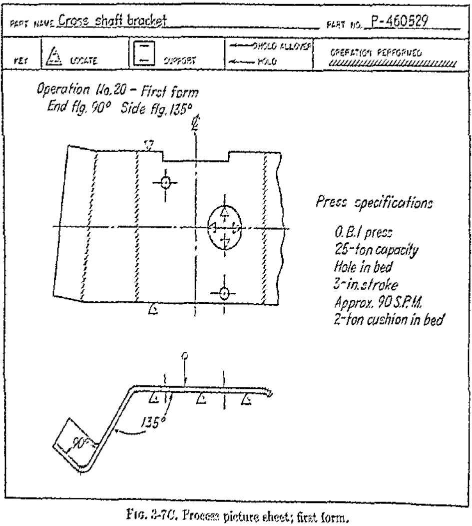

FIG. 3-7C. Process picture sheet; first form.

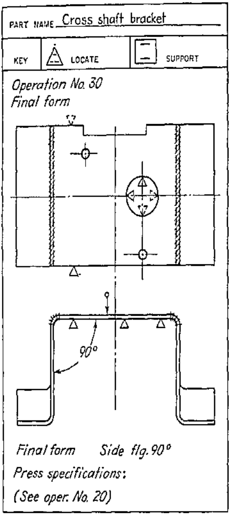

FIG. 3-7D. Process picture sheet; final form.

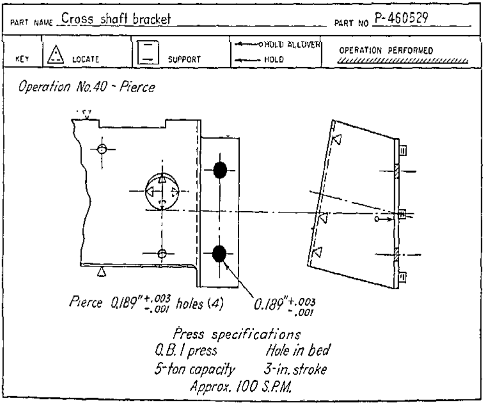

FIG. 3-7E. Process picture sheet; pierce flange holes.

Since the same locating system can be used both for the forming operations and for piercing the 0.189-in. holes, this information is now passed along to the die designer in the form of process picture sheets (Figs. 3-7A to 3-7E inclusive), which supplement the usual machine and tool routing sheet.

Process picture sheets show the workpiece for each operation. Only those views are shown which are necessary to specify the surfaces of registry and any dimensions needed other than those given on the part print. On each sheet showing an operation, the required press specifications are given.

The machine and tool routing sheet will indicate the gages which must be either designed or selected from commercial standard sizes.

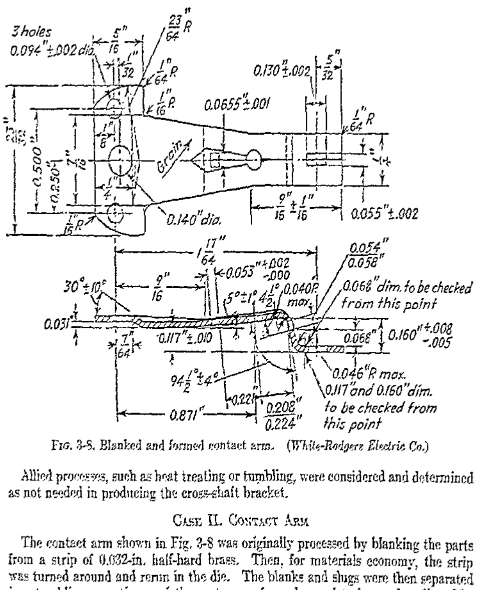

FIG. 3-8. Blanked and formed contact arm. (*White-Rodgers Electric Co.*)

Allied processes, such as heat treating or tumbling, were considered and determined as not needed in producing the cross-shaft bracket.

CASE II. CONTACT ARM

The contact arm shown in Fig. 3-8 was originally processed by blanking the parts from a strip of 0.032-in. half-hard brass. Then, for materials economy, the strip was turned around and rerun in the die. The blanks and slugs were then separated in a tumbling operation, and the parts were formed complete in another die. The strip development for this part is shown in Fig. 15-7, and described in its accompanying text.

This appears a simple enough process that should work out well. However, considering the indicated close tolerances on so complicated a shape, it was difficult to keep the part within specified tolerances. Since the production was fairly high, and more than one set of dies was needed, regular periodic inspections called for frequent shutdowns, with consequent die revision.

It became evident that, by combining pierce, blank, and form operations, and by building a scrap separator into the die, so that parts and slugs fell into different containers, much better production and reduced maintenance would result. By using coil stock, the presses could run automatically.

Net results were direct labor savings of 1.3 hr per 1,000 pressed parts, increased die life, and liberation of one press. Indirect savings were made through eliminating shearing, extra setup, added inspection, a tumbling operation, and excessive scrap removal.

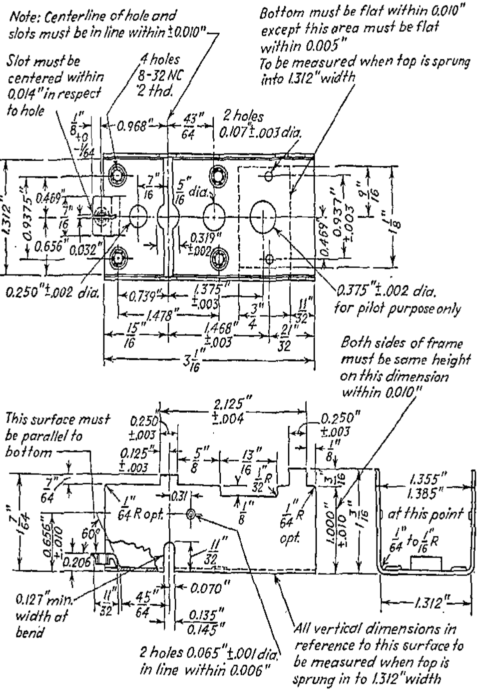

Fig. 3-9. Part print of housing frame. (*White-Rodgers Electric Co.*)

Case III. Housing Frame

The housing frame shown in Fig. 3-9 was originally made by the following operations: (1) shear; (2) pierce, emboss, and blank; (3) form; (4) pierce and extrude; (5) pierce, extrude, and stamp; (6) tap four 8-32 holes, singly; (7) tap one hole; (8) mill one slot; (9) three deburring operations.

By tooling redesign, the part is now produced as follows: (1) pierce, blank, and form complete, except for the small pierced and extruded hole in the tongue; (2) pierce, extrude, and stamp; (3) mill one slot; (4) tap four 8-32 holes; (5) tap one hole. (A transfer machine is now in design to allow combining of the last four operations with the first.)

Direct-labor saving is 6.2 hr per 1,000 parts, largely due to combining of operations and to use of a multispindle tapper. There has also been substantial saving through reduced floor space, waiting time, and tied-up inventory.

Case IV. Stamped Eyelet

Figure 3-10 illustrates the case where study and production data may reveal the wisdom of converting from some other process to pressworking; originally it was a

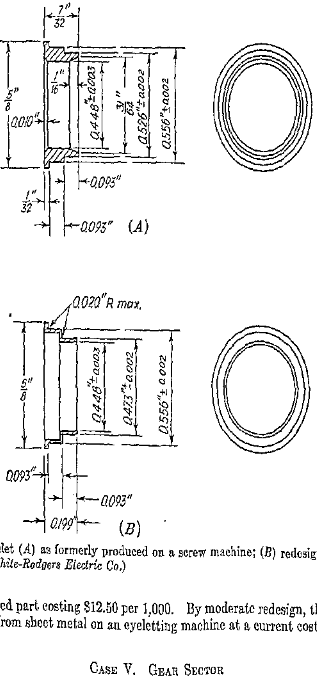

Fig. 3-10. Eyelet (*A*) as formerly produced on a screw machine; (*B*) redesigned for pressworking. (*White-Rodgers Electric Co.*)

screw-machined part costing $12.50 per 1,000. By moderate redesign, the part could be produced from sheet metal on an eyeletting machine at a current cost of $3.40 per 1,000.

Case V. Gear Sector

Presswork redesign should be studied for possible elimination of allied processes. The gear sector of Fig. 3-11 was formerly made up of a stamped gear sector and another stamped part called an "indicator," both parts being subsequently welded together at a total production cost of $52 per 1,000. The cost of the single-piece redesign is $10 per 1,000.

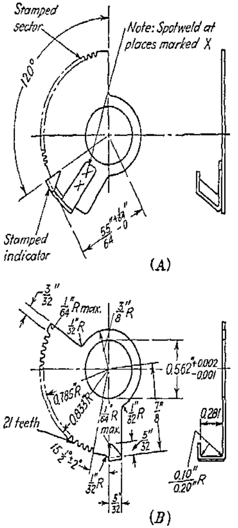

FIG. 3-11. Gear sector: (A) former two-piece welded construction; (B) redesigned one-piece stamping. (*White-Rodgers Electric Co.*)

CASE VI. ACTUATOR SHAFT ASSEMBLY

Another example of successful design revision, shown in Fig. 3-12, enabled production costs to be reduced from $113 per 1,000 by the older method to $50 per 1,000.

In the former method, the part was made from ¼-in. round cold-headed stock; the elongated holes or slots were pierced with a die, and the flat was milled. The part designated as a "stop" was made by cutting off and forming from strip stock. The two parts were then spot-welded together.

In the new method, the round shaft is made by cutoff in a screw machine, and the stop (now incorporating the slotted circular head) is made complete in a progressive die. After stud welding, the flat is milled.

PRESSWORKING COST COMPARISONS*

The previously described methods of presswork process planning, consistently followed, will in most cases narrow down the final decisions to a very few of many seeming possibilities. But several alternatives may remain for combining operations, making second passes through a die, selecting from available presses of different types and capacities, and other factors.

Under these conditions, comparisons of costs for different feasible dies and processing methods may quickly reveal the combination that will result in lowest total cost per pressworked part.

* Reviewed by F. G. Von Brecht, Manager, Manufacturing Engineering Division, White-Rodgers Electric Co.

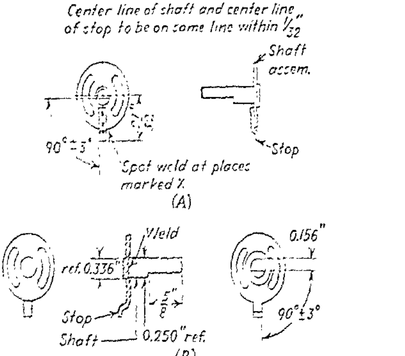

Fig. 3-12. Actuator shaft assembly: (A) original design; (B) redesigned. (*White-Rodgers Electric Co.*)

Let N_T = total number of parts to be produced in a single run
N_B = number of parts for which the unit costs will be equal for each of two compared methods Y and Z ("break-even point")
D_Y = total die cost for method Y
D_Z = total die cost for method Z
P_Y = unit pressworking cost for method Y
P_Z = unit pressworking cost for method Z
C_Y, C_Z = total unit cost for methods Y and Z, respectively

Then

$$N_B = \frac{D_Y - D_Z}{P_Z - P_Y} \qquad (1)$$

$$C_Y = \frac{P_Y N_T + D_Y}{N_T} \qquad (2A)$$

$$C_Z = \frac{P_Z N_T + D_Z}{N_T} \qquad (2B)$$

Example 1: The aircraft flap nose rib shown in Fig. 3-13, of 0.02-in. 24ST Alclad, was separately calculated to be formed by Hydropress, drop hammer, Marform, steel draw die, and hand forming. For such reasons as die life, equipment available, and handwork required, the choice narrowed down to Hydropress vs. steel draw die. With Hydropress, the flanges had to be fluted, and for piece quantities over 50, a more expensive steel die costing $292 had to be used.

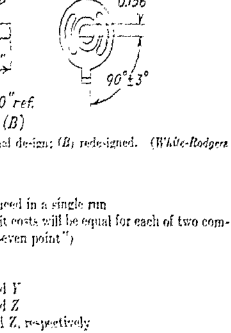

Fig. 3-13. General specifications for aircraft flap nose rib.[4]

Actual die and processing costs for both methods are listed in Table 3-1. P_Y and P_Z are processing costs, and D_Y and D_Z are die costs, for the steel draw die and Hydropress methods, respectively.

Figures in the last column of Table 3-1 were not stated in the original report but can properly be extrapolated on the basis of apparent stability of P_Y and P_Z at N_T = 500, and assuming their stability at higher production.

TABLE 3-1. COST COMPARISON OF METHODS FOR PRODUCING AIRCRAFT FLAP NOSE RIB

N_T*	5	25	50	100	500	760†
P_Y	$ 3.00	$ 1.18	$ 1.11	$ 1.05	$ 1.05	$ 1.05
P_Z	4.40	2.05	1.96	1.85	1.85	1.85
D_Y	810.00	810.00	810.00	810.00	810.00	810.00
D_Z	103.00	103.00	103.00	103.00	202.00	202.00
C_Y	165.00	33.60	17.30	9.15	2.67	2.12
C_Z	25.00	6.17	4.02	2.88	2.25	2.12

* Symbols in this column are the same as in Eqs. (2A) and (2B).
† Extrapolated.

On the basis of listed figures at N_T = 500, and from Eq. (1), the production at which total unit costs C_Y and C_Z will be the same for both methods is

$$N_B = \frac{810 - 202}{1.85 - 1.05} = 760 \text{ pieces}$$

Combined Operations. Under certain conditions, operations can be advantageously combined. The total cost of tooling may be reduced, or production costs, or both. A further advantage may be gained in combining a fast operation with another operation which, separately performed, might be slower. A precaution, however, is that setup and maintenance costs may increase.

Table 3-2 gives cost comparisons for a three-setup method vs. a single-setup method for blanking a 1- by 2- by $\frac{1}{16}$-in. rectangular cold-rolled-steel part, and perforating holes in it. Lots are sufficiently small to require no estimates of maintenance cost.

TABLE 3-2. COMPARISON OF SINGLE-SETUP VS. THREE-SETUP PRESSWORKING METHODS[7]

Lot quantity	Method I			Method II		
	500	5,000	10,000	500	5,000	10,000
Tool cost	$30.00	$30.00	$30.00	$15.00	$15.00	$15.00
Setup cost	1.00	1.00	1.00	3.00	3.00	3.00
Processing cost	0.75	2.50	5.00	1.60	15.00	30.00
Total cost	$31.75	$33.50	$36.00	$19.60	$33.00	$48.00

Method I (single setup): Blank and perforate from roll stock.
Method II (three setups): Blank and perforate from sheet stock, sheared into 2-in.-wide strips, and further sheared into 1-in.-wide strips.

Method II is clearly the lowest in total cost for 500 parts. At 5,000 parts, costs are virtually the same, and the choice of methods may be chiefly determined by the likelihood of future required reruns or other factors. At 10,000 parts, the advantage is heavily with method I and will increase as production goes higher.

Table 3-3 reflects a case where the cost of combined tools was less than the total cost of the separate tools. The combined operation was done at the speed of the blanking operation.

TABLE 3-5. COSTS OF COMBINED VS. SEPARATE OPERATIONS[1]

Costs	Blanking operation alone	Forming operation alone	Total blank and form	Combined operation
Tool cost..................	$40.00	$30.00	$ 70.00	$50.00
Setup cost	2.00	2.00	4.00	3.00
Maintenance cost...........	2.00	......	2.00	2.00
Processing cost............	4.00	30.00	34.00	4.00
Total cost...............	$48.00	$62.00	$110.00	$59.00

STEPS IN DESIGNING SPECIFIC DIES*

In order to avoid false starts and consequent expensive design changes, it is advisable to make the many necessary design-detail decisions in some orderly, logical sequence. The following steps are suggested to be taken as nearly in their indicated order as possible. All the listed steps should be considered for single-stage dies; some are applicable only to progressive dies.

A. Preliminary Planning.

1. Develop *the blank* with special reference (*a*) to best grain direction; (*b*) to bending, forming, and drawing strains; (*c*) to available press equipment.

2. Decide the *tentative sequence of operations.*

   a. Are idle stations needed in progressive dies for strength of sections or punches?
   b. Will preformed blanks be preferable to complete stamping in a single progressive die?

3. Lay out the *stock strip*, preferably using at least three part templets.

   a. Can required dimensional accuracy be realized?
   b. Material between holes or between edge of stock and edge of blank should be stock thickness or $\frac{1}{16}$ in., whichever is larger.
   c. Are half holes and partial blanks properly planned?
   d. Can the burr be so placed as to eliminate need of removal?
   e. Where pierced holes are to be countersunk, can the die be so laid out that the countersinking will remove any burr?
   f. Is the correct side of the blank *up* with respect to any shaved portions (punch side of blank to be die side of shave die)?
   g. In blanking such parts as side plates or outside parts of a unit, will the sheared or die side of the blank be *out?*

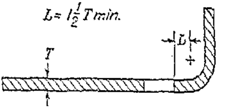

FIG. 3-14. Relation of bend radius to nearest edge of pierced hole.

   h. For parts to be formed; does the *forming come across the grain (optimum),* or not to exceed 45°?
   i. Is material utilization maximum?
   j. Place holes in proper relation to bends (Fig. 3-14). Hole edges should **be** $1\frac{1}{2}T$ minimum distant from blend point between the flat and **the curved** sections.

* Reviewed by Jay Bowen, Chief Engineer, McReynolds Die & Tool Co.

4. Consider the press *accommodation of the die set.*
   a. Have clamping provisions been made?
   b. Have proper provisions been made for slug-disposal holes through die shoe and bolster plate?
   c. Check design features as affected by the shut height of the closed die.
   d. Will the ram accommodate the punch-holder shank?

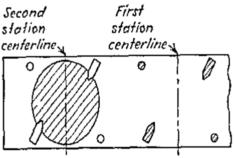

FIG. 3-15. Partial blanking in first station to avoid weak inserts.

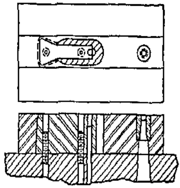

FIG. 3-16. Insert construction for weak projections.[8]

   e. Check for suitability of the die to the intended press in all respects, especially as to fit, power required, stroke, and speed.

5. Check for *frail inserts or projections.*
   a. Portions of the blank can perhaps be punched in one station, and the remaining portions blanked in a subsequent station (Fig. 3-15).
   b. Delicate projections on the die should, if possible, be inserts for economical replacement in case of breakage (Fig. 3-16).

6. Establish *center line of pressure.*
   a. When design calls for two or more cutting or forming punches of unequal size in a single-stage die, the center line of pressure should coincide with the

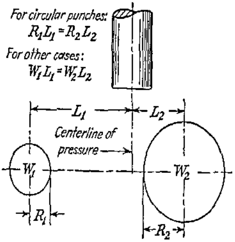

FIG. 3-17. Establishing the center line of pressure where punches of unequal tonnage requirements are on same punch plate.

axis of the punch-holder shank, and can be determined from Fig. 3-17 for two punches. Individual tonnages (W_1, W_2, etc.) for any number of regular- or irregular-shaped punches can be similarly calculated both for single-stage dies, and for the combined moments of all stages in a progressive die.

7. Establish location of *pilot-hole punches.*

   a. Particularly check for pilots coming in pierce-outs.
   b. Pierce for pilots in first station, except when draw work is done in the first station.
   c. Make sure the second-stage operation is piloted by at least two pilots, unless the part can have only one possible hole available.

8. Decide *whether to bend* by (a) making bends downward, or (b) ramping the strip and forming upward.
9. Are the *materials specifications* optimum in all respects? (See Secs. 24, 25, 26, and 27.)
10. Establish *final* sequence of operations.

B. Punch Planning.

11. Locate and design any *notching punches*, usually in the first or the second station, or both. Usually they require heel blocks or other backup support.
12. Locate any *forming punches.*

   a. For a single form operation, location is usually immediately before or after the cutoff.
   b. Determine whether shedder provision is needed.

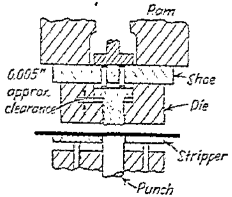

FIG. 3-18. Shedder clearance in maximum ejection position for compound die.

   c. In compound dies, allow some shedder clearance in extreme ejector position (Fig. 3-18) to avoid dangerous pressure upon shedder pins.

13. Locate and design *pierce-and-blank punches.*

   a. If a slender punch must be located close to a large punch, with risk of deflection due to metal crowding to one side, make the slender punch shorter than the large punch by at least one-half metal thickness.
   b. Plan to step small punches which are grouped closely together, for reduction of total shearing pressure.
   c. Where part design cannot avoid a bent tab or other formed part that would be damaged through incomplete ejection, design the punch long enough to push the blank through the die.
   d. Where a small unguided punch must pierce stock thicker than punch diameter, make punch shank at least twice hole size in diameter, and grind cutting end to hole size for a distance of about twice stock thickness.
   e. Avoid designing punches that would have more than about 4-in. unguided length. Instead, consider spacer or filler plates (*A*, Fig. 3-19).
   f. Where punch diameter is too small to incorporate push-off pins, rounding the punch face will prevent slugs from pulling up, provided the hole diameter is at least $2T$ to $3T$.
   g. Make heel punch fillets as large as possible.

h. When pierced holes are to be countersunk, design the punches so as not to destroy the accurate portion of hole.

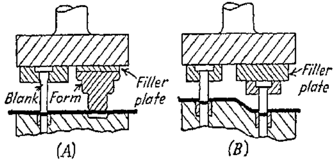

FIG. 3-19. Use of filler plates: (*A*) Filler plate and blanking punch both have same amount ground off at each sharpening; (*B*) filler plate used to avoid too long a blanking punch at right.

14. Locate and design any *spanking punches.*
    a. Usual location, for a single spank, is at next-to-last station.
    b. Where possible, combine with bending or forming.
15. Consider the *guiding and supporting of punches*, generally advisable for precision work in better-grade dies.
    a. Where flange width of blanking punches is less than punch height, guiding is indicated.
    b. Angular-headed drill-rod punches should always be guided in the stripper.
16. *Punches for long slots* should be ground low ($1T$ to $1\frac{1}{2}T$) in the center of the face, to permit the ends to start cutting first. The face should be left flat at the ends for $\frac{1}{8}$ in.
17. If *blanking punches have pilots*, time them ahead of any piercing punches, to enable the pilot to locate the strip before the piercing punches can start cutting; otherwise, stock may shift, causing binding or bending of the piercing punches.
18. Set *grinding allowances* for pierce and blank punches; $\frac{1}{4}$ in. is usual.
19. When a forming punch is in the same station with a pierce or blank punch, a *filler plate* or spacer block (*B*, Fig. 3-19) will permit relationship to be maintained, when sharpening, by grinding the same amount off both the cutting punch and the filler plate. In some cases, only one punch need be resharpened, and the other can be shimmed out.

C. **Die Plates and Punch Plates.**

20. Make preliminary layout of *die block.*
    a. Has it been finished square on all six sides?
    b. Make the minimum distance from outside edge of block to edges of die openings from 1 to $1\frac{1}{2}$ times the block thickness.
    c. Sharp-cornered die openings require about $\frac{1}{4}$ in. more supporting metal around them than round-cornered openings.
    d. Is the block large enough to withstand repeated shocks, or excessive warping or cracking during hardening?
21. Make punches and dies *sectional*, where feasible, for easy construction, sharpening, hardening, and replacement.
    a. To avoid chipping, do not design sectional dies with acute included angle in corner members (Fig. 3-20). If corners are radiused, plan the parting line to come outside the arc, to avoid the machining and blending of two separate arcs.

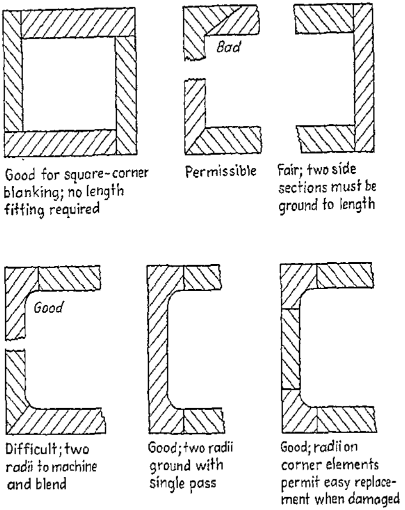

FIG. 3-20. Design of corners for joining members of sectional dies.

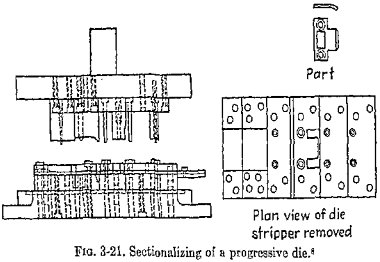

FIG. 3-21. Sectionalizing of a progressive die.[8]

b. Be sure that the sections have sufficient area to prevent their moving in operation.

c. For progressive dies, it is well to have a separate section for each station (Fig. 3-21); more may be needed for intricate operations.

22. Locate and design any finger, swing-type, or automatic *stops*.

a. Try to save the first blank.

b. Work location must be such that, as the blanking pilot enters the previously pierced hole, the stock will be pulled away from the stop a sufficient distance to prevent the blanking punch from forcing the scrap strip against the stop.

c. Locate finger stops so as to avoid cutting on only one edge of the die.

d. Position each automatic stop so that its working end cannot catch in any *scrap stock projections.*

23. Plan to have *inserts and bushings* wherever needed to facilitate diemaking and heat treatment, or for easy replacement of worn or broken sections.
24. Select the best *die set,* total design considered (see Sec. 18).

a. For thin material, or extreme accuracy requirements, use sets with four guide posts and extra long or antifriction bushings.

b. Posts should be from ¼ to ⅝ in. shorter than the shut height, to allow for sharpening or reworking, and on short-stroke presses to provide an oil pocket.

c. Check for parallelism of mounting surfaces.

d. Check for fit of guide posts in their bushings.

e. Heavy or overhanging dies call for diagonal or four-post die sets.

f. Use semisteel die shoes or all-steel sets of requisite thickness, for severe duty.

25. Decide on grinding allowance for die plate.
26. Locate and design any required *scrap cutter.*
27. Make adequate provisions for *scrap disposal.*

a. On die plate, mark locations of bolster-plate scrap-disposal openings.

28. Decide best *keying* methods, depending on whether the die elements are set *into* or on *top* of the die shoe. If set on top, doweling is indicated.
29. Check for good *doweling* practice.

a. Where misassembly is possible, stagger one or more dowels.

b. Noncircular punches must be secured in such a manner that they cannot shift out of position.

c. Where a dowel large enough to withstand shearing action cannot be used, keys are preferable.

d. Space dowels far enough apart in the die to be most effective.

e. Provide means for removal of dowels from blind holes.

f. Enough screws and dowels should be used to prevent any movement of die elements.

30. If punches must be held in *quills,* plan to install the quills in individual punch plates, where interchangeability or replacement is a likely requirement.
31. Make *punch plate* sufficiently thick to support all punches adequately. Small punches (¼ in. or less) may need punch-plate thickness equal to punch diameter for adequate support.
32. Decide best method of *strip location.*

a. Plan to guide before the first station for a distance at least two times the stock width.

33. Decide upon *stripper and shedder* locations and requirements.

a. Make inside width of channel stripper 0.004 in. minimum wider than a strip high-limit width, to accommodate stock variations.

b. So design strippers for progressive dies that they will not distort the stock, and so that the guide rails overhang the stock sufficiently to prevent stock from pulling out of guides.

c. Consider whether special strippers might be heavier or of larger section than the standard stock die sets will accommodate.

d. Check for any necessary clearance holes in die block or stripper, for transport of blanks or slugs.

e. Is stripper opening provided with lead-in surfaces for convenient feeding of fresh stock strips?

f. Design shedders for compound dies with suitable corner radius on the retaining flange. Flange should be $\frac{3}{16}$ in. thick minimum and should not undermine any weak or protruding die elements.

34. *Hardened punches* should be mounted in a soft plug, rather than be pressed directly into a hardened punch plate.
35. Where runs are long, or punch heads are small, *back up the punches* with a hardened plate about $\frac{1}{4}$ in. thick.

a. Punches that cut on only one side should be heeled, with the heel entering the die before the punch starts cutting.

36. Width of *punch and die plates or retaining strips* should be from $1\frac{1}{4}$ to $1\frac{1}{2}$ times plate height for best stability.

D. General Design Details.

37. If *die setup pins* seem advisable, are they far enough apart, and large enough for needed rigidity?
38. Check for need, location, and action of any release or vacuum pins.
39. Check *blank-hole and scrap-hole clearances.*

a. Sides must be straight for $\frac{1}{8}$ in. minimum from top surface.

b. Clearance holes should be taper-reamed to the bottom with sufficient draft to avoid sticking of blanks and slugs (see Sec. 5).

40. Calculate sizes of all *springs.*

a. Be sure their length permits operation under maximum compression. The average spring can be safely compressed about 25 per cent of its free length.

41. Check for good *bushing* practice.

a. Are bushings needed in the die shoe or block, or the stripper?

b. Check location of bushings and guide pins for interference.

c. Is the bushing sufficiently long so that it will have sufficient bearing?

d. Does design permit several or all of the bushing holes to be of same size in the die block, the punch plate, and the stripper, so that they can all be bored together?

42. Check for good *piloting* practice.

a. Try to have pilots removable to facilitate punch grinding.

b. Can the pilot be made adjustable, so as to raise it when the punch ends have been reground?

c. Because of unavoidable misfeeds, pilots will occasionally push scrap down; therefore, carry pilot holes all the way through the die block.

d. Spring pilots may have to be used on stock heavier than about $\frac{1}{16}$ in. thickness; avoid their use when possible.

e. Pilots should be about 0.001 in. smaller in diameter than their piercing punches, but a minimum of $\frac{3}{16}$ in. diameter except in special cases.

43. Any *boltheads in die plates* should be set sufficiently below the top surface to allow for maximum die sharpening.
44. *Holes for fastening gages* should be tapped from $\frac{1}{4}$ to $\frac{3}{8}$ in. deeper than threading requirements, or through, to permit die sharpening.
45. Locate any necessary *air vent holes.*
46. *Counterboring* for screwheads should be deep enough to allow for grinding.

47. Are *stop or bumper blocks* needed anywhere? Their use is advisable on expensive and complicated dies.
48. For high-production *dies using roll feed,* consider the trimming of stock in the first station, to eliminate stock camber.
49. Any required *spring plungers* should be accessible for adjustment or grinding.
50. Check for *safety* to the operator, the die, and the press (see Sec. 22).

    a. Is necessary *shear provision* on the die, for protection where applied power can possibly exceed a safe maximum?

51. Check die all over for *grinding.*

    a. Will any parts have to be removed or altered to permit die sharpening?

52. Can any *future requirements* be anticipated by altering the present design?

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SECTION 4

SHEAR ACTION IN METAL CUTTING*

The cutting of metal between die components is a shearing process in which the metal is stressed in shear between two cutting edges to the point of fracture, or beyond its ultimate strength.

The metal is subjected to both tensile and compressive stresses (Fig. 4-1); stretching beyond the elastic limit occurs; then plastic deformation, reduction in area, and finally, fracturing starts through cleavage planes in the reduced area and becomes complete.

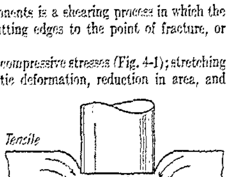

FIG. 4-1. Direction of stresses in metal cutting.[1]†

The fundamental steps in shearing or cutting are shown in Fig. 4-2. The pressure applied by the punch on the metal tends to deform it into the die opening. When the elastic limit is exceeded by further loading, a portion of the metal will be forced into the die opening in the form of an embossed pad on the lower face of the material and a corresponding depression on the upper face, as indicated at *A*. As the load is further increased, the punch will penetrate the metal to a certain depth and force an equal portion of metal thickness into the die, as indicated at *B*. This penetration occurs before fracturing starts and reduces the cross-sectional area of metal through which the cut is being made. Fractures will start in the reduced area at both upper and lower cutting edges, as indicated at *C*. If the clearance is suitable for the material being cut, these fractures will spread toward each other and eventually meet, causing complete separation. Further travel of the punch will carry the cut portion through the stock and into the die opening.

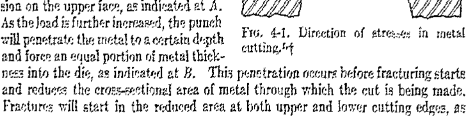

FIG. 4-2. Steps in shearing metal.[2]

* Reviewed by J. S. Brozek, Superintendent, Tooling and Maintenance Division, Sargent & Co., and J. R. Paquin, Tool Engineer.

† Superior numbers relate to References at the end of this section.

Clearances. Clearance is the measured space between the mating members of a die set. Proper clearance between cutting edges enables the fractures to meet and the fractured portion of the sheared edge has a clean appearance. For optimum finish of a cut edge, proper clearance is necessary and is a function of the kind, thickness, and temper of the work material. Clearance, penetration, and fracture are shown schematically in Fig. 4-3.

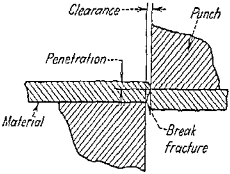

FIG. 4-3. Schematic drawing illustrating clearance, penetration, and fracture.[3]

In Fig. 4-4, characteristics of the cut edge on stock and blank, with normal clearance, are schematically shown. The upper corner of the cut edge of the stock (indicated by *A*) and the lower corner of the blank (indicated by *A*-1) will have a radius where the punch and die edges, respectively, make contact with the material. This is due to the plastic deformation taking place. This edge radius will be more pronounced when cutting soft metals. Excessive clearance will also cause a large radius at these corners, as well as a burr on opposite corners.

In ideal cutting operations, the punch penetrates the material to a depth equal to about one-third of its thickness before fracture occurs, and forces an equal portion of

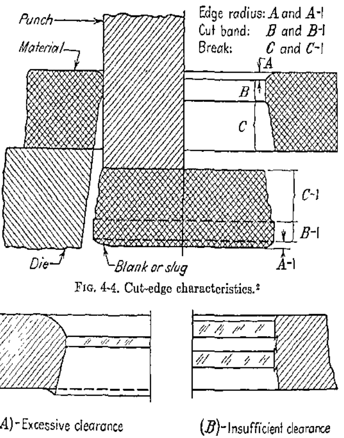

FIG. 4-4. Cut-edge characteristics.[2]

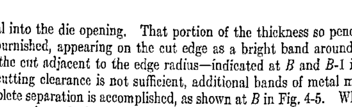

FIG. 4-5. The greater the clearance, the closer the condition approaches forming instead of cutting.[2]

the material into the die opening. That portion of the thickness so penetrated will be highly burnished, appearing on the cut edge as a bright band around the entire contour of the cut adjacent to the edge radius—indicated at *B* and *B*-1 in Fig. 4-4. When the cutting clearance is not sufficient, additional bands of metal must be cut before complete separation is accomplished, as shown at *B* in Fig. 4-5. When correct cutting clearance is used, the material below the cut will be rough on both the stock and the slug. With correct clearance, the angle of fracture will permit a clean break below the cut band because the upper and lower fractures extend toward one another. Excessive clearance will result in a tapered cut edge since, for any cutting operation, the opposite side of the material which the punch enters will, after cutting, be the same size as the die opening.

The width of the cut band is an indication of the hardness of the material, provided that the die clearance and material thickness are constant; the wider the cut band,

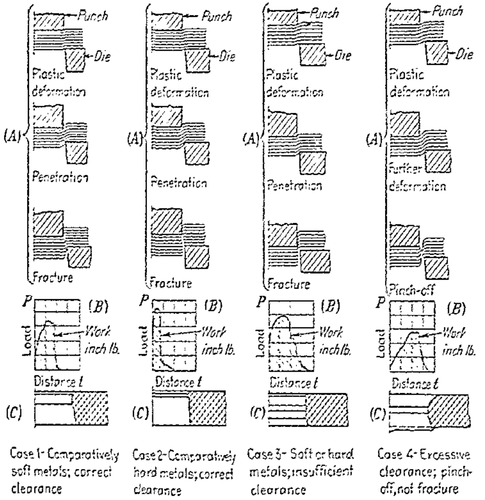

Fig. 4-6. Effect of certain clearances.[2]

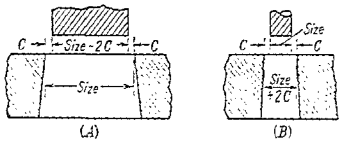

Fig. 4-7. Clearance location related to part, punch and die dimensions: (A) Slug is desired part; (B) slug is scrap.

the softer the material. The harder metals require larger clearances and permit less penetration by the punch than ductile metals; dull tools create the effect of too small a clearance as well as a burr on the die side of the stock. The effects of various amounts of clearance are shown in Figs. 4-5 to 4-7. Defective or nonhomogeneous material cut with the proper amount of clearance will produce nonuniform edges.

The edge conditions C and the hypothetical load curves B (Fig. 4-6, cases 1, 2, 3, and 4) are shown, as well as the amount of deformation and extent of punch penetration.

Location of the proper clearance (Fig. 4-7) determines either hole or blank size; punch size controls hole size; die size controls blank size.

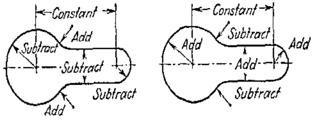

FIG. 4-8. How to apply clearances.[6]

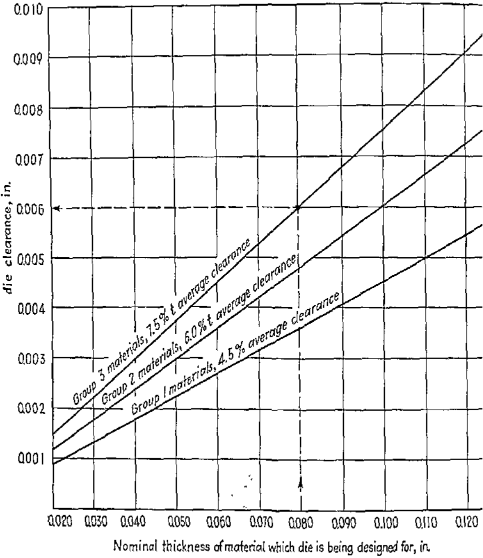

FIG. 4-9. Die-clearance chart by groups of materials, using the recommended percentage metal thickness (indicated clearances are per side).[5]

At A, which shows clearance C for blanks of a given size, make die to size and punc smaller by total clearance $2C$. At B, which shows clearance for holes of a given siz make punch to size and die larger by the amount of the total clearance $2C$.

The application of clearances for holes of irregular shape is diagramed in Fig. 4- at B the hole will be of punch size, while at A the blank will be of the same dimensio as the die.

One manufacturer charts clearances per side for groups of materials up to and including thicknesses of 0.125 in. (Fig. 4-9), and provides correlating charts (Figs. 4-10 to 4-13).

The die-clearance chart (Fig. 4-9) may be used to find the recommended die clearance to be allowed, and to be provided for, in designing a die for service as determined by the materials groups listed below, and for the preestablished percentage of material thickness of the original part which the die is designed to produce.

Group 1. 2S and 52S aluminum alloys, all tempers. An average clearance of 4½ per cent of material thickness is recommended for normal piercing and blanking.

Group 2. 24ST and 61ST aluminum alloys; brass, all tempers; cold-rolled steel, dead soft; stainless steel soft. An average clearance of 6 per cent of material thickness is recommended for normal piercing and blanking.

Group 3. Cold-rolled steel, half hard; stainless steel, half hard and full hard. An average clearance of 7½ per cent is recommended for normal piercing and blanking.

Example: In Fig. 4-9, it is seen that, for a nominal stock thickness of 0.080 in., the die clearance for any group 1 materials would be 0.0035 in.; for any group 2 materials, 0.0045 in.; for any group 3 materials, 0.006 in.

Interchangeable Use of Same Die. It is often good economy to use a die originally designed for a given type and thickness of material, for piercing or blanking material of a different type and/or thickness. Figures 4-10 to 4-13 provide four convenient charts for such a purpose.

Unlike Fig. 4-9, which is based on single average clearance values, these four charts are based on clearance ranges of 3.4 to 6.8 per cent, 4.5 to 9.0 per cent, and 5.6 to 11.2 per cent for material groups 1, 2, and 3, respectively. Materials groups are the same as for Fig. 4-9.

Example 1: Die made for 52S aluminum alloy, 0.030 in. thick. Can it be used for same material, 0.064 in. thick? Since the material lies in group 1, use Fig. 4-10. On the 0.030-in. abscissa, find minimum and maximum points for group 1 materials. Horizontal extensions from these points show a permissible material thickness range of 0.020 to 0.040 in.; 0.064-in. thickness would therefore exceed the permissible maximum, and *the die should not be used,* since clearance on the original die would be below the range minimum for group 1 materials of 0.064-in. nominal stock thickness.

Example 2: Die made for 24ST aluminum alloy, 0.090 in. thick. Can it be used for cold-rolled steel, half hard, 0.042 in. thick? Since the die was originally designed for a group 2 material, use Fig. 4-11. The intended material is group 3. On the 0.090-in. abscissa, find maximum and minimum points for group 3 materials. Horizontal extensions from these points show a permissible thickness range of 0.048 to 0.095 in. for the cold-rolled steel, half hard. Since the intended thickness is 0.042 in., or less than the range minimum, *the die should not be used,* since clearance on the original die would be below the range minimum for group 3 materials of 0.042-in. nominal stock thickness.

Example 3: Die made for cold-rolled steel, half hard, 0.060 in. thick. Can it be used for 61ST aluminum alloy, 0.064 in. thick? Since the die was originally designed for a group 3 material, use Fig. 4-12. The intended material is group 2. On the 0.060 abscissa, find maximum and minimum points for group 2 materials. Horizontal extensions show a permissible thickness range of 0.050 to 0.100 in. for the 61ST alloy. Since the intended thickness of 0.064 in. lies within this range, *the die may be used.*

Working only from the known clearance for which a die was originally built, Fig. 4-13 may be used to find the thicknesses of a material of any group, for which the die may be used.

Example 4: Given a clearance of 0.0045 in., can a die with this clearance be used for stainless steel, full hard, 0.042 in. thick? This is a group 3 material. Along the 0.0045-in. abscissa of Fig. 4-13, find maximum and minimum points for group 3 materials. Horizontal extensions from these points show a permissible thickness range for the stainless steel, full hard, of 0.040 to 0.080 in. Since the intended thickness lies within the range, *the die may be used.*

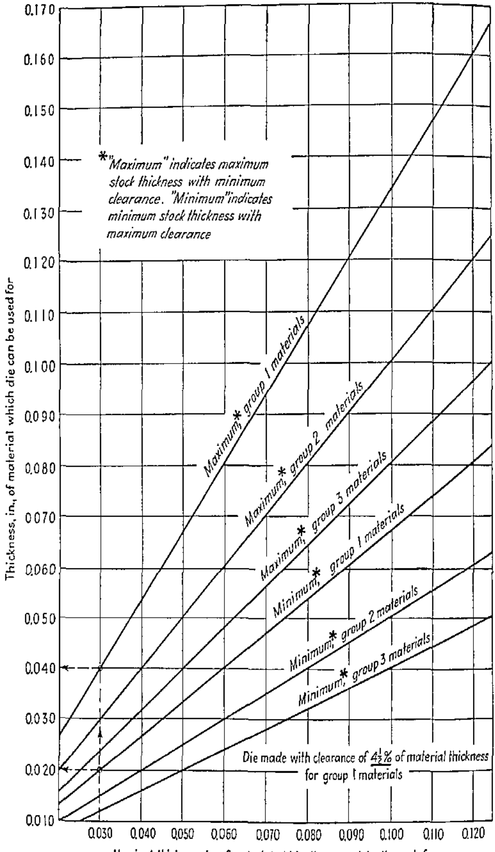

FIG. 4-10. Interchangeable material thickness chart, based on die originally made for group 1 materials (indicated clearances are per side).[6]

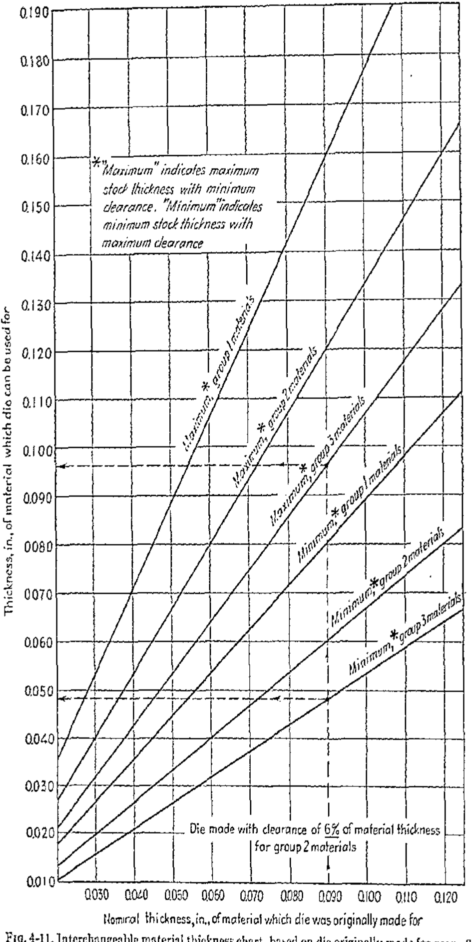

FIG. 4-11. Interchangeable material thickness chart, based on die originally made for group 2 materials (indicated clearances are per side).[5]

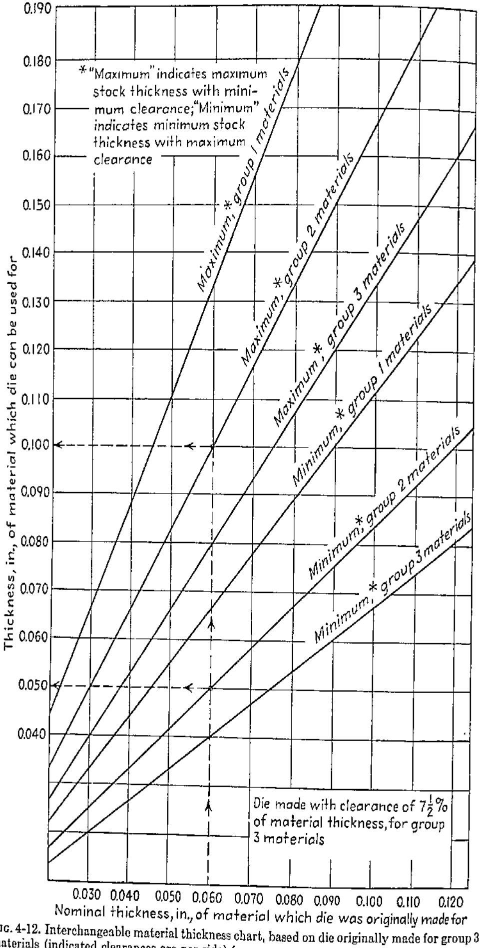

FIG. 4-12. Interchangeable material thickness chart, based on die originally made for group 3 materials (indicated clearances are per side).[6]

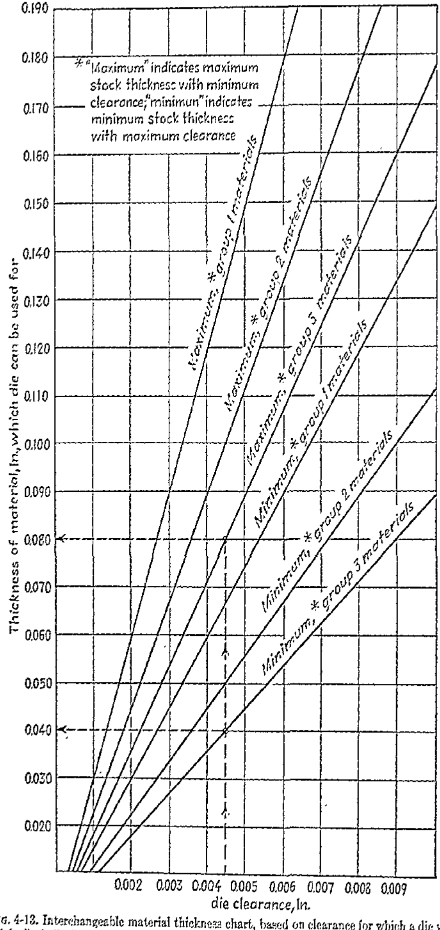

FIG. 4-13. Interchangeable material thickness chart, based on clearance for which a die was originally built (indicated clearances are per side).[5]

Clearance ranges to produce uniformly good cuts for aluminum are listed in Table 4-1.

TABLE 4-1. TOTAL CLEARANCES FOR BLANKING ALUMINUM

Alloy	*Clearance Range, % of Total Stock Thickness*
2SO	7-16
2SH	8-17½
17ST	10-18

Clearances for punching electrical steel laminations are listed in Table 4-2 arranged in the order of decreasing silicon content. The data indicate that, the greater the silicon content, the greater is the required die clearance. A softer stock will require smaller die clearance, but greater angular clearance to prevent scoring of die walls. Angular clearances, per side in 1½-in. length, ground after hardening, are 0.001 to 0.002 in. for hard stock, and 0.002 to 0.003 in. for soft stock.

TABLE 4-2. PER-SIDE CLEARANCE, INCHES, FOR LAMINATION DIES

Grades of steel	29 gage (0.0155 in.)	26 gage (0.0186 in.)	24 gage (0.0249 in.)
Transformer grades	0.0007	0.00085	0.001
Dynamo special	0.0007	0.00085	0.001
Dynamo	0.0006	0.00075	0.0009
Electrical	0.0006	0.00075	0.0009
Armature	0.0005	0.00065	0.0008
Export armature	0.0005	0.00065	0.0008

Data courtesy of Sterling Tool Co.

CLEARANCES FOR NONMETALLIC MATERIALS

For nonmetallic materials other than cellulose acetate, cloth, and paper, the total clearance between punch and die should be 2½ per cent of stock thickness. For mica (data supplied by New England Mica Co.), the die set should be built to a shear fit, *i.e.*, tissue paper will be cut cleanly; the weight alone of the lower half of a new die is not sufficient to open up the die set. Normal die wear ordinarily will allow the die set to be separated by shaking, without tapping with a hammer.

Clearances for fully cured C-stage thermosetting laminated plastics should be approximately 0.0005 in. for sheet thicknesses of 0.015 to 0.032 in. and 0.0015 in. for sheets 0.040 to 0.093 in. thick.

CLEARANCES AND ALLOWANCES FOR SHAVE DIES

Where only one shave is required, a leading manufacturer's standard clearance is 0.001 in. per side; in some cases, clearance can be 1½ per cent of stock thickness. This same manufacturer uses a shaving allowance per side of 10 per cent of stock thickness plus 0.002 ± 0.001 in. tolerance; minimum allowance is 0.005 in.

Small gears should have an allowance of 0.0035 in. for each 1/32-in. thickness of the blank; two-step shaving operations should remove two-thirds of such allowance in the first shave, and the balance in the second shave.[10]

Allowances for shaving the softer metals are larger than for the harder metals; compare Tables 4-3 and 4-4, which were taken from another manufacturer's standard data sheets.

Die-cut holes of less than 1 in. diameter tend to close in; blanks under 1 in. diameter tend to swell. Allowances should be added to the punch diameter, or subtracted from the die diameter (Table 4-5). One-half the given figure should be added or subtracted all around a punch or die of irregular contour.

TABLE 4-3. SHAVING ALLOWANCES PER SIDE, INCHES, FOR STEEL, BRASS, AND GERMAN SILVER STOCK[1]

Thickness of blank, in.	Steel			Brass and german silver
	Hardness, 50–60 Rb	Hardness, 75–90 Rb	Hardness, 90–105 Rb	
Where One Shave Is Necessary				
3/64 (0.0469)	0.0025	0.003	0.004	0.005
1/16 (0.0625)	0.003	0.004	0.005	0.006
5/64 (0.078)	0.0035	0.005	0.006–0.007	0.007
3/32 (0.0938)	0.004	0.006	0.007–0.009	0.008
7/64 (0.1094)	0.005	0.007	0.009–0.011	0.010
1/8 (0.125)	0.007	0.009	0.012–0.014	0.014
Where a Second Shaving Operation Is Necessary				
3/64 (0.0469)	0.00125	0.0015	0.002	0.0025
1/16 (0.0625)	0.0015	0.002	0.0025	0.003
5/64 (0.078)	0.00175	0.0025	0.003–0.0035	0.0035
3/32 (0.0938)	0.002	0.003	0.0035–0.004	0.004
7/64 (0.1094)	0.0025	0.0035	0.0045–0.0055	0.005
1/8 (0.125)	0.0035	0.0045	0.005–0.007	0.007

TABLE 4-4. SHAVING ALLOWANCES FOR ALUMINUM[1]

Thickness, in.	First shave allowance, in.	Final shave allowance, in.
0.03	.....	0.004
0.05	.....	0.006
0.06	.....	0.007
0.08	0.007	0.003
0.100	0.008	0.004
0.125	0.010	0.005
0.175	0.013	0.007
0.250	0.020	0.010

TABLE 4-5. COMPENSATING ALLOWANCE FOR PART-SIZE CHANGE IN ROUND HOLES[1]

Stock Thickness, Gage	*Allowance,* In.*
Less than 22	0.001
22–16	0.0015
16–10	0.002

* Add to punch diameter or subtract from die diameter.

ANGULAR CLEARANCE

Angular clearance is defined as that clearance below the straight portion of a die surface introduced for the purpose of enabling the blank or the slug (piercing operation) to clear the die (Fig. 4-14). Angular clearance is usually ground from 1/4 to 3/4° per side but occasionally as high as 2°, depending mainly on stock thickness and the frequency of sharpening.

Other definitions pertinent to die clearances are:

Land. A flat surface contiguous to the cutting edge of a die, its purpose being to reduce the area to be ground and reground in maintaining a sharp cutting edge (Fig. 4-14).

Straight. That portion of the die surface between the cutting edge and the angular clearance in a blanking or piercing die (Fig. 4-14). It has been found to be good practice to maintain a minimum straight-wall height of ⅛ in. on all materials less than

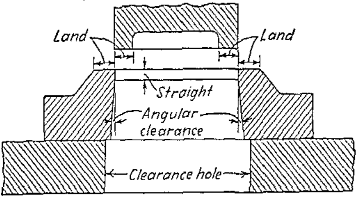

FIG. 4-14. Schematic drawing showing straight, land, and angular clearances.[3]

⅛ in. thick. Straight-wall height for thicker materials, equal to material thickness, has proved to be good practice. These rules hold generally good for all classes of dies.[3]

Draft. Draft is the amount of taper placed on a die to enable the severed slug or blank to drop through without binding. In Fig. 4-16, it is shown as A, the projection

TABLE 4-6. DIE-OPENING INCREASES (DRAFT), INCHES PER SIDE, DUE TO RESHARPENING

Amount ground below die straight, in.	Draft or clearance angle											
	0°15′	0°30′	1°	1°30′	2°	2°30′	3°	4°	5°	6°	7°	8°
0.010	0.00004	0.00009	0.00018	0.00026	0.00034	0.00043	0.00052	0.00070	0.00087	0.00105	0.00123	0.00140
0.015	0.00006	0.00013	0.00026	0.00039	0.00052	0.00066	0.00079	0.00104	0.00131	0.00158	0.00184	0.00211
0.025	0.00011	0.00022	0.00044	0.00065	0.00087	0.00109	0.00131	0.00175	0.00219	0.00263	0.00307	0.00351
0.035	0.00015	0.00030	0.00061	0.00092	0.00122	0.00153	0.00183	0.00245	0.00306	0.00369	0.00430	0.00492
0.040	0.00017	0.00038	0.00070	0.00105	0.00139	0.00174	0.00210	0.00280	0.00350	0.00420	0.00491	0.00562
0.045	0.00020	0.00039	0.00078	0.00118	0.00157	0.00196	0.00236	0.00315	0.00394	0.00473	0.00552	0.00632
0.050	0.00022	0.00044	0.00088	0.00131	0.00174	0.00218	0.00262	0.00350	0.00437	0.00525	0.00614	0.00703
0.060	0.00026	0.00052	0.00105	0.00157	0.00209	0.00262	0.00314	0.00419	0.00525	0.00631	0.00737	0.00843
0.070	0.00030	0.00061	0.00122	0.00183	0.00244	0.00301	0.00367	0.00489	0.00612	0.00736	0.00859	0.00984
0.080	0.00034	0.00070	0.00140	0.00210	0.00309	0.00349	0.00419	0.00559	0.00700	0.00841	0.00982	0.01124
0.090	0.00039	0.00078	0.00158	0.00236	0.00314	0.00392	0.00472	0.00629	0.00787	0.00946	0.01105	0.01265
0.100	0.00044	0.00087	0.00175	0.00262	0.00349	0.00437	0.00524	0.00699	0.00875	0.01051	0.01228	0.01405
0.125	0.00055	0.00109	0.00218	0.00327	0.00436	0.00546	0.00655	0.00874	0.01094	0.01314	0.01535	0.01757
0.150	0.00065	0.00131	0.00262	0.00393	0.00523	0.00654	0.00786	0.01049	0.01312	0.01576	0.01842	0.02108
0.175	0.00076	0.00153	0.00305	0.00458	0.00611	0.00764	0.00917	0.01224	0.01531	0.01839	0.02149	0.02459
0.200	0.00087	0.00175	0.00350	0.00524	0.00698	0.00873	0.01048	0.01399	0.01750	0.02102	0.02456	0.02811
0.225	0.00098	0.00196	0.00393	0.00589	0.00786	0.00982	0.01179	0.01573	0.01968	0.02365	0.02762	0.03162
0.250	0.00110	0.00218	0.00438	0.00655	0.00872	0.01091	0.01310	0.01748	0.02187	0.02628	0.03069	0.03513
0.275	0.00120	0.00240	0.00480	0.00720	0.00960	0.01201	0.01441	0.01923	0.02406	0.02890	0.03376	0.03865
0.300	0.00131	0.00262	0.00523	0.00785	0.01048	0.01310	0.01572	0.02098	0.02625	0.03153	0.03683	0.04216
0.325	0.00142	0.00284	0.00567	0.00850	0.01135	0.01419	0.01703	0.02273	0.02843	0.03416	0.03990	0.04567
0.350	0.00153	0.00305	0.00611	0.00891	0.01222	0.01528	0.01834	0.02447	0.03062	0.03678	0.04297	0.04919
0.375	0.00164	0.00327	0.00654	0.00916	0.01309	0.01638	0.01965	0.02622	0.02381	0.03942	0.04604	0.05270
0.400	0.00174	0.00349	0.00698	0.01047	0.01397	0.01746	0.02096	0.02797	0.03500	0.04204	0.04911	0.05622
0.425	0.00185	0.00361	0.00742	0.01113	0.01484	0.01855	0.02227	0.02972	0.03718	0.04467	0.05218	0.05973
0.450	0.00196	0.00393	0.00785	0.01178	0.01571	0.01965	0.02358	0.03147	0.03937	0.04729	0.05525	0.06324
0.475	0.00207	0.00415	0.00829	0.01243	0.01659	0.02074	0.02489	0.03322	0.04156	0.04992	0.05892	0.06676
0.500	0.00218	0.00436	0.00872	0.01309	0.01746	0.02183	0.02620	0.03496	0.04374	0.05255	0.06139	0.07027

of the angular clearance. When a die is sharpened below the straight, the die opening is increased. This increase *per side* can be calculated as

$$A = B \tan \alpha \qquad (1)$$

where α = clearance or draft angle, deg

Table 4-6 lists the increase per side in die openings, ground from the die face below the straight for small angles. This table is useful for checking to see that regrinding in the tapered area does not result in excessive clearance.

Example: Calculate how much a die, initially ground with *minimum hole clearance*, can be reground below the straight, and still keep within maximum clearance limits, for the following three materials, all 0.03125 in. thick.

Stock *A*: 2S aluminum alloy, with 3.4 to 6.8 per cent *T* die-clearance range.

Stock *B*: Stainless steel, soft, with 4.5 to 9 per cent *T* die-clearance range.

Stock *C*: Cold-rolled steel, half hard, with 5.6 to 11.2 per cent *T* die-clearance range.

Since minimum clearance was ground on the die, the remaining available clearances for stocks *A*, *B*, and *C* are 0.00106 in., 0.00141 in., and 0.00175 in., respectively. In Table 4-6, selecting the exact or next lower listed values, the maximum permissible depths of regrind are found as shown in Table 4-7.

TABLE 4-7. MAXIMUM REGRIND DEPTHS, INCHES, FOR CLEARANCE ANGLES AND STOCKS LISTED

Clearance angle	Stock *A**	Stock *B*†	Stock *C*‡
15′	0.250	0.300	0.400
30′	0.100	0.150	0.200
1°	0.050	0.080	0.100
1°30′	0.040	0.050	0.060
2°	0.025	0.040	0.050
2°30′	0.025	0.025	0.040
3°	0.015	0.025	0.025
4°	0.015	0.015	0.025
5°	0.010	0.015	0.015
6°	0.010	0.010	0.015
7°	No regrind	0.010	0.010
8°	No regrind	0.010	0.010

* 2S aluminum alloy, 0.03125 in. thick.
† Stainless steel, soft, 0.03125 in. thick.
‡ Cold-rolled steel, half hard, 0.03125 in. thick.

SHEAR

Shear is the amount of relief ground off the face of a die or punch, primarily for reducing the required shearing force, to reduce stress on the tool, to enable thicker or more resistant stock to be punched on the same press, or to permit use of lower-rated presses.

Relation of Forces to Amount of Shear. Forces, but not work done, vary with various amounts of shear (Fig. 4-15).

View *A* of Fig. 4-15 shows a cutting operation in which the cutting edges are parallel, *i.e., shear is zero. Stock thickness is indicated by t.* Since the cut takes place on the entire periphery at once, it is obvious that the operation will entail maximum load. The load diagram at right shows the rapid rise at maximum pressure, then the sudden load release, sometimes severe on both press and dies, as the cut is completed.

View *B* of the same figure shows a punch ground with shear. If the punch were to be ground so that the height of the angle equals one-third of the metal thickness, *i.e.*, shear equals ⅓ *t*, its leading edge would start cutting before the rest of the punch made contact. With this condition, only part of the punch would be cutting at any one instant. While cutting load would be decreased, the punch would have to progress further through the stock to complete the cut. With the punch in position shown, cutting pressure would be at maximum for this amount of shear, and because the cut is more or less complete the total cutting load would be less than that required for the condition shown in view *A*. Pressure is slightly less than when shear is zero, but as the work done is the same, the distance through which pressure is applied is greater. Load release is also somewhat less sudden.

View *C* of same figure shows that, if shear is ground on the punch so that the height of the angle equals the full thickness of the metal cut, the shear would be equal to 1*t*.

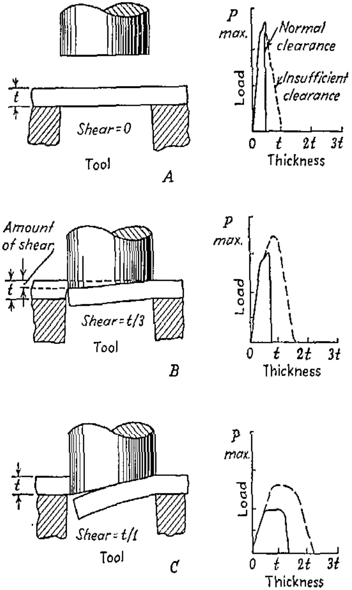

FIG. 4-15. Loads for various amounts of shear.[2]

When the leading edge has progressed entirely through distance *t*, the trailing edge is just making contact with the metal. Maximum pressure would be at this position of the punch, and since most of the cut is complete the total load would be about half that required when shear is zero. The distance through which the punch load functions is greater still than that indicated in view *B*.

Concave shear has been cylindrically ground on the long sides of the die of Fig. 4-16 (*A*), which produces a rectangular blank. The punch first cuts along the short sides of the blank, and at these locations the punch is supported as it cuts the long sides toward their centers. The stock is held more securely than by first cutting the long sides, with the shear ground on the short sides of the die. If the blank is round, a series of scalloped or wavelike shear areas should be ground on the die. The amount of shear varies from less than 1*t* for heavy ferrous material to 2*t* for thin stock. Flat blanks will also be produced by a die with convex shear [Fig. 4-16 (*B*)], but the upper part of the die section will be weak. *The punched-out metal* [Fig. 4-16 (*C*), (*D*), (*E*)] will be distorted, but the stock will be flat.

In the die shown in Fig. 4-17, flat areas around the corners at *D* provide a level support for the stock and prevent its slippage at the time of punch engagement. With the amount of shear *B* and angle of shear *A*, cutting progresses from the outside to the center, producing a flat blank.

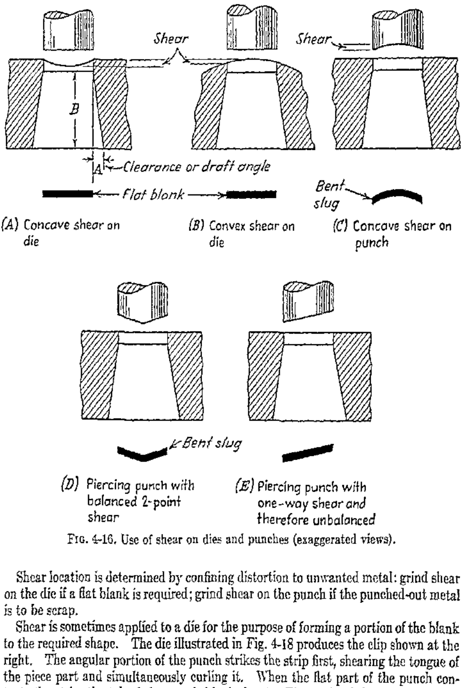

FIG. 4-16. Use of shear on dies and punches (exaggerated views).

Shear location is determined by confining distortion to unwanted metal: grind shear on the die if a flat blank is required; grind shear on the punch if the punched-out metal is to be scrap.

Shear is sometimes applied to a die for the purpose of forming a portion of the blank to the required shape. The die illustrated in Fig. 4-18 produces the clip shown at the right. The angular portion of the punch strikes the strip first, shearing the tongue of the piece part and simultaneously curling it. When the flat part of the punch contacts the strip, the tab of the part is blanked out. The angle of the punch must be determined by trial and error. After it has been established, a gage is made for use in future punch-sharpening operations.

PUNCHING AND BLANKING PRESSURES

The formula for the pressure *P* required to punch or blank a given material, assuming there is no shear on the punch or die, is

$$P = SLT \text{ lb for any shape of aperture} \tag{2}$$

or

$$P = S\pi DT \text{ lb for round holes} \tag{2A}$$

where S = shear strength of material, psi
L = sheared length, in.
D = diameter, in.
T = thickness of material, in.

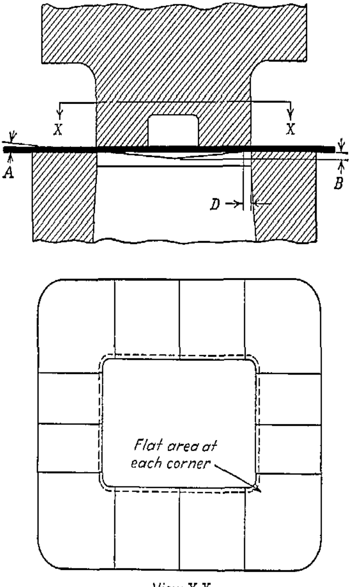

FIG. 4-17. When shear is applied so that the die face is concave, cutting progresses from outside to center.

Blanking or piercing pressures for various materials can be calculated with the aid of Table 4-9.

Pressures required to pierce round holes up to 2.5 in. diameter in various thicknesses and gages of sheet steel having a shearing strength of 50,000 psi can be taken from Table 4-8.

Blanking or piercing pressures for various materials can be determined from the nomograph (Fig. 4-19). Shear strength of some metals is listed in Table 4-9.

Example: Given: Material, 24ST aluminum, 0.051 in. thick. Part is to be blanked with 3-in.-diameter hole.

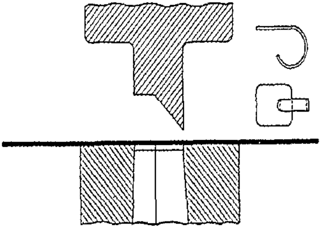

FIG. 4-18. Angular part of punch shears tab of the part and curls it, then the flat part of the punch blanks the completed piece.[4]

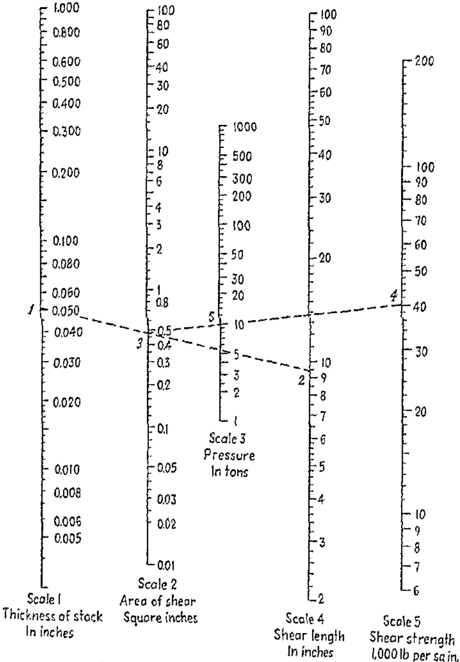

FIG. 4-19. Chart for determining blanking pressure.[8]

TABLE 4-8. PRESSURE, TONS REQUIRED TO PIERCE ROUND HOLES IN STEEL OF 50,000 PSI SHEAR STRENGTH

Metal thickness (gage), in.	Hole size, in.																			
	1/8	1/4	3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2	2 1/8	2 1/4	2 3/8	2 1/2
(28) 0.0149	0.15	0.29	0.44	0.58	0.73	0.88	1.0	1.2	1.3	1.5	1.6	1.7	1.9	2.1	2.2	2.3	2.5	2.6	2.8	2.9
(27) 0.0164	0.16	0.32	0.48	0.64	0.80	0.97	1.1	1.3	1.4	1.6	1.8	1.9	2.1	2.2	2.4	2.6	2.7	2.9	3.0	3.2
(26) 0.0179	0.17	0.35	0.53	0.70	0.88	1.05	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.4	2.6	2.8	3.0	3.2	3.3	3.5
(25) 0.0209	0.20	0.41	0.61	0.82	1.02	1.23	1.4	1.6	1.8	2.0	2.2	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.1
(24) 0.0239	0.23	0.47	0.70	0.94	1.17	1.41	1.6	1.9	2.1	2.3	2.6	2.8	3.0	3.3	3.5	3.7	4.0	4.2	4.4	4.7
(23) 0.0269	0.26	0.53	0.79	1.06	1.32	1.58	1.8	2.1	2.4	2.6	2.9	3.2	3.4	3.7	4.0	4.2	4.5	4.7	5.0	5.3
(22) 0.0299	0.29	0.59	0.88	1.17	1.47	1.76	2.0	2.3	2.6	2.9	3.2	3.5	3.8	4.1	4.4	4.7	5.0	5.3	5.6	5.9
(21) 0.0329	0.32	0.64	0.97	1.29	1.62	1.94	2.3	2.6	2.9	3.2	3.5	3.9	4.2	4.5	4.8	5.2	5.5	5.8	6.1	6.4
(20) 0.0359	0.35	0.70	1.06	1.41	1.76	2.11	2.5	2.8	3.2	3.5	3.9	4.2	4.6	4.9	5.3	5.6	6.0	6.3	6.7	7.0
(19) 0.0418	0.41	0.82	1.23	1.64	2.05	2.46	2.9	3.3	3.7	4.1	4.5	4.9	5.3	5.7	6.1	6.6	7.0	7.4	7.8	8.2
(18) 0.0478	0.47	0.94	1.41	1.88	2.35	2.81	3.3	3.7	4.2	4.7	5.2	5.6	6.1	6.6	7.0	7.5	8.0	8.4	8.9	9.4
(17) 0.0538	0.53	1.06	1.58	2.11	2.64	3.17	3.7	4.2	4.7	5.3	5.8	6.3	6.7	7.4	7.9	8.4	9.0	9.5	10.0	10.6
(16) 0.0598	0.59	1.17	1.76	2.35	2.93	3.52	4.1	4.7	5.3	5.9	6.4	7.0	7.6	8.2	8.8	9.4	10.0	10.6	11.1	11.7
(15) 0.0673	0.66	1.32	1.98	2.64	3.30	3.96	4.6	5.3	5.9	6.6	7.3	7.9	8.6	9.2	9.9	10.6	11.2	11.9	12.5	13.2
(14) 0.0747	0.73	1.47	2.20	2.93	3.67	4.40	5.1	5.9	6.6	7.3	8.1	8.8	9.5	10.3	11.0	11.7	12.5	13.2	13.9	14.7
(13) 0.0897	0.88	1.76	2.64	3.52	4.40	5.28	6.2	7.0	7.9	8.8	9.7	10.6	11.4	12.3	13.2	14.1	15.0	15.8	16.7	17.6
(12) 0.1046	1.03	2.05	3.08	4.11	5.13	6.16	7.2	8.2	9.2	10.3	11.3	12.3	13.3	14.4	15.4	16.4	17.4	18.5	19.5	20.5
(11) 0.1196	1.17	2.35	3.52	4.70	5.87	7.04	8.2	9.4	10.6	11.7	12.9	14.1	15.3	16.4	17.6	18.8	20.0	21.1	22.3	23.5
(10) 0.1345	1.32	2.64	3.96	5.28	6.60	7.92	9.2	10.6	11.9	13.2	14.5	15.8	17.2	18.5	19.8	21.1	22.4	23.8	25.1	26.4
(9) 0.1495	1.47	2.93	4.40	5.87	7.34	8.80	10.3	11.7	13.2	14.7	16.1	17.6	19.1	20.5	22.0	23.5	25.0	26.4	27.9	29.3
(8) 0.1644	1.61	3.23	4.84	6.45	8.07	9.69	11.3	12.9	14.5	16.1	17.7	19.4	21.0	22.6	24.2	25.8	27.4	29.0	30.6	32.3
(7) 0.1793	1.76	3.52	5.28	7.04	8.80	10.56	12.3	14.1	15.8	17.6	19.4	21.1	22.9	24.6	26.4	28.1	30.0	31.7	33.4	35.2
(6) 0.1943	1.91	3.81	5.72	7.63	9.54	11.44	13.3	15.3	17.2	19.1	21.0	22.9	24.8	26.7	28.6	30.5	32.4	34.3	36.2	38.1
(5) 0.2092	2.05	4.11	6.16	8.21	10.27	12.32	14.4	16.4	18.5	20.5	22.6	24.6	26.7	28.7	30.8	32.8	35.0	37.0	39.0	41.1
(4) 0.2242	2.20	4.40	6.60	8.80	11.00	13.21	15.4	17.7	19.8	22.0	24.2	26.4	28.6	30.8	33.0	35.2	37.4	39.6	41.8	44.0
(3) 0.2391	2.35	4.69	7.04	9.39	11.74	14.08	16.4	18.8	21.1	23.5	25.8	28.2	30.5	32.8	35.2	37.5	40.0	42.2	44.6	46.9
0.250	2.45	4.91	7.36	9.82	12.27	14.73	17.2	19.7	22.1	24.5	27.0	29.4	31.9	34.3	36.8	39.2	41.7	44.2	46.6	49.1
0.2812	2.76	5.52	8.28	11.04	13.80	16.56	19.3	22.1	24.8	27.6	30.4	33.1	35.9	38.6	41.4	44.1	47.0	49.7	52.4	55.2
0.3125	3.07	6.13	9.20	12.27	15.34	18.41	21.5	24.5	27.6	30.7	33.7	36.8	39.9	42.9	46.0	49.1	52.1	55.2	58.3	61.3

1. Length of sheared edge = 9.42 in. (πD).
2. Find 0.051 on scale 1 (at point 1) and 9.42 in. on scale 4 (at point 2).
3. Connect points 1 and 2.
4. The line connecting points 1 and 2 intersects scale 2 at 0.480, or point 3.
5. From Table 27-3, it will be seen that the shear strength for 24ST is 40,000 psi.
6. From point 4 on scale 5 (representing 40,000 psi) draw a line to point 3 on scale 2.
7. The line connecting points 3 and 4 intersects scale 3 at point 5, giving a reading of 9.8 tons.

When the above problem is calculated with the formula $P = SLT/2{,}000$, the result is 9.6 tons. The error in reading the nomograph is not important, because an error of 500 lb would not impose an excessive load on the press, considering the factor of safety used in the design of such equipment.

Pressures in pounds per linear inch of perimeter, for piercing or blanking operations for thicknesses of various materials up to and including 0.250 in., are tabulated in Table 4-10.

The shear strength of various nonmetallic materials may be taken from Table 4-11.

SHRINKAGE ALLOWANCE FOR BLANKING HEATED PHENOL FABRICS AND PHENOL FIBER

In general, the expansion coefficient of phenol fabrics and phenol fiber is 0.00003 in. per inch per degree centigrade change in temperature or 0.0000167 in. per inch per degree Fahrenheit change in temperature. When this material is blanked or perforated hot, it will in most cases shrink by the above amount.

TABLE 4-9. SHEAR STRENGTH, PSI, OF VARIOUS MATERIALS[3]

Ferrous Materials			
Carbon steel:		Nickel steel (drawn to 800°F and water-quenched):	
Soft open-hearth; annealed	42,000	SAE 2320	98,000
SAE 1020; water-quenched; drawn to 400°F	60,000	SAE 2330	110,000
SAE 1045; water-hardened; drawn to 800°F	9,000	SAE 2340	125,000
Chromium-molybdenum steel; SAE 4130:		Nickel-chromium steel (drawn to 800°F):	
90,000 ultimate tensile strength	55,000	SAE 3120	95,000
100,000 ultimate tensile strength	65,000	SAE 3130	110,000
125,000 ultimate tensile strength	75,000	SAE 3140	130,000
150,000 ultimate tensile strength	90,000	SAE 3250	135,000
180,000 ultimate tensile strength	105,000	SAE 3240	150,000
		SAE 3250	165,000
Nonferrous Materials			
Aluminum and alloys (see Table 27-3)		Nickel:	
Copper and alloys (see Table 27-8)		68,000 ultimate tensile strength	52,300
Magnesium alloys (see Table 27-15)		120,500 ultimate tensile strength	75,300
Monel metal:		Inconel (nickel-chromium-iron):	
69,000 ultimate tensile strength	42,900	80,000 ultimate tensile strength	59,000
105,000 ultimate tensile strength	65,200	90,000 ultimate tensile strength	63,000
K monel:		100,000 ultimate tensile strength	65,000
97,500 ultimate tensile strength	65,300	115,000 ultimate tensile strength	71,000
155,000 ultimate tensile strength	98,700	140,000 ultimate tensile strength	78,000
		160,000 ultimate tensile strength	84,000
		175,000 ultimate tensile strength	87,000

STRIPPING PRESSURE

According to reports received from representative metal fabricators, stripping pressure varies from 2½ to 20 per cent of the blanking and/or piercing pressure. A formula frequently used is

$$P_s = 3{,}500\, LT \qquad (3)$$

where P_s = stripping pressure, lb

L = perimeter of cut, in.

T = stock thickness, in.

The above is commonly used as a rough guide, but it cannot be closely relied upon, because of the many other variables which are extremely difficult to evaluate:

1. Angle and roughness of the fracture
2. Ratio of blank length to width
3. Condition of punch and die cutting edges
4. Die clearance
5. Lubrication of punch
6. Distance between holes, slots, and notches; or between notches and the sheet edge
7. Punch surface condition: (a) ground; (b) unground; (c) direction of grinding or lapping; (d) plated or unplated
8. Number of holes
9. Amount of stock left around punched or blanked piece
10. Grade and kind of material

Shear ground on the punch or die will reduce the blanking pressure but will not affect the stripping pressure.

If punches are stepped one-half of the metal thickness or more, the total blanking pressure will be reduced as follows:

Punches on two levels, divide by 2.
Punches on three levels, divide by 3.
Punches on four levels, divide by 4.

TABLE 4-10. BLANKING PRESSURES, POUNDS PER LINEAL INCH, FOR VARIOUS MATERIALS

Thickness of stock, in.	Steel			Magnetic iron	Nickel silver	Permalloy	Phosphor bronze	Brass	
	High-carbon	Low-carbon	Silicon					Soft	Hard
0.0156	1,404	780	1,170	624	837	1,232	824	546	675
0.0171	1,539	850	1,282	684	918	1,351	903	595	769
0.0187	1,683	940	1,402	748	1,004	1,477	987	615	841
0.0218	1,962	1,090	1,635	872	1,170	1,722	1,151	770	981
0.0250	2,250	1,250	1,875	1,000	1,342	1,975	1,320	875	1,125
0.0281	2,529	1,405	2,107	1,124	1,508	2,220	1,484	980	1,264
0.0312	2,808	1,560	2,340	1,248	1,675	2,465	1,647	1,085	1,404
0.0343	3,087	1,715	2,572	1,372	1,842	2,710	1,811	1,190	1,543
0.0375	3,375	1,875	2,812	1,500	2,014	2,962	1,980	1,312	1,687
0.0437	3,933	2,185	3,277	1,748	2,347	3,452	2,307	1,540	1,966
0.0500	4,500	2,500	3,750	2,000	2,685	3,950	2,640	1,750	2,250
0.0562	5,058	2,810	4,215	2,248	3,017	4,440	2,967	1,960	2,529
0.0625	5,625	3,125	4,687	2,500	3,356	4,938	3,300	2,187	2,812
0.0703	6,327	3,515	5,272	2,812	3,775	5,554	3,712	2,480	3,162
0.0781	7,029	3,905	5,857	3,124	4,194	6,170	4,124	2,710	3,514
0.0937	8,433	4,700	7,028	3,748	5,032	7,402	4,947	3,290	4,216
0.1093	9,837	5,465	8,198	4,372	5,869	8,635	5,771	3,815	4,918
0.1250	11,250	6,250	9,375	5,000	6,712	9,875	6,600	4,375	5,625
0.1406	12,654	7,030	10,545	5,624	7,550	11,107	7,424	4,935	6,327
0.1562	14,058	7,810	11,715	6,248	8,388	12,340	8,247	5,460	7,029
0.1718	15,462	8,598	12,885	6,872	9,226	13,572	9,071	6,020	7,731
0.1875	*16,875*	*9,375*	*13,762*	*7,500*	*10,069*	*14,812*	*9,900*	*6,562*	*8,437*
0.2031	18,279	10,155	14,062	8,124	10,906	16,045	10,723	7,075	9,139
0.2187	19,683	10,935	15,232	8,748	11,744	17,277	11,547	7,667	9,841
0.2343	21,087	11,715	17,572	9,372	12,582	18,510	12,371	8,190	10,543
0.2500	22,500	12,500	18,750	10,000	13,425	19,750	13,200	8,760	11,250

TABLE 4-11. SHEAR STRENGTH OF VARIOUS NONMETALLIC MATERIALS

Material	Shearing strength, psi	Material	Shearing strength, psi
Asbestos board	5,000	Leather, rawhide	13,000
Cellulose acetate	10,000	Mica	10,000
Cloth	8,000	Paper*	6,400
Fiber, hard	18,000	Bristol board	4,800
Hard rubber	20,000	Pressboard	3,500
Leather, tanned	7,000	Phenol Fiber†	26,000

* For hollow die, use one-half value shown for shearing strength.
† Blank and perforate hot.

SCRAP ALLOWANCE FOR BLANKING

The optimum strip stock layout for blanking and perforating operations will provide sufficient material around the cutout to prevent distortion in the blank or scrap stock.

This material allowance provides an adequate area *to support or hold down the strip during* the operation. Minimum material or scrap allowances have been standardized by a large manufacturer and are listed in Table 4-12.

The width of sheared stock should be given in thirty-seconds of an inch or larger; the width of rolled stock may be given in thousandths of an inch. The scrap allowances given are for the general run of work: when blanks are exceptionally large, a greater amount of scrap should be allowed. The width of stock may be 10 per cent of the scrap allowance less than the width calculated from the table.

TABLE 4-12. SCRAP ALLOWANCE FOR BLANKING

Material	When length of skeleton segment between blanks or along edge is equal to or less than $2T$			When length of skeleton segment between blanks or along edge is greater than $2T$		
	Thickness of stock (T), in.	Edge of stock to blank, in.	Between blanks, same row, in.	Thickness of stock (T), in.	Edge of stock to blank, in.	Between blanks, same row, in.
Cloth, paper (bond, manila, red rope, etc.)	All	3/32–5/32	3/32–5/32	All	3/32–5/32	3/32–5/32
Felt, leather, soft rubber	Under 0.062 Above 0.062	1/16 T	1/16 T	Under 0.062 Above 0.062	1/16 T	1/16 T
Hard rubber, celluloid, Protectoid	All	$0.4T$* or 0.040 min	$0.4T$* or 0.040 min	All	$0.4T$* or 0.040 min	$0.4T$* or 0.040 min
Metals, general:						
Standard strip stock	Under 0.021 0.022–0.055 Above 0.055	0.050 0.040 $0.7T$	0.050 0.040 $0.7T$	Under 0.044 Above 0.044	0.050 $0.9T$	0.050 $0.9T$
Extra-wide stock and weak scrap skeleton	Under 0.042 Above 0.042	0.060 $1.4T$	0.050 $1.2T$	Under 0.033 Above 0.032	0.060 $1.8T$	0.050 $1.6T$
Stock run through twice	Under 0.042 0.043–0.055 Above 0.055	0.060 $1.4T$ $1.4T$	0.050† 0.040 $0.7T$	Under 0.033 0.034–0.044 Above 0.044	0.060 $1.8T$ $1.8T$	0.050† 0.040 $0.9T$
Stock run through twice and first and second rows of blanks interlock	Under 0.042 Above 0.042	0.060 $1.4T$	0.050* $1.4T$†	Under 0.033 Above 0.033	0.060 $1.8T$	0.050* $1.8T$†
Mica, Micanite, phenol fabrics, and phenol fiber	All	$0.6T$* or 0.060 min	$0.6T$* or 0.060 min	All	$0.6T$* or 0.060 min	$0.6T$* or 0.060 min
Permalloy	All	0.060	0.060	All	T‡	T‡
Pressboard, asbestos board	Under 0.031 Above 0.031	1/16 $2T$	1/16 $2T$	Under 0.031 Above 0.031	1/16 $2T$	1/16 $2T$
Steel (silicon, spring, stainless)	Under 0.042 Above 0.042	0.060 min $1.4T$	0.060 min $1.4T$	Under 0.033 Above 0.033	0.060 min $1.8T$	0.060 min $1.8T$
Vulcanized fiber	All	$0.8T$* or 0.080 min	$0.8T$* or 0.080 min	All	$0.8T$* or 0.080 min	$0.8T$* or 0.080 min

* Allow 0.060 between blanks at first and second rows.

† Allowance between blanks in same row and also between blanks of first and second rows.

‡ When the blank edge parallels the edge of stock or between blanks more than four times the thickness, the allowance of 1.8 thickness of stock shall apply.

References

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2. Langbridge, J. W.: The Theory and Practice of Pressing Aluminum, *The Tool Engineer*, June, 1948–July, 1949.

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9. "Tool Engineering Reference Sheets," International Business Machines Corp.
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SECTION 5

CUTTING DIES*

PIERCING AND PERFORATING DIES

Single-station Piercing and Perforating Dies. Dies described under this classification are those dies whose function is to punch out regular or irregular shapes from metal stock. The punched-out stock is typically scrap.

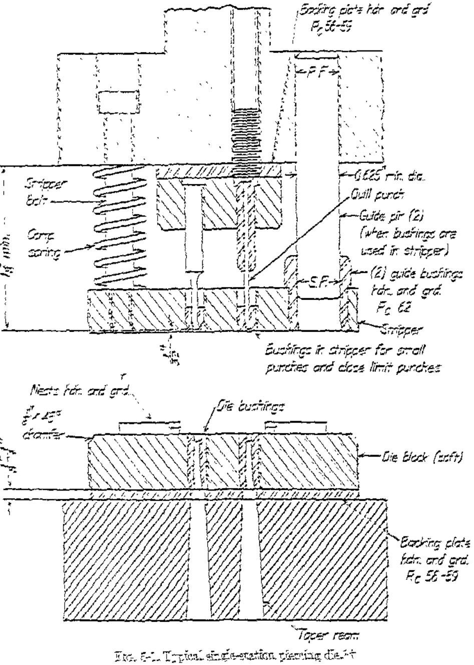


Fig. 5-1. Typical single-station piercing die.[1]†

* Reviewed by J. E. Bracek, Superintendent, Tooling & Maintenance Division, Sargent & Co., and J. E. Baquin, Tool Engineer.

† Superior numbers relate to References at the end of this section.

Typical Single-station Piercing Die. One large manufacturer classifies the die shown in Fig. 5-1 as a typical piercing die. General specifications included in this manufacturer's manual of tool engineering are noted on the drawing.

Magnetic Locating Piercing Die. The die shown in Fig. 5-2 pierces one 0.0937-in.-diameter hole only, in a keyboard lockout detent part of quarter-hard 0.031-in. cold-rolled steel which has been previously blanked, slotted, and formed. Four permanent magnets (*D*2)* in bronze bushings (*D*1) hold the piece part after it has been located on the gage pins (*D*3). These gage pins are set in removable blocks (*D*4, *D*6) so that they may be relocated after the die has been sharpened. As the ram descends, a positive locater or wiper contacts the cam block (*D*5) and holds the work against the side of the die as the punch pierces the 0.0937-in. hole. Nominal punch diameter is 0.09455 in., allowing 0.00085 in. for punch wear.

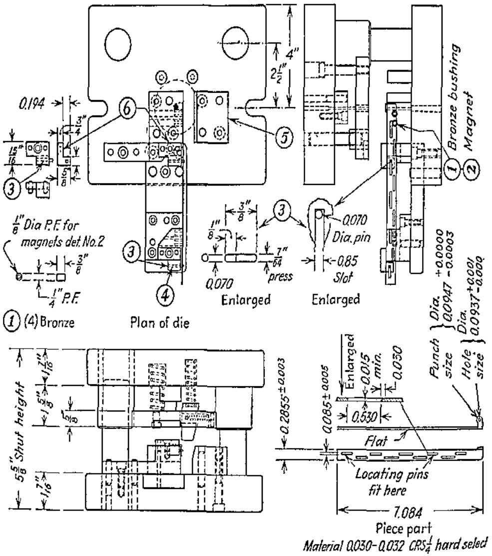


FIG. 5-2. Magnetic locating piercing die. (*National Cash Register Co.*)

* *D* indicates detail number on drawing.

Die for Piercing and Slotting a Key. Two end slots, two holes, and a central slot are separately cut by punches (*D*1, *D*2, *D*3) at one press stroke in the die shown in Fig. 5-3. The workpiece is held in nests (*D*4, *D*5). The two punches for notching the end slots are heeled (section *A-A*). A cam stripper (*D*6) is provided which is bushed for the guide pins (*D*7, *D*8).

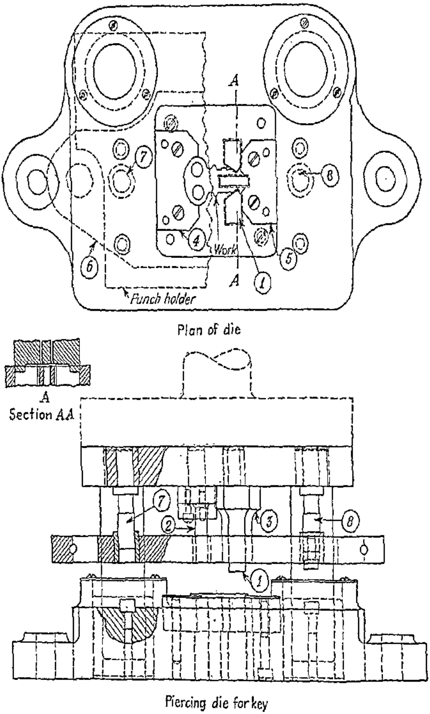


FIG. 5-3. Die for piercing and slotting a key.[4]

Piercing Die for Press Brake. This die (Fig. 5-4) is one of several set up in a press brake for a number of operations on steel strip used in blank books. A specially designed feeder (not shown) facilitates strip movement between the series of dies which constitute a progressive arrangement of independent single-station dies, any one of which can be removed from the brake without disturbing the remaining dies. *Strip stock is positioned by guides (D5) and removed from the punches (D1, D2, D3)* by a stripper (*D*6). The die sections (*D*4) are of split design for ease of grinding and construction.

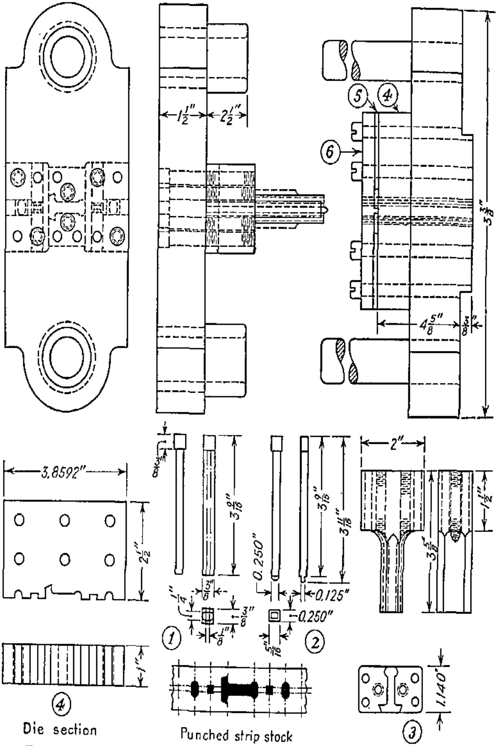


FIG. 5-4. Single-station piercing die for a press brake. (*National Blank Book Co.*)

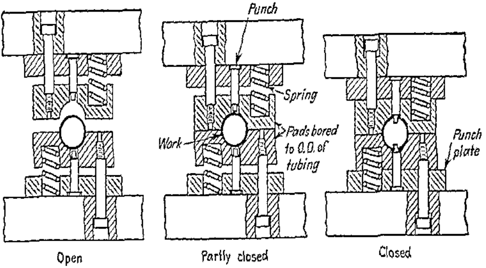


FIG. 5-5. Tube-piercing die. (*O. H. Mathiesen, ASTE.*)

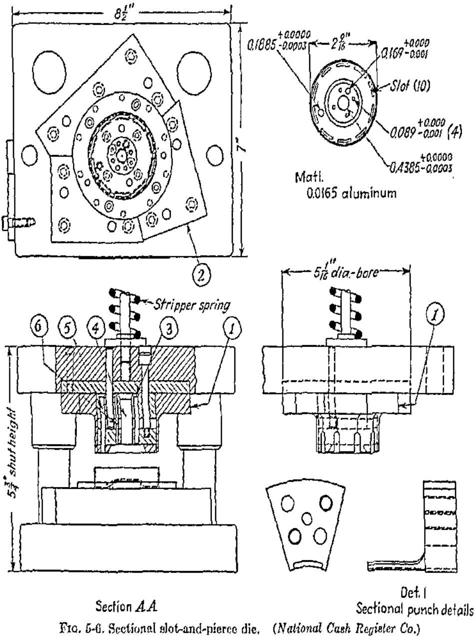
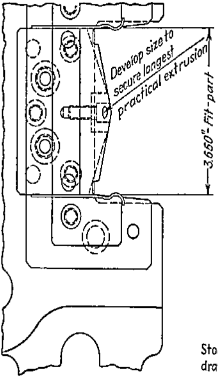


FIG. 5-6. Sectional slot-and-pierce die. (*National Cash Register Co.*)

Tube-piercing Die. This die (Fig. 5-5) pierces tubing without inside support, such as a mandrel or horn. Spring-loaded upper and lower pads enclose and clamp the outside diameter of the work, before the opposed punches pierce the holes from the outside. This design results in slight depressions around the punched holes; countersunk or embossed (flanged) holes may be produced with suitable punches.

Sectional Slot and Pierce Die. A light-gage (0.0165-in.) aluminum cup is radially slotted and pierced to close tolerances in the die shown in Fig. 5-6. Seven closely



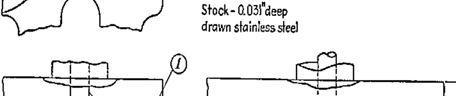


FIG. 5-7. Inverted pierce die. (*Harig Mfg. Corp.*)

spaced punches (*D3, D4, D5, D6*), four 0.089-in. diameter, one 0.169-in. diameter, one 0.1885-in. diameter, and one 0.4385-in. diameter, are well guided by the combination stripper plate and pressure pad. Pressure is applied to the plate by a spring through shedder pins. The piercing and slotting punches are backed up with a hardened steel plate.

Slotting punches and dies (*D1, D2*) are of sectional design to facilitate construction and sharpening.

Inverted Pierce Die. A stainless-steel (0.031-in. deep-drawing quality) drip pan is held on a spring-loaded horn (Fig. 5-7, *D3*) by flat springs. A spring-loaded shedder pin (*D2*) pushes the oval slug out of the inverted die (*D1*). There is some extrusion (flanging) around the oval hole.

Piercing Holes of Less Than Stock Thickness. Eight holes, somewhat closely spaced, whose diameters (0.125 and 0.093 in.) are less than stock thickness (0.156 in.) are punched in stainless steel in the die shown in Fig. 5-8. Intermeshing sleeved punches (*D1, D2, D3, D4*) ensure maximum rigidity and support for the entire length of each punch. A manual ejector (*D5*) is used.

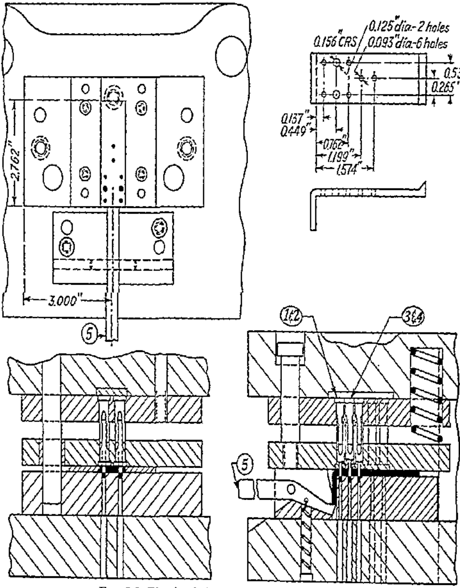


FIG. 5-8. Piercing holes of less than stock thickness.[1]

Side-piercing Cam-actuated Die. Horizontally operating cams are frequently used when the shut height of a press is limited or when it is necessary to pierce two or more holes whose center lines are not parallel. In the die shown in Fig. 5-9, three side ("dog-leg") cams (*D*1) transmit pressure to the side-piercing punches (*D*3). A single cam (*D*2) operates two opposed slides (*D*4, *D*5). These slides drive punches (*D*6) through pivoted arms (*D*7) shown in section *B-B*. The sliding punch-holder blocks actuated by the arms are returned to the open position by springs. The work is removed from the locating post by three stripping hooks (*D*8) attached to the upper shoe.

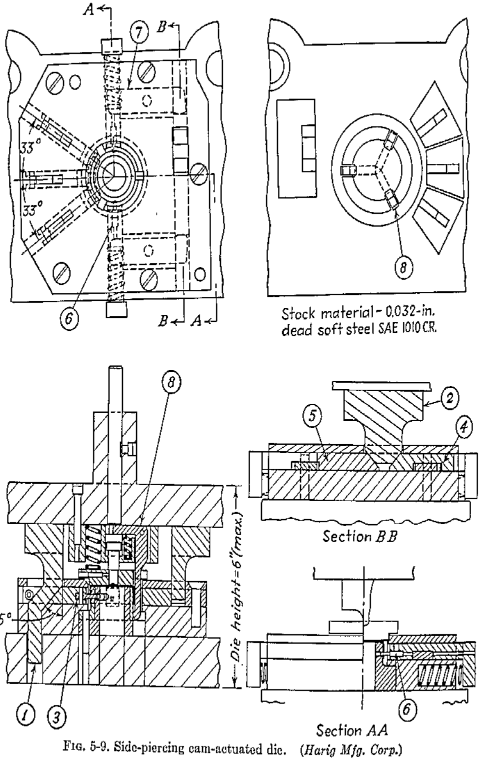


FIG. 5-9. Side-piercing cam-actuated die. (*Harig Mfg. Corp.*)

Combined Vertical and Side-piercing Die for Heavy Stock. Sliding punch blocks (Fig. 5-10, section *A-A*, *D*5), to which eight horizontal punches (*D*13) are mounted, are actuated by vertical cams (*D*2), which are backed up by heel blocks (*D*3). Hardened wear plates are provided for all wear surfaces of moving parts of the cam assemblies. The ball-lock punches are held by retainers (Fig. 5-10*A*, section *B-B*, *D*11, *D*12). The punches enter die buttons (Fig. 5-10, section *A-A*, *D*1) and cut four 0.406-in.-diameter holes in the flanges at each end of the part, an automotive-transmission support (Fig. 5-10*C*). Spring-loaded strippers (Fig. 5-10, section *A-A*, *D*4) strip the ends of the part from these punches. Three vertical punches (*D*9, *D*10) shown in section *C-C*, Fig. 5-10, cut oval holes in the middle of the part. A double pry-bar assembly (Fig. 5-10*B*, *D*7, *D*8) taken as a section through *D-D*, Fig. 5-10, raises the center part of the part out of the die as the operator pushes a handle (Fig. 5-10*B*, *D*6) downward.

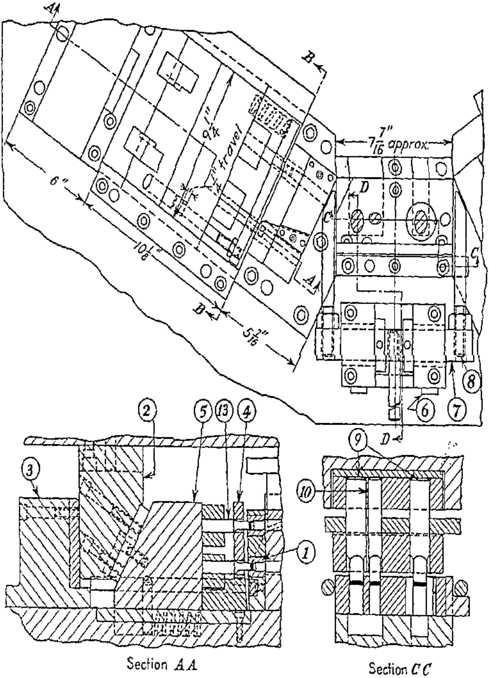


Fig. 5-10. Combined vertical and side-piercing die for heavy stock. (*Buick Division, General Motors Corp.*)

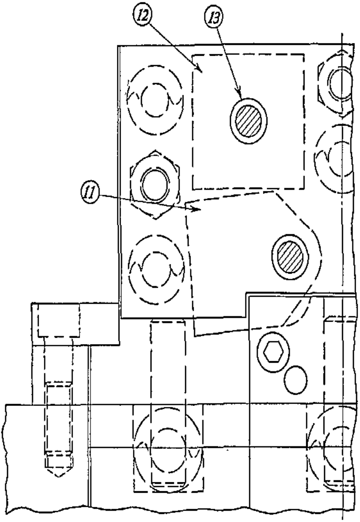


Fig. 5-10A. Section B-B showing punches and retainers.

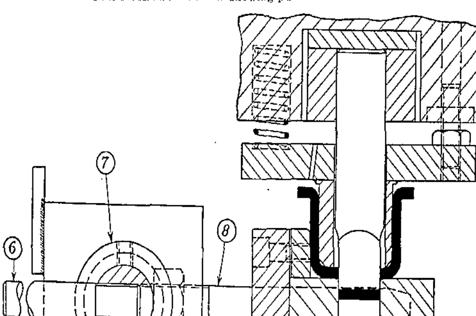


Fig. 5-10B. View showing ejector mechanism.

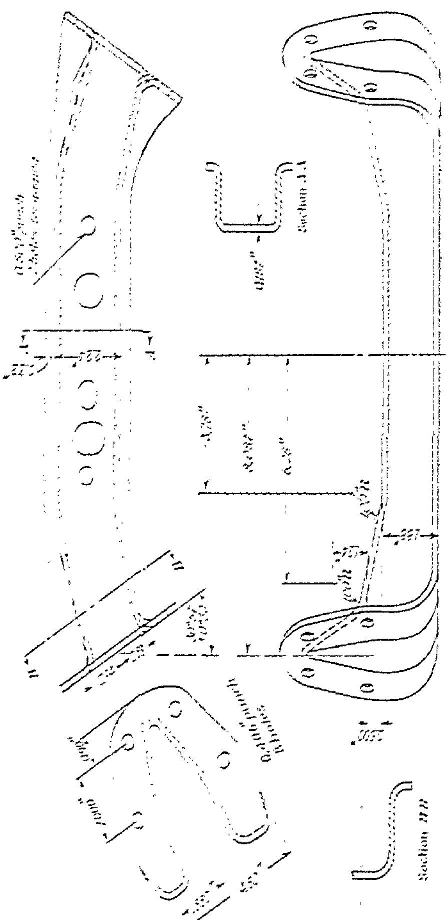


Fig. 5-10A. Automobile-transmission support part drawing for Fig. 5-10.

Cam Die for Perforating 1,080 Holes. Six holes of $1\frac{9}{32}$ in. diameter and 1,074 holes of $\frac{3}{16}$ in. diameter are pierced outwardly in a cylindrical tub by the die whose plan view is shown in Fig. 5-11. An indexing mechanism rotates and locates the tub so that a total of 180 holes are perforated every 60°. Two cam blocks (*D*12, Fig. 5-11*B*) carrying punch holders (*D*4), each equipped with 90 punches (*D*11), and strippers (*D*2), are located inside the tub. Two sliding die blocks (*D*5), actuated by right- and left-hand cams (*D*1), each carrying 90 die buttons (*D*6), slide inwardly. Six holes ($1\frac{9}{32}$ in. diameter) are embossed as well as pierced per complete revolution of the ball-bearing indexing and supporting table (*D*8) for the tub. A spring-loaded pad (*D*3, Fig. 5-11*B*) clamps the tub. Spring pins (Fig. 5-11*A*, *D*10) locate the tub to the index plate or table. Felt washers (*D*9) retain lubricant for the revolving indexing table. A heel block (*D*7, Fig. 5-11*B*) takes the side thrust of the right and left vertical cams. One automatic cycle of six press strokes per minute in a 300-ton Verson mechanical press pierces all 1,080 holes. Other views of the die blocks and punch plates are shown in Fig. 5-11*C*, section *A*-*A*. The part is the inner tub of an automatic washing machine.

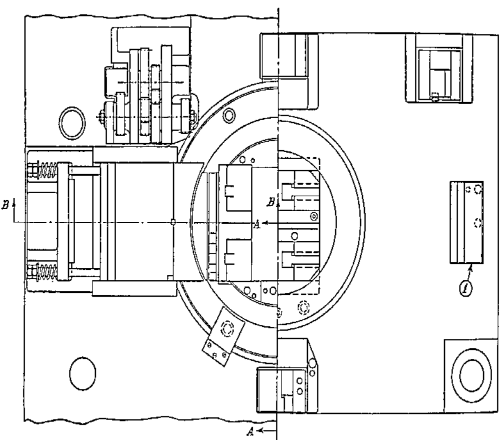
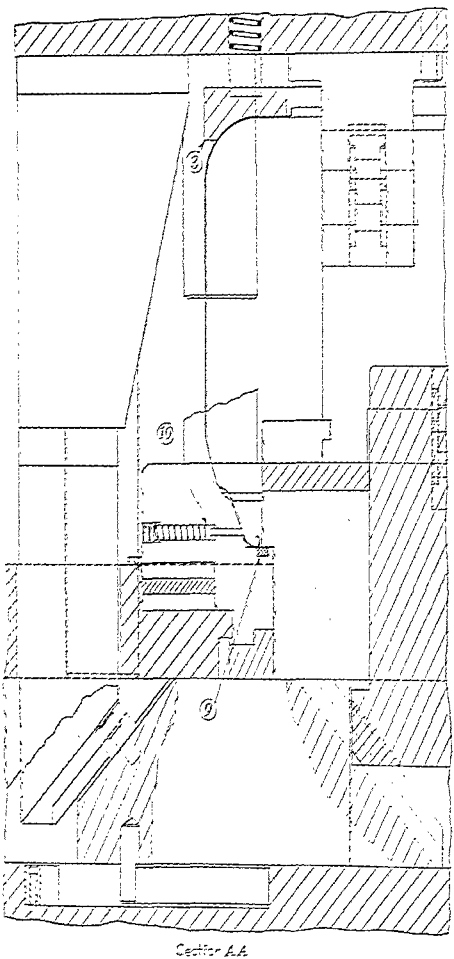


FIG. 5-11. Plan view of cam die for perforating 1,080 holes. (*Maytag Co.*)



Section AA

FIG. 5-11A. Section A-A of Fig. 5-11.

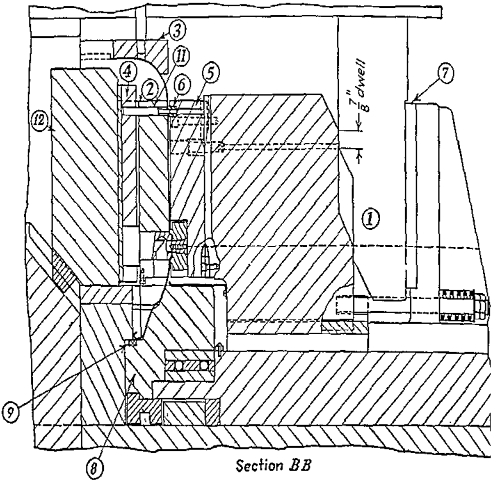


FIG. 5-11B. Section B-B of Fig. 5-11.

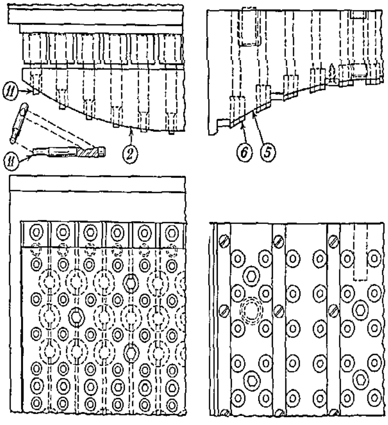


FIG. 5-11C. Punch-and-die blocks of cam die shown in Fig. 5-11.

Universal Holder for Piercing Single Holes. Punch diameters from $\frac{1}{16}$ to $\frac{5}{8}$ in. are incorporated in punch units (Fig. 5-12, *D5*). For details of these units see Fig. 18-31. Adjustable jaws (*D1*, *D2*, *D3*) clamp the work, and brackets (*D4*) support sheet or strip stock. The design is useful for short-run punching of various shapes (Fig. 5-12*A*). The illustration shows the jaws in various positions to locate the blanks on the die.

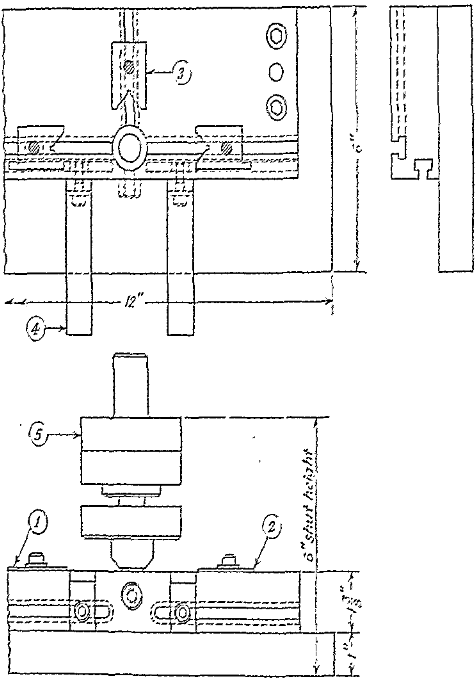
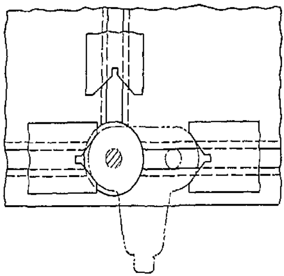
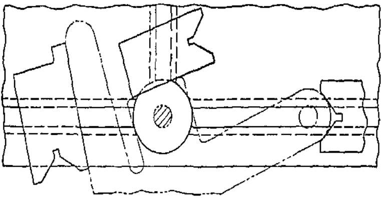


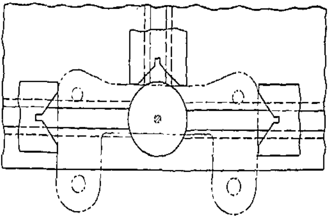
FIG. 5-12. Universal holder for piercing single holes. (*General Electric Co.*)



(A) Typical set-up to pierce (1) hole in irregular blank



(B) Typical set-up to pierce(1)hole in irregular blank



(C) Typical set-up to pierce (1) hole in irregular blank

Fig. 5-12A. Typical setups for piercing in universal holder of Fig. 5-12.

Inverted Universal Die for Piercing Multiple Holes. This die design (Fig. 5-13) incorporates a punch-holder plate (*D7*), held to a punch backing plate (*D15*) by eccentric pins (*D10*) contained in a clamp assembly (*D12*, *D13*). Inverted punches (*D5*), grooved around their bases, are secured in the countersunk holes in the punch-holder plate with a low-melting anchoring alloy (Cerromatrix). Spring pins (*D14*) passing through the lower shoe and the punch backing plate push the stripper plate (*D4*) upward, allowing the slugs to accumulate in the space *A*. A dovetailed slide (*D1*, *D2*, *D3*) is held to the upper shoe (*D9*) by retainers (*D6*). The die (*D8*) is bolted to the slide. The use of the slides and eccentric pins permits quick changes of punch and die setups. Gages are mounted on the stripper plate as shown in Fig. 5-13*B*. The details of some of the parts used in this die are shown in Fig. 5-13*A*.

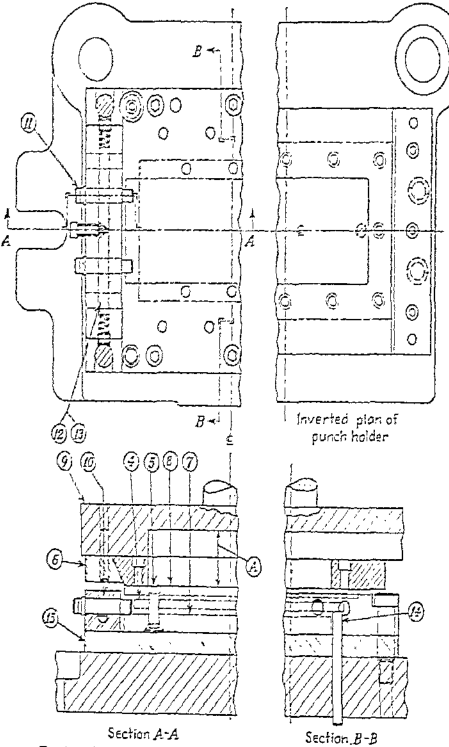


FIG. 5-13. Universal die for piercing multiple holes. (*General Electric Co.*)

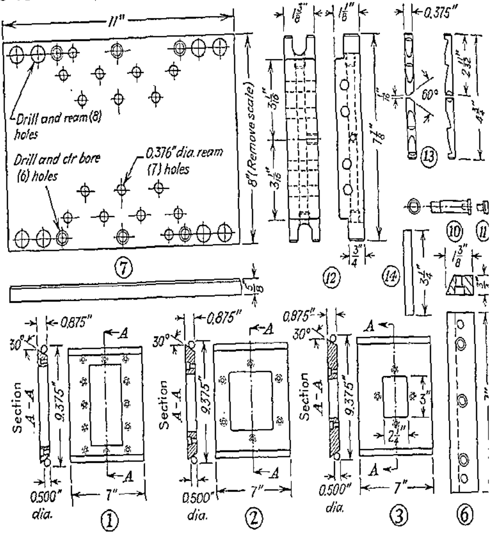


Fig. 5-13A. Details of die shown in Fig. 5-13.

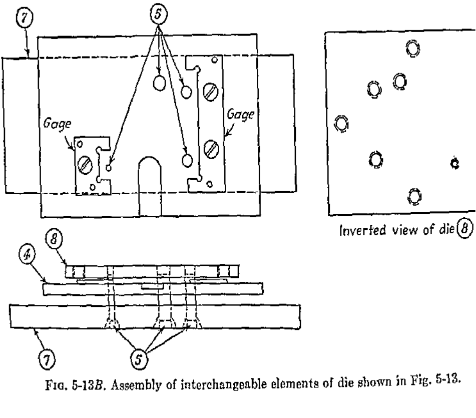


Fig. 5-13B. Assembly of interchangeable elements of die shown in Fig. 5-13.

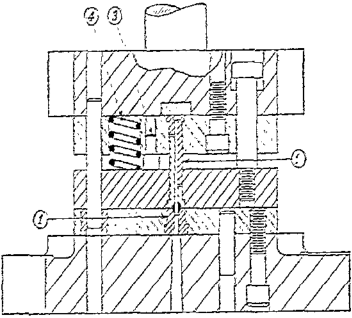


FIG. 5-14. Die for piercing round rod.[1]

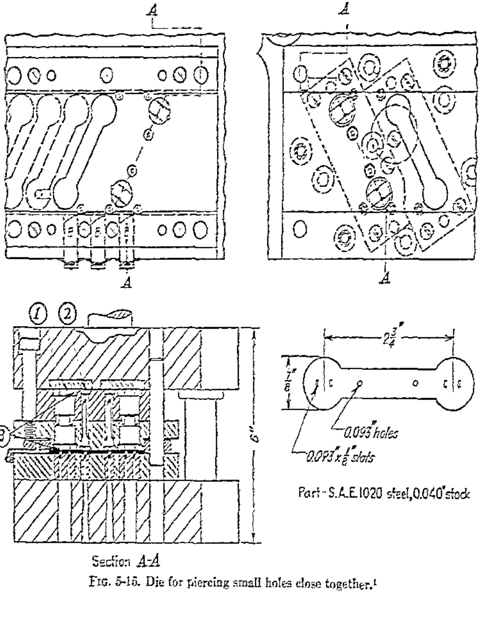
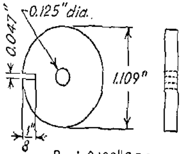


FIG. 5-15. Die for piercing small holes close together.[1]

Die for Piercing Round Cold-rolled-steel Rods. According to the designers of the die illustrated in Fig. 5-14, holes whose diameters are 40 per cent of the rod diameter can be punched with some slight bulging of the rod, provided that the center of the hole is not less than stock thickness (rod diameter) away from the end of the rod. Both the die button (*D*1) and the punch sleeve (*D*2) fit the outside of the rod. Two limit pins (*D*3) check punch overtravel, and heavy *stripper springs* (*D*4) *minimize* rod distortion. A 3/32-in. hole is pierced 3/16 in. from the end of 3/16-in. rod.

Die for Piercing Small Closely Spaced Holes. Conventional design of small individual punches for the cutting of the twin slots in the part (Fig. 5-15) would inevitably result in their frequent breakage. Both sets of piercing (*D*2) and slotting punches (*D*1) are inserted in upper and lower intermeshing sleeves. The twin slotting punches are contained in upper and lower halves made in three pieces and are assembled with a ring (*D*3) to keep them together.

Cutting Slots Narrower Than Stock Thickness. Buckling of the thin blade of the *sleeved punch* (*Fig. 5-16, D*1), *equipped with a heel, is prevented since it enters the die button before the slot is cut. The gage plate* (*D*2), 0.004 in. thinner than the workpiece, allows the stripper plate to clamp the work firmly, so as to prevent distortion of the part on both upstroke as well as downstroke. Punch travel is controlled by a limit stop pin (*D*3).



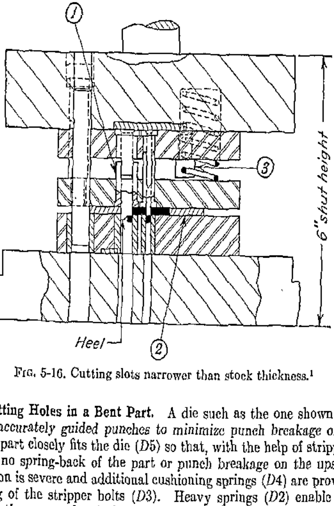


FIG. 5-16. Cutting slots narrower than stock thickness.[1]

Die for Cutting Holes in a Bent Part. A die such as the one shown in Fig. 5-17 *incorporates accurately guided punches to minimize punch breakage on the downstroke.* The part closely fits the die (*D*5) so that, with the help of stripper pressure, there will be no spring-back of the part or punch breakage on the upstroke. The stripping action is severe and additional cushioning springs (*D*4) are provided to prevent breaking of the stripper bolts (*D*3). Heavy springs (*D*2) enable the stripper (*D*1) to clamp the part to the die, but its pressure would be insufficient to stop spring-back if the part and die were not well mated.

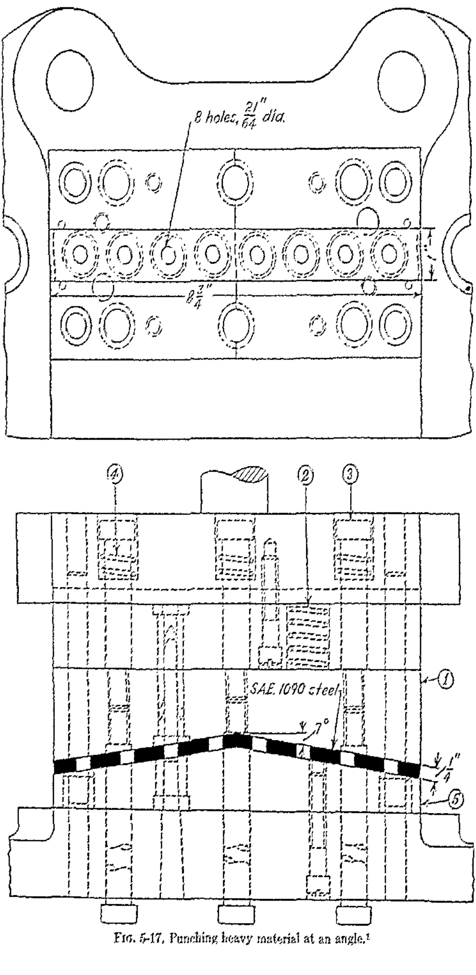


FIG. 5-17. Punching heavy material at an angle.[1]

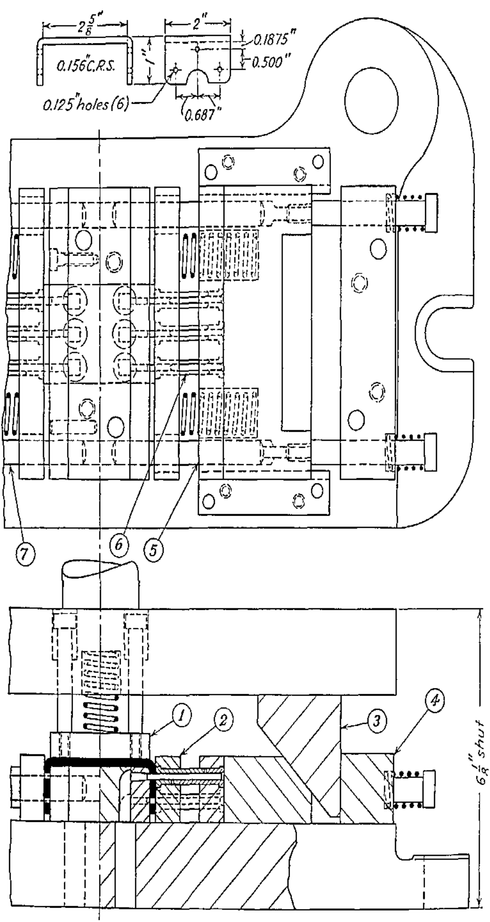


FIG. 5-18. Cam design with guided slides and sleeved punches.[1]

Cam Die Design for Accurate Punching. Precise alignment of holes in the workpiece (for shaft bearings) is ensured by the use of guide pins (Fig. 5-18, *D7*) as well as sleeved punches (*D6*). A spring-loaded pad (*D1*) clamps the work before the cams (*D3*) actuate the slides to which punch pads (*D5*) are fastened. Spring-loaded strippers (*D2*) strip the punches. The heel block (*D4*) minimizes side thrust of the cam.

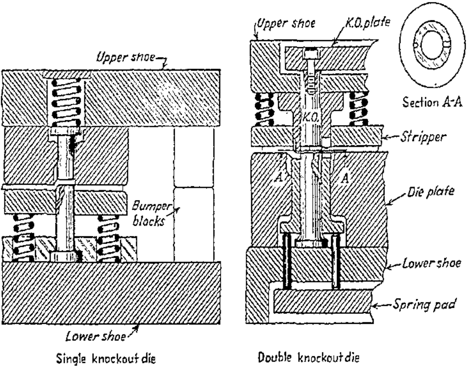


Fig. 5-19. Single and double knockout dies. (*General Electric Co.*)

MISCELLANEOUS SLOTTING, NOTCHING, AND CUTTING DIES

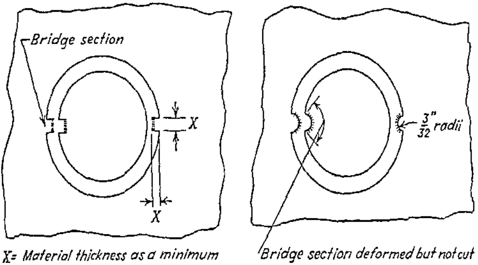
Knockout Dies. Typical single and double dies for producing knockouts in conduit boxes, enclosing boxes, and similar products are shown in Fig. 5-19.

Bumper blocks between the punch holder and die shoe (Fig. 5-19, single knockout die) limit the punch penetration to a predetermined depth. To ensure a clean cut around the knockout periphery without unduly straining the holding tabs, penetration is limited to the minimum depth that will allow daylight to be seen around the edge of the cut. This usually requires a minimum penetration of about two-thirds the material thickness or more.

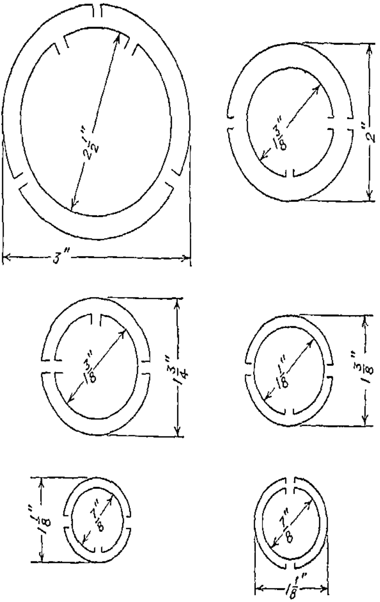
Knockout slugs should be readily removable from the outside of the box; so care should be exercised to see that the material is pierced from the proper side in view of subsequent operations. On single knockouts, the slug should be pushed toward the inside of the box. For double knockouts, the outer ring is pushed toward the outside of the box, while the center slug and the balance of the blank remain on the same plane.

Die clearance in knockout dies is generally reduced to one-half the customary clearance for pierce dies. Thus the clearance between punch and die is about 3 per cent of the material thickness per side when cutting medium rolled steel. A flattening operation is used to force the knockout slug or ring partially back into the material. This can be combined with subsequent forming operations or may be performed as an individual operation. In general, the slug or ring is forced back till it protrudes a maximum of one-half the material thickness for material $\frac{1}{32}$ in. thick and under, and a maximum of $\frac{1}{32}$ in. for heavier materials.

Holding tabs bridge the knockout slugs to the parent metal. Tabs are produced by providing matching grooves in the punch and die periphery which do not cut the material at these points. Figure 5-19*A*, upper view, shows two tab shapes commonly used. The straight tab is preferred, because it does not work the material so severely and



Common holding tab shapes. Square tabs preferred



Tabs for double knockouts

FIG. 5-19A. Tab shapes and sizes of knockouts commonly used. (*General Electric Co.*)

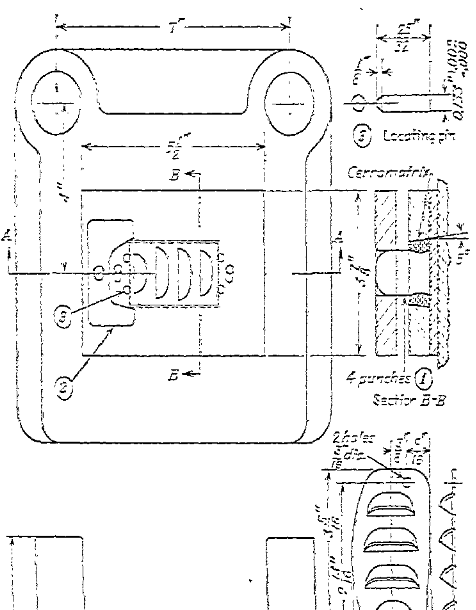


FIG. 5-20. Louvering die. (Century Electric Co.)

therefore can be made smaller. The width of the straight tab is made to a minimum of the material thickness.

Holding tabs for double knockouts must be so located that the inner slug can be removed without loosening the outer ring. In addition, more tabs are used in the larger sizes. Figure 5-19*A*, lower view, shows recommended location and number of straight tabs in double knockouts of various sizes. In the case of single knockouts it is customary to use one holding tab on diameters up to 1½ in., and two tabs on larger diameters.

For small-lot production, a knockout die may be used to cut different thicknesses of material, in which case specific rules are followed to establish die clearance and width

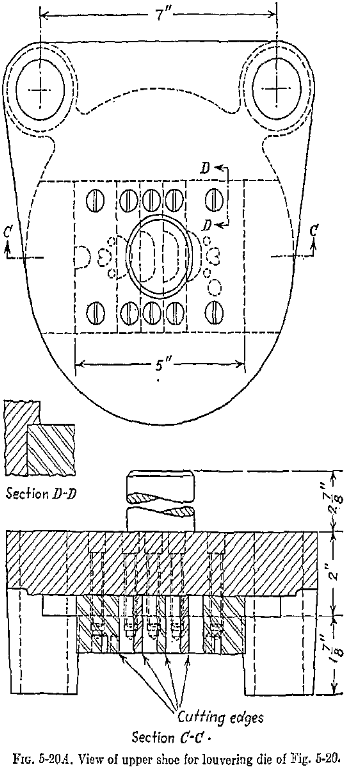


Fig. 5-20*A*. View of upper shoe for louvering die of Fig. 5-20.

of straight tabs. For example, a die made to cut materials from 1/16 to 1/8 in. thick will use the mean thickness of material cut to determine die clearance. For medium rolled steel, the clearance per side would be 3 per cent of the mean thickness, 3/32 in., or 0.0028 in. The width of a straight-type tab would be equal to the greatest material thickness to be cut, or 1/8 in.

Louvering Die. Strictly speaking, the die of Fig. 5-20 should be classified with dies in which cutting and noncutting operations are combined. It is included in this section, however, as illustrative of punch design for the shearing function in fabricating louvers. Four inverted punches (*D1*), secured with screws and a low-melting-point alloy, *are provided with a cutting or slitting edge as well as a forming surface. A nest* plate ("foolproof" plate, *D2*) and a locating pin (*D3*) position the workpiece. This die was made to form the same louver pattern in four different parts. One of the parts is an opposite hand to the one shown and the other two are a right- and left-hand pair with a blank of a different contour. The foolproof nesting plate is turned over and the locating pins, which are held in place by a setscrew, are moved to the opposite position to make the part of opposite hand. For producing the other two parts, a similar foolproof plate was made to match the contour of the part and is used in the same manner as described above.

Notching Die. In the die illustrated in Fig. 5-21, the workpiece is shifted by the handle (*D1*), allowing 10 slots to be punched at each position per stroke. Twenty slots each 0.018 in. wide could not be punched at one stroke, since 20 punches, 1/4 in. apart, center to center, could not be mounted in the punch block.

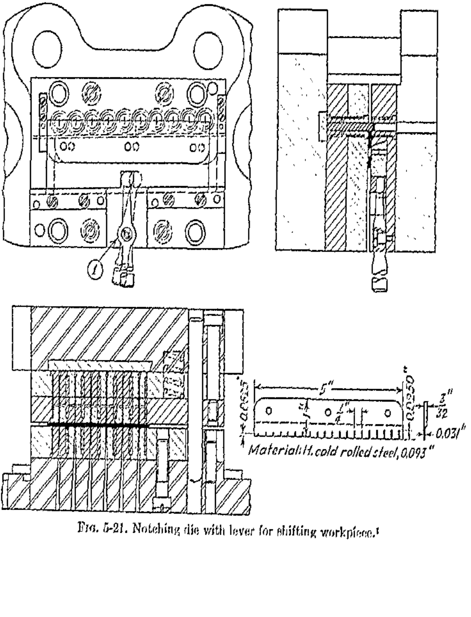


FIG. 5-21. Notching die with lever for shifting workpiece.[1]

Slotting Die. Bullet-nosed pins are located in bushings mounted on the die slide of the die shown in Fig. 5-22. Holes previously punched in the fan-blade stock, of eight different-sized blades, are engaged by the pins, so that slots of eight different lengths but of constant width are cut by the elongated nibbling punch. Setup time and tooling costs for eight conventional slotting dies are reduced by this die design. There are four bushings in the forward end of the slide plate, and five bushings in the rear end, to receive the removable locating pins. Two pins are placed in the proper set of holes to position the blank for notching.

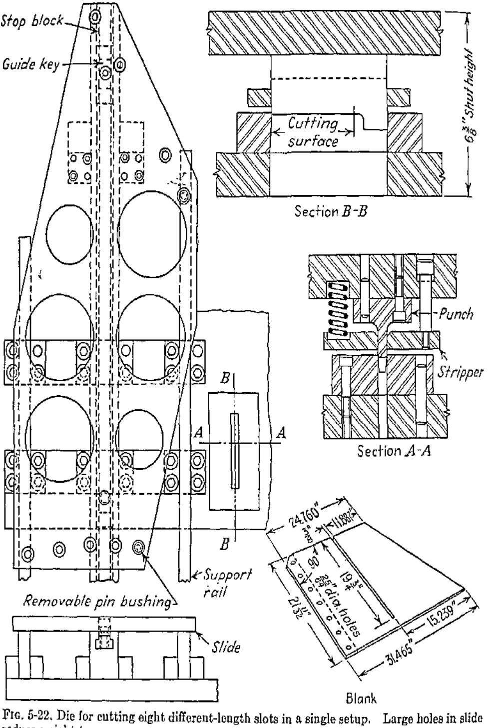


FIG. 5-22. Die for cutting eight different-length slots in a single setup. Large holes in slide reduce weight.[4]

Tube-slotting Die. Two slots (19/32 in. long by 0.143 ± 0.003 in. wide) are cut in the die shown in Fig. 5-23, to a slot alignment of 0.005 in. in SAE 1137 steel tubing. Positive-return cams actuate slide blocks, which are provided with clamp inserts to hold the workpiece. The work is revolved after the first slot is cut until the locator pin enters the slot, thus aligning the tubing for punching the second slot by the hollow-ground punch. Turning the key depresses the locating pin and allows part removal.

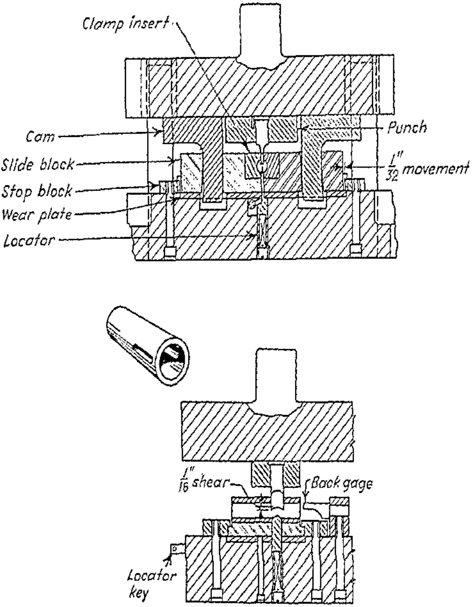
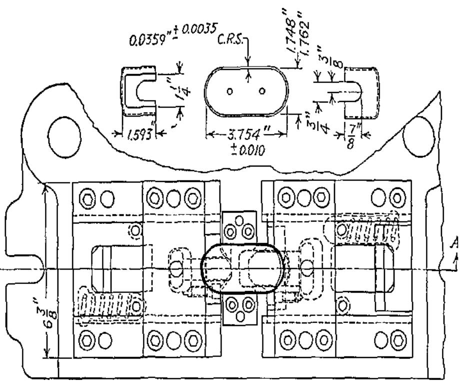
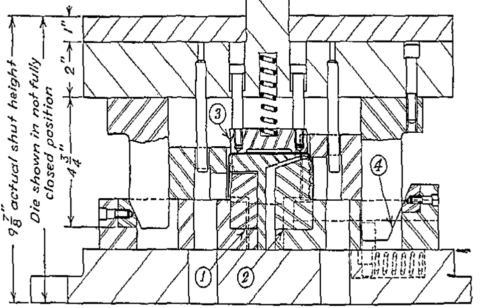


Fig. 5-23. Tube-slotting die.[5]

Notching Die. Two dissimilar notches are cut out of the ends of a box-shaped part in the die shown in Fig. 5-24. Cams (*D4*) actuate internal sliding punches (*D1*, *D2*) on the opposite ends of the die, which leave the burrs on the outside of the part and also drive the slugs outwardly to openings in the die block and die shoe. Heavy die-section design ensures long life. Parts are clamped in the die by a spring-loaded pad (*D3*). Production is 500 parts per hour in a No. 4 Niagara press.



Plan of die



Section A-A
Die shown with one end cut through only

Fig. 5-24. Notching die. (*White-Rodgers Electric Co.*)

HORN-TYPE CUTTING DIES

Horn Die for Slotting Tubes. A horn (mandrel) may support a tube or shell (Fi| 5-25*A*) during the die-cutting operation. Two notches are cut in shell or tube en(with this die. The part is slipped over the locating plug, the upper edge entering slot cut into the punch. On the ram descent, both notches are cut. The lower sl drops through the die; the upper slug is raised flush with the locating plug and is blow off. The free end of the work is supported by a rest pad.

Indexing Horn Die for Slotting. Another type of horn die (Fig. 5-25*B*) notches or slot at a time. The part is placed over the horn and located by a pilot entering a ho previously pierced in the flange of the part. A hardened block is set into the horn and does the cutting in conjunction with the heeled punch. The part is then pulled back and rotated so that the pilot enters the next locating hole.

Horn-type Die for Piercing Shells. Two opposed holes are accurately located by the use of a sliding locating pin in this die design (Fig. 5-25C). With the sliding plate (on which the pin is mounted) pushed to the right, the shell is placed over the horn. After the first hole is pierced, the shell is rotated and the slide is moved left to a stop pin. With the locating pin engaged in the first pierced hole, the press is again tripped to pierce the second hole. This is inexpensive construction for dies of this type.

Horn-type Piercing Die for Shallow Shells. A die for this purpose (Fig. 5-25D) incorporates a horn secured to an angle block. A flat on the bottom of the horn provides slug relief.

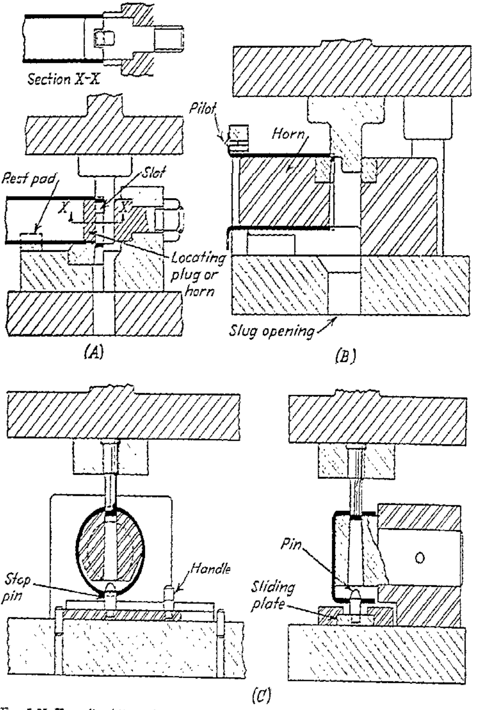


FIG. 5-25. Horn dies (A) cutting two opposed notches in one stroke with only one punch; (B) notching in relation to hole in flange; (C) with movable gage pin to locate second hole.[47]

Horn-type Piercing Die for Large Shells. The die design shown in Fig. 5-25*E* permits the piercing of shells larger in diameter than the maximum opening between ram and bolster plate by incorporating a horn which overhangs the bolster plate. The eccentric punch is well guided for close alignment with the die button in the horn.

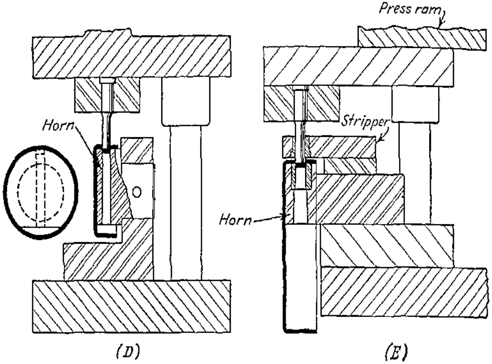


FIG. 5-25 (*Continued*). Horn dies (*D*) for small-diameter shells; (*E*) part overhangs bolster plate to accommodate large shells.[6,7]

Die for Punching Opposite Holes in a Shell or Tube in One Stroke. This operation (Fig. 5-26*A*) is done by using the slug from the upper hole as the punch for the lower hole. Fracture will be fairly clean, but there will be a burr on the lower side of the part. A spring stripper contacts the work first, causing the spring-supported horn to

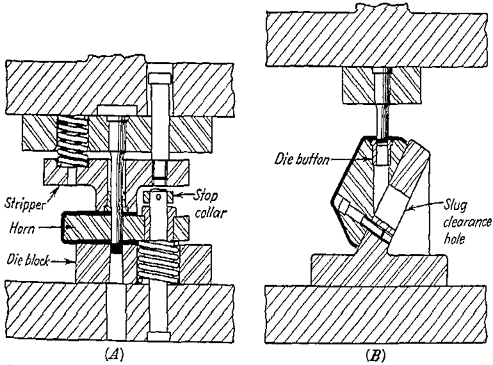
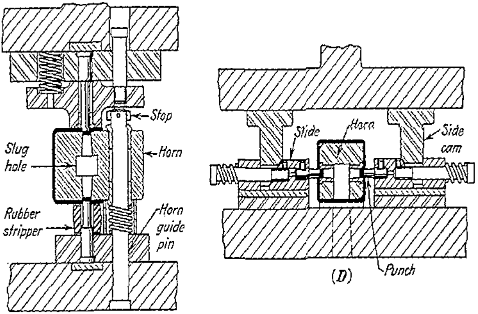


FIG. 5-26. Horn dies (*A*) piercing opposite holes in shell with one punch in one press stroke; (*B*) piercing irregularly shaped shells.[7]

bottom on the die block. Further ram descent results in piercing of the upper and lower holes. A spring raises the horn to the loading position as the ram ascends.

Die for Piercing Irregular Shells. A horn on the die shown in Fig. 5-26*B* is mounted on an angle plate or bracket so that punch travel is at a right angle to the surface to be punched. Cast iron can be used for the bracket if light piercing is involved; cast steel is used for shells of thick cross section. A weldment is not recommended, since it may not withstand repeated shock.

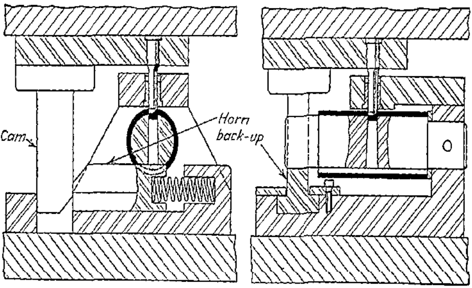


(*C*)

FIG. 5-26 (*Continued*). Horn dies (*C*) with floating horn and (*D*) cam-actuated die.[7]

Die for Punching Internally Burred Opposing Holes in Shells. A spring-loaded horn is provided with a stop to limit horn travel upward on its guide pin in the design shown in Fig. 5-26*C*. Punches located in both punch holder and die holder are stripped, respectively, by a conventional spring-loaded stripper and a rubber stripper.

Horizontal Cam-actuated Horn Die. A die incorporating horizontal cam-actuated punches (Fig. 5-26*D*) is useful when shut height is limited. The horn is bored out for



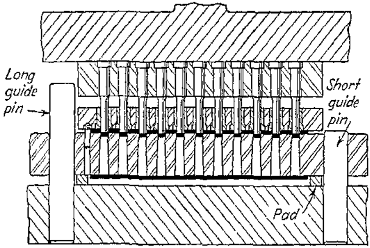
(*E*)

FIG. 5-26 (*Continued*). Horn dies with backup block to support horn.[7]

slug drop-out. When the ram ascends punch slides are retracted by rods under spring tension.

Horn-die Design for Heavy Pressures. In this design (Fig. 5-26E) a spring-loaded backup block is used to overcome any misalignment due to the overhanging horn and severe pressures. On the ram ascent, the backup block returns to the idle position for removal of the work. The punch is guided in a solid stripper to further ensure alignment.

Horn Die for Long Parts. A swinging horn is engaged by a short guide pin after the long workpiece is slid on the horn in the die shown in Fig. 5-26F. The part is loaded by raising the horn until it clears the short guide pin, then swinging it to one side. In the piercing position the horn is supported by solid pads. The long guide pin could be equipped with a spring and a limit stop at its upper end for ease of part insertion and removal.



(F)

FIG. 5-26 (*Continued*). Horn die for long parts.[7]

Die Design for Incorporating Entire Cam Mechanism in the Punch Holder. A spring-loaded cam plate, in a die of this type (Fig. 5-27), descends ahead of the punch holder to clamp the workpiece first. Piercing action begins when the cam blocks strike the heads on the punches. Each punch is spring-retracted for stripping.

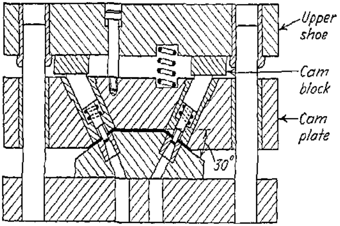


FIG. 5-27. Cam-piercing die design for movable cams integral with punch holder. (*Design Service Co.*)

Lever-actuated Piercing Die. This die (Fig. 5-28) is similar to a conventional cam die in that the vertical movement of the punch holder (*D2*) actuates slides (*D3*), carrying horizontal punches (*D4*) by means of levers (*D1*) and slots in camlike members (*D5*), which are backed up by heel blocks (*D6*). The ejector mechanism's operating lever (*D8*) is provided with an idle time slot, so that ejection is not accomplished until all punches are retracted.

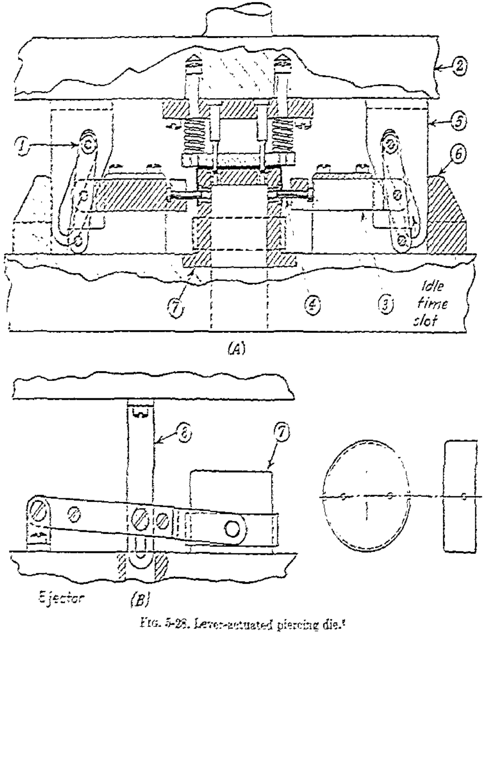


Fig. 5-28. Lever-actuated piercing die.[1]

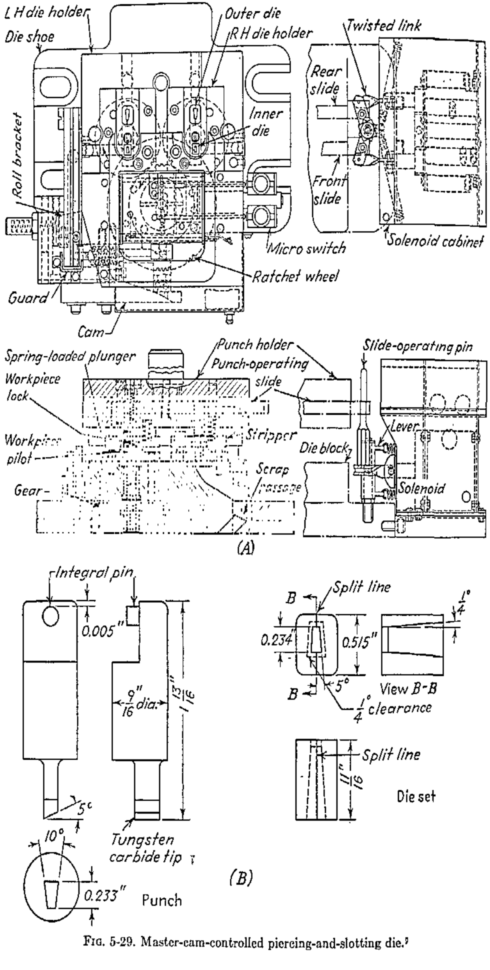


FIG. 5-29. Master-cam-controlled piercing-and-slotting die.[9]

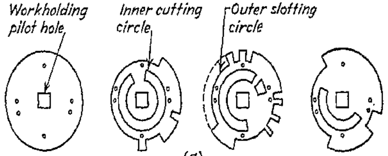
Master-cam-controlled Piercing and Slotting Die. Precut blanks (2 in. diameter) of phosphor bronze 0.020 in. thick (Fig. 5-29*C*) are radially pierced and slotted in the die illustrated in Fig. 5-29. Three of the many possible combinations of slots in a finished part (a telephone-exchange contact cam) are shown in the same figure. The square hole accommodates a workholding pilot.

The punch and die, which can cut a minimum arc of 10° in the inner cutting circle, are shown in Fig. 5-29*B*. Punches and dies for slotting the blank's periphery are of similar design.

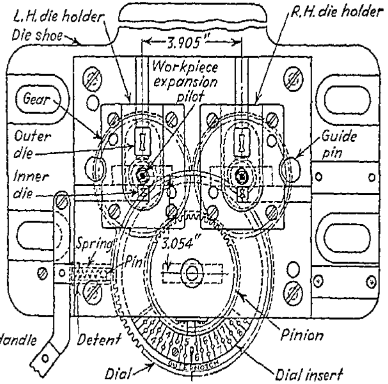
Since the workholding pilots are indexed for each 5° of rotation, any angular slot from 10 to 355° can be cut in the inner and outer cutting circles. The number of possible combinations of slots of various size in both cutting circles is more than a million.

A replaceable revolving master cam located in the lower part of the die set rotates both workholding pilots (in both right- and left-hand die sets). The master cam actuates solenoids (through switches) which govern the movement of punch-operating slides. The punches are shifted by the slides into cutting positions as determined by the master cam. Two identical telephone-switch cams are produced per stroke. The switches could be connected to solenoids of a series of dies to operate simultaneously in a bank of presses.

The die shown in Fig. 5-29*D* punches out the master cams and is hand-indexed by the dial plate and by manual positioning of the punches.



(*C*)



(*D*)

FIG. 5-29 (*Continued*). Blank, typical finished parts, and die for punching master cams.

BLANKING DIES

Single-station Blanking Dies. Blanking heavy (0.75 in. thick) cold-rolled-steel stock 1$\frac{3}{8}$ in. long around part of its perimeter reduces scrap but necessitates the use of a heel block (Fig. 5-30, *D*1). A spring-loaded plunger (*D*2) clamps the stock against the heel block. The punch holder (*D*3) is machined to fit the punch blade (*D*4) to which it is welded. Blanking pressure is reduced by grinding shear equal to one-third stock thickness on the die only. Since the finished blanks fall through the die, this die design can be classified as a drop-through die.

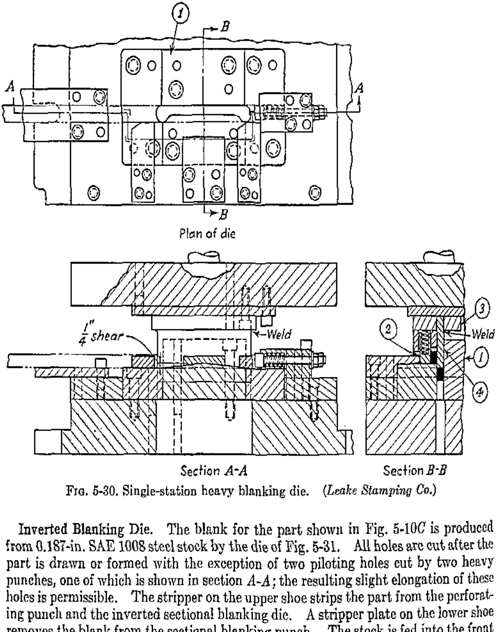


Fig. 5-30. Single-station heavy blanking die. (*Leake Stamping Co.*)

Inverted Blanking Die. The blank for the part shown in Fig. 5-10*C* is produced from 0.187-in. SAE 1008 steel stock by the die of Fig. 5-31. All holes are cut after the part is drawn or formed with the exception of two piloting holes cut by two heavy punches, one of which is shown in section *A-A*; the resulting slight elongation of these holes is permissible. The stripper on the upper shoe strips the part from the perforating punch and the inverted sectional blanking die. A stripper plate on the lower shoe removes the blank from the sectional blanking punch. The stock is fed into the front of the die where it is positioned from left to right by guide strips and front to back by the spring-loaded stop pins shown in section *B-B*. The scrap skeleton is chopped by two scrap cutters whose construction is shown in section *C-C*.

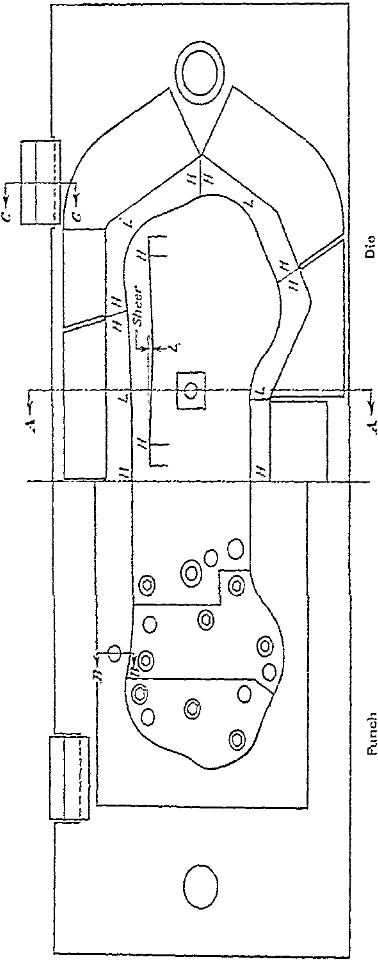
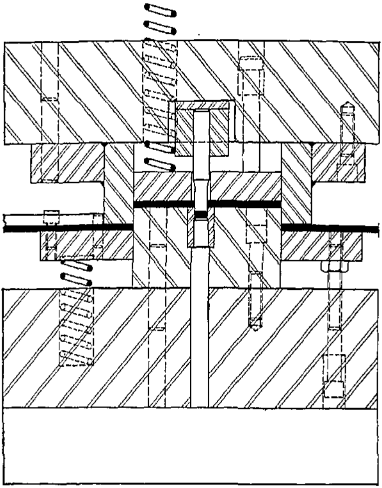
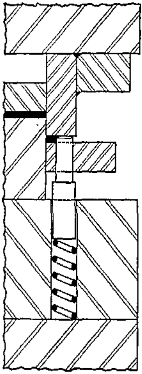


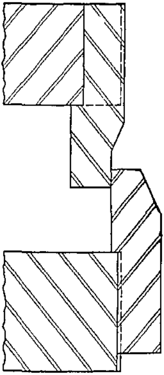
Fig. 5-31. Inverted blanking die. (Buick Division, General Motors Corp.)



Section A-A



Section B-B



Section C-C

FIG. 5-31A. Die-sections detail of die of Fig. 5-31.

Dinking Dies. Cutting rules and dinking dies are used principally for the blanking of fibrous and other nonmetallic materials, though some users have reported economical blanking of aluminum alloy stock up to 0.040 in. thick. Costs of dinking-die operations compared with conventional tools are listed in Table 5-1. Typical dinking-die construction is shown in Fig. 5-32.

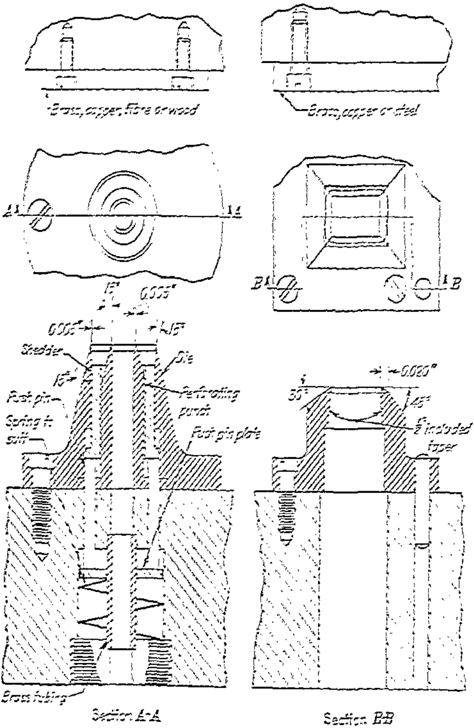


FIG. 5-32. Dinking dies: (Left) Dies for felt, cardboard, cork, and other materials of similar composition; (right) dies for phenol fiber, phenolized canvas, and hard rubber. When blanking phenol fiber over ½ in. thick, allow $\frac{1}{16}$ in. on each side to be shaved.

TABLE 5-1. COMPARATIVE PRODUCTION COSTS PER PART, DINKING DIES VS. OTHER TOOLS AND METHODS[10]

Production	Dinking die	Standard tools		Routing	Press plate	Blanking die
		3 setups	6 setups			
100 parts, 20 by 26 in.	$1.08	$0.96	$1.19	$1.21	$3.10	$6.38
500 parts, 12 by 15 in.	0.16	0.20	0.29	0.31	0.43	0.90
2,500 parts, 5 by 5 in.	0.05	0.08	0.12	0.13	0.08	0.12

Hand- or Press-operated Washer Die. Inside circular blades (*D*1) and outside circular blades (*D*2) held by setscrews (*D*3, *D*4) can be unscrewed and replaced by blades of different diameters in the die shown in Fig. 5-33. A pin (*D*5) is actuated by the press knockout rod when this dinking die is press-operated. Hand operation is achieved by an initial hammer blow to cut out the washer or disk and a second blow on the pin for knockout action. For either operation, some resilient stock may have to be hand-stripped from the circular blades.

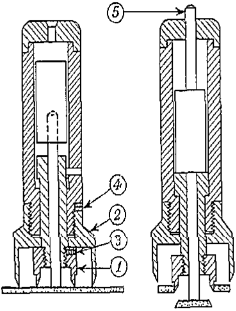


FIG. 5-33. Hand- or press-operated washer die.[17]

Die for Blanking Lead Foil. This die, similar to a dinking die, shown in Fig. 5-34, consists of a hardened-steel die and a rubber punch. The thickness of the rubber is critical; it should not exceed ½ in. for clean cutting of the blank (3 in. OD; 1 in. ID, 0.005 in. thick).

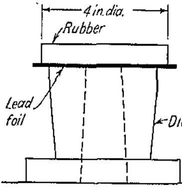


FIG. 5-34. Die for blanking lead foil.[11]

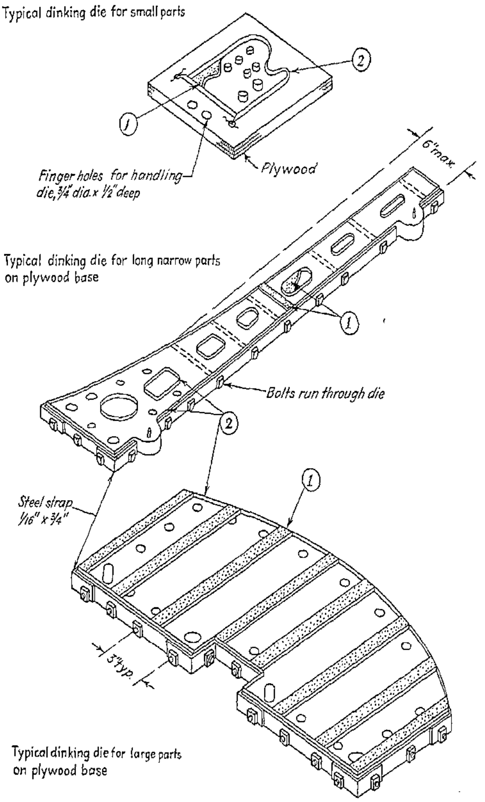
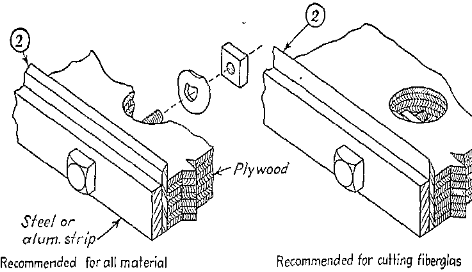


FIG. 5-35. Cutting-rule dinking die.[18]



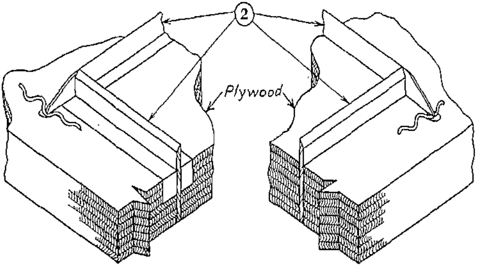


Fig. 5-35A. Enlarged details of cutting-rule die.[18]

Dinking Dies Using Steel Cutting Rule. Steel cutting rule (*D*2), obtainable from printers' supply houses, is used for the cutting blades of the dies of Fig. 5-35. Rule is furnished 0.937 ± 0.0005 in. wide and thickness desired is ordered by points:

Points	Thickness, in.	Points	Thickness, in.
1	0.014	6	0.083
1½	0.021	8	0.112
2	0.028	10	0.140
3	0.042	12	0.166
4	0.056		

Rules having a center bevel are recommended for cutting soft metals. Stripper material (*D*1) is 3/16-in. Neoprene cork sheet; die plate is ¾-in. hard plywood. Rules must be at 90° ± ¼° to surface of die plate and should be hardened to a range of Rockwell C57 to 61. The die plate should rest on a heavy flat ground surface plate.

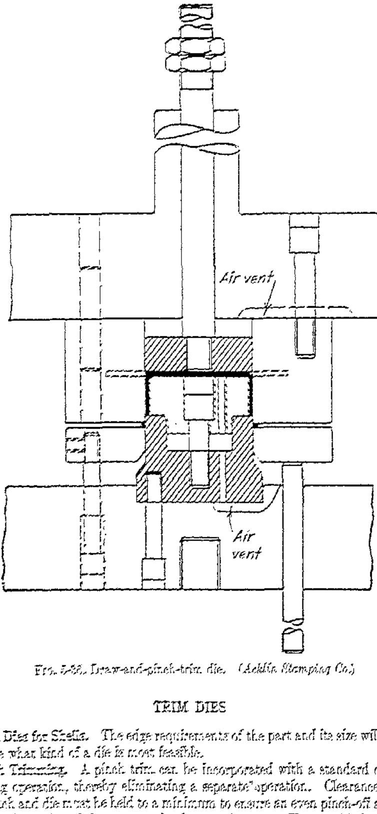


Fig. 5-36. Draw-and-pinch-trim die. *(Acklin Stamping Co.)*

TRIM DIES

Trim Dies for Shells. The edge requirements of the part and its size will generally indicate what kind of a die is most feasible.

Pinch Trimming. A pinch trim can be incorporated with a standard drawing or redrawing operation, thereby eliminating a separate operation. Clearances between the punch and die must be held to a minimum to ensure an even pinch-off and to prevent the formation of sharp or rough edges on the part. Figure 5-36 shows a die in which drawing and pinch trimming are combined. Pinch trimming may also be done in a push-through die (Fig. 5-37). In this type of die the sharp cutting edge of the punch trims the shell flange against the radius on the die opening, where there is some ironing action. The shell is pushed entirely through the die.

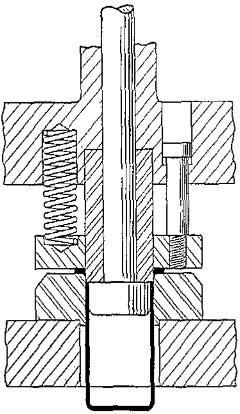


Fig. 5-37. Push-through pinch-trim die.[6]

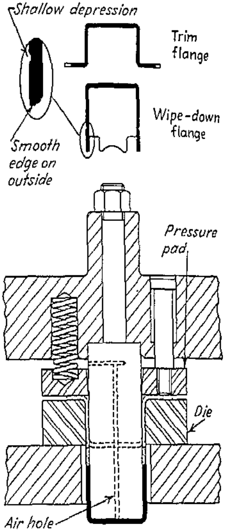
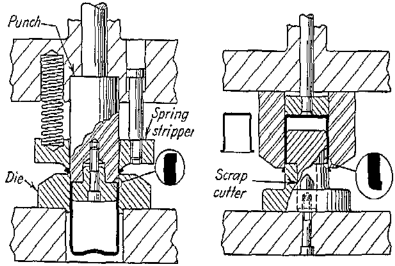


Fig. 5-38. Wipe-down trim die.[5]

Wipe-down Trimming. This type of trimming, more commonly known as a trim and wipe-off operation, allows a previously drawn part to be produced with a trimmed edge normal (at 90°) to the center line of the part. There is a tendency for this operation to leave a wipe-off line or shallow depression on the outside of the part. The finished edge will be identical with the original edge of the flange. A wipe-down and



(A) Die for long shells (B) Die for average shells

Fig. 5-39. Flush-trim dies for shells.[6]

trim die is shown in Fig. 5-32. The shell is pushed through the die and is stripped by the edges of the lower side of the die.

Flush Trimming. This type of trimming leaves a slight projection on the outside rim of the shell (due to clearance), a condition often desirable. Flush-trim dies for long shells and shells of average length are shown in Fig. 5-39. Shells to be flush-trimmed are drawn with a small flange.

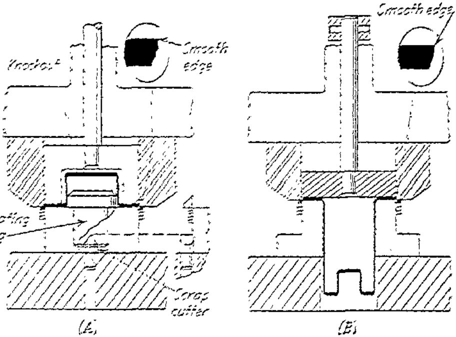


Fig. 5-40. Inverted dies for trimming flanges.[3]

Burr-location Considerations in Flange-trimming-die Design. The desired location of burrs on a flanged shell may alone determine the type of die design, since burr location and direction are important in many assemblies.

Inverted Dies for Trimming Flanges. The inverted die (Fig. 5-40A) trims the inverted shell and leaves the burr on the top of the flange. Scrap cutters at the base of the punch split the scrap ring. Another inverted die, shown at B, receives the shell in the upright position, but the burr is left on the underside of the flange. Scrap cutters (not shown) are provided.

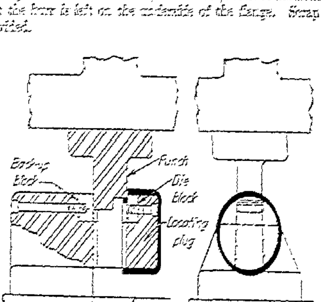


Fig. 5-41. Horn-type die for square trimming of shells.[3]

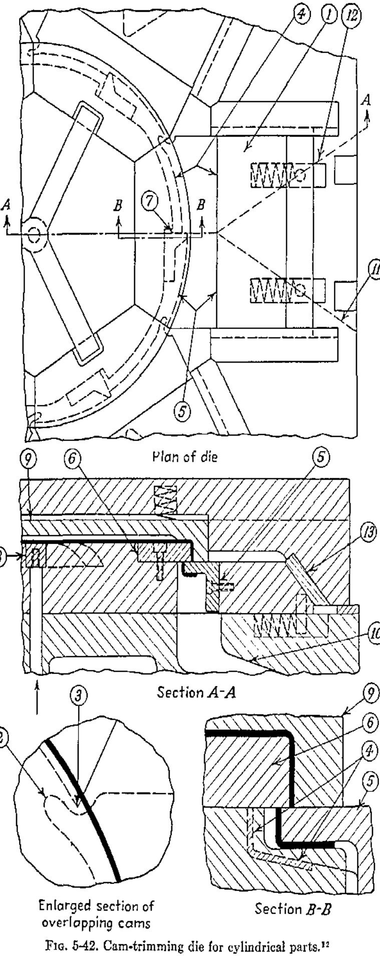


Fig. 5-42. Cam-trimming die for cylindrical parts.[12]

Horn-type Die for Square Trimming of Shells. This design (Fig. 5-41) can be classified as a notching die, since only a segment of the shell is cut at one press stroke. The shell is rotated on the horn after the punch trims a peripheral section. This die design is suitable for low-production requirements.

Cam Trimming a Continuous Flange. A die design for this operation (Fig. 5-42) includes six cams (*D*1, *D*4) provided with trim punches (*D*5). A hooklike extension (*D*2) allows overlapping of adjoining trim punches. The ring or collar of scrap cutoff is split into six segments by six scrap cutters (*D*7, *D*4). There is considerable distortion of the scrap, but not of the part, which is clamped securely by a spring-loaded stripper (*D*3). The part is cut between the two sharp edges of the cutting or trim punches (*D*5, *D*6). The part is lifted by a spider-shaped lifter harness (*D*8), operated by an air cylinder properly synchronized with the upstroke of the ram. The part is manually or mechanically pulled or pushed off the lifter before the end of the upstroke. The mechanism for such part removal is not shown. The vertical cam is fitted with a wear plate (*D*13). The six scrap segments slide down six radiating cored passages (*D*10), whose walls are indicated by the lines *D*11 and *D*12.

Combined Vertical and Horizontal Trimming. A partially flanged part is trimmed on three sides (Fig. 5-43, at *D*1, *D*2, *D*3) by direct (vertical) action, and on the fourth side (*D*4) by the outside cammed steel (*D*5) and the inside steel (*D*6). The latter is backed up by the shoulder in the die shoe (*D*7). The design incorporates three scrap cutters (*D*8, *D*9, *D*10), two gage plates (*D*11, *D*12), and a spring-loaded cam stripper (*D*13), which locate the part. The cam casting (*D*15) is guided and held down by hardened steel gibs (*D*16), and its back travel is limited by a stop block (*D*14). The ample initial contact area between the vertical driver cam *D*17 and the cam casting prevents rapid wear of the wear plate.

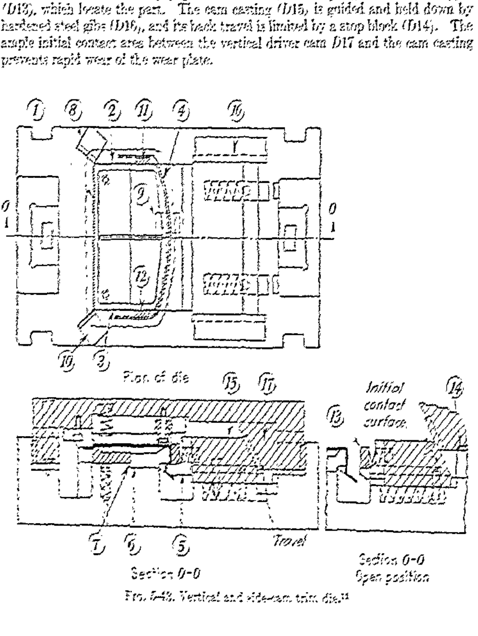


FIG. 5-43. Vertical and side-cam trim die.[11]

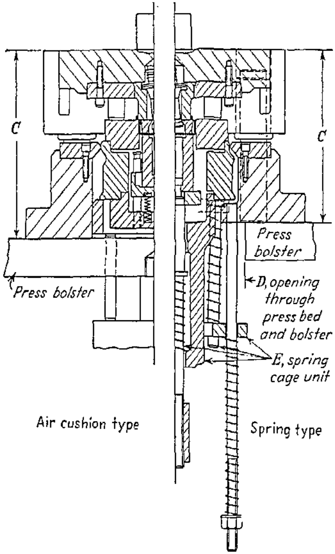


FIG. 5-44. Shimmy (Brehm) trim die.[13]

Shimmy (Brehm Trimming) Die. A die design in which the lower floating die moves from right to left and front to back to trim or notch shallow or deep shells and boxes may be of two types, air cushion or spring (Fig. 5-44). Dies for trimming parts of over 10 in. (largest dimension across the trimmed edge) should be of the air-cushion type, which requires no opening through the center of bolster, requires less setup time, and has greater shut height *C*, compared with the spring type. Increased shell height does not affect the shut die height of the spring type, and trimmed parts can be ejected higher than by the cushion type. Quality of production is the same in either die.

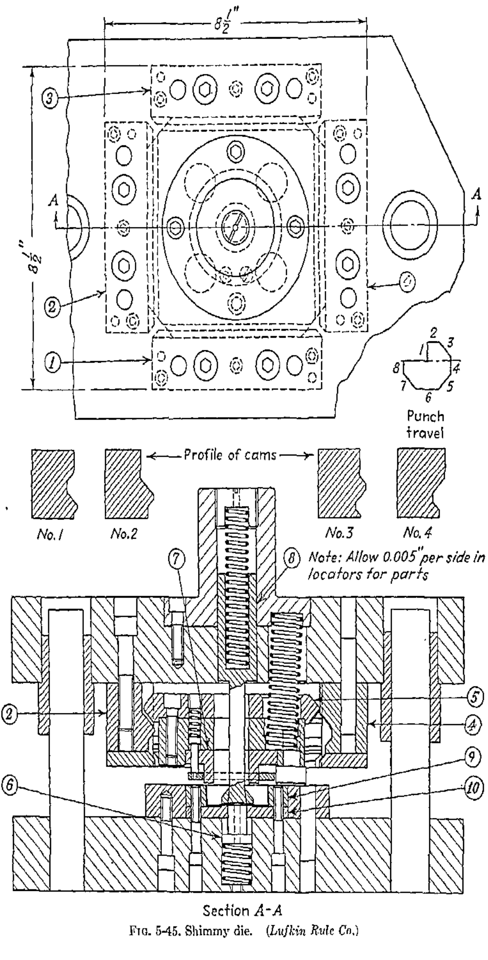


FIG. 5-45. Shimmy die. (*Lufkin Rule Co.*)

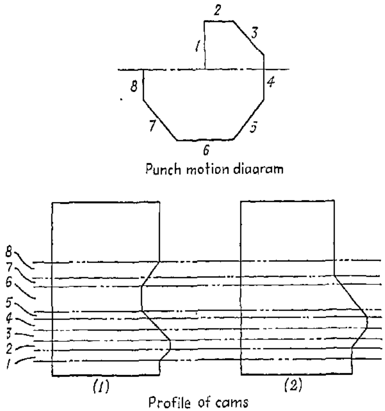


FIG. 5-45A. Profile of the cams in the die of Fig. 5-45.

Shimmy Die. A cup of 0.025-in.-thick stock is set in a holder (Fig. 5-45, *D9*, *D10*) to which it is clamped by spring-loaded plungers (*D6*, *D8*) and is trimmed along its top from the inside by a horizontally moving punch (*D7*). During a 3-in. press stroke the angular surfaces of the cams (*D1*, *D2*, *D3*, *D4*) move downward to contact the outside surface of the cam follower (*D5*), to which the punch is attached. Horizontal movements of the punch result only from angular contacts between the follower and the four cams; vertical contacts produce no motion. There are eight horizontal punch movements which complete the trimming: the initial movement, actuated by cam *D1*, starting at the center of the punch-travel diagram (Fig. 5-45*A*) is directly backward; numbered consecutively the remaining movements are: (2) to the right, actuated by cam *D2*; (3) to the right and front by cams *D2* and *D3*; (4) to the front by cam *D3*; (5) to the front and left, by cams *D3* and *D4*; (6) to the left, by cam *D4*; (7) to the left and backward, by cams *D4* and *D1*; (8) to the back by cam *D1*. Numbered spaces (Fig. 5-45*A*) between the lines drawn on the cam profiles are the cam surfaces which generate the correspondingly numbered punch movements.

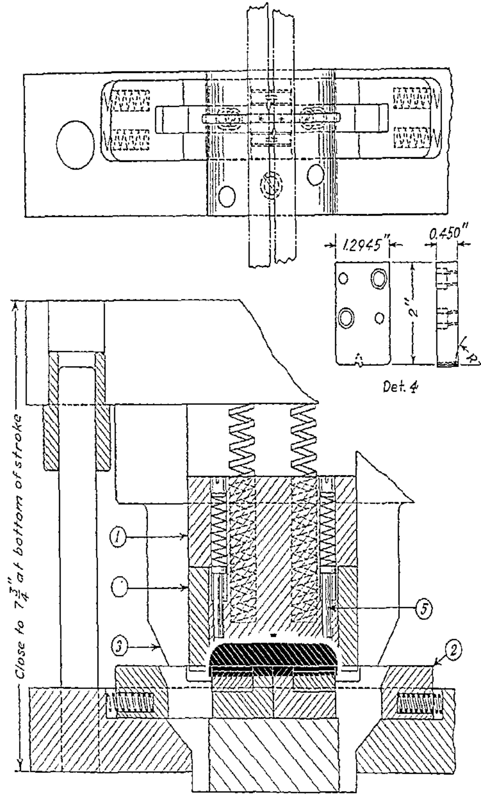


Fig. 5-46. Cam-trim die for rings. (*National Blank Book Co.*)

Die for Trimming Rings. A cam-actuated trim die (Fig. 5-46) incorporates a spring pad (*D*1) to clamp the workpiece (a ringed plate of a loose-leaf blank book) and trims the overhanging ring between the cam-actuated cutter slides *D*2 (which are forced outward) and the upper cutters (*D*4). The cutter slides are moved by cams (*D*3) on opposite sides of the die. Spring-loaded pins (*D*5) prevent the part from adhering to the upper die member.

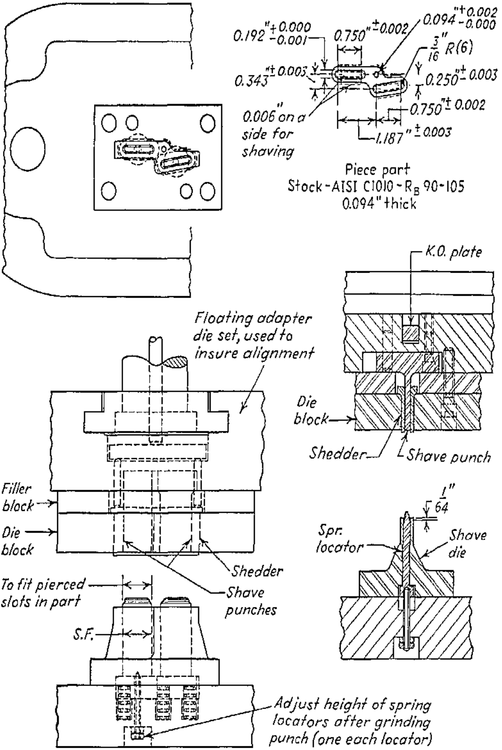


FIG. 5-47. Die for shaving slots. (*International Business Machines Corp.*)

SHAVING DIES

Die for Shaving Slots. Approximately 10,000 parts (0.094 in. thick, SAE 1010 steel) per grind are shaved 0.006 in. to a 64-microinch finish in the die shown in Fig. 5-47. Simultaneous and equal shaving of the slots and the outside of the part opposite, with no distortion, is ensured by the use of adjustable spring locators. The part remains in the die block until a positive knockout pin ejects it at the top of the stroke, thereby preventing the spring locators from pushing the shavings back into the part. The part and the chips are simultaneously blown off the die. Maximum accuracy and straightness of holes are secured when the burr side of the hole is toward the punch, so that the shaved chip becomes smaller as the punch progresses.

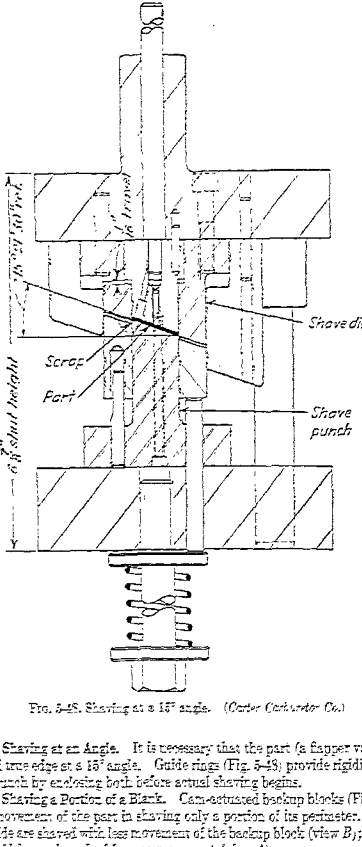


FIG. 5-48. Shaving at a 15° angle. (*Carter Carburetor Co.*)

Die for Shaving at an Angle. It is necessary that the part (a flapper valve) have a sharp and true edge at a 15° angle. Guide rings (Fig. 5-48) provide rigidity for shave die and punch by enclosing both before actual shaving begins.

Die for Shaving a Portion of a Blank. Cam-actuated backup blocks (Fig. 5-49, *D1*) prevent movement of the part in shaving only a portion of its perimeter. Parts uniformly wide are shaved with less movement of the backup block (view *B*); those which vary in width are shaved with more movement (view *A*).

Die for Shaving Small Gears. Leveling studs (Fig. 5-50, *D1*) contact the face of the die (*D2*), resulting in uniform and accurate contact with the work, a small gear (*D3*). An enlarged view of the shedder pin (*D4*) is shown. The punch (*D6*) is counterbored for the gear hub. Stripper pins (*D7*) actuate a stripper plate (*D5*).

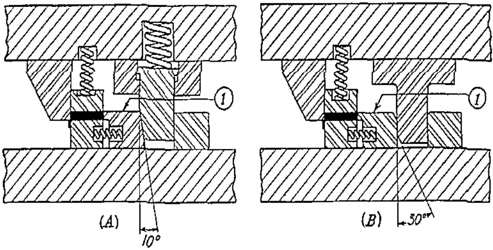


Fig. 5-49. Dies for shaving a portion of a blank.[14]

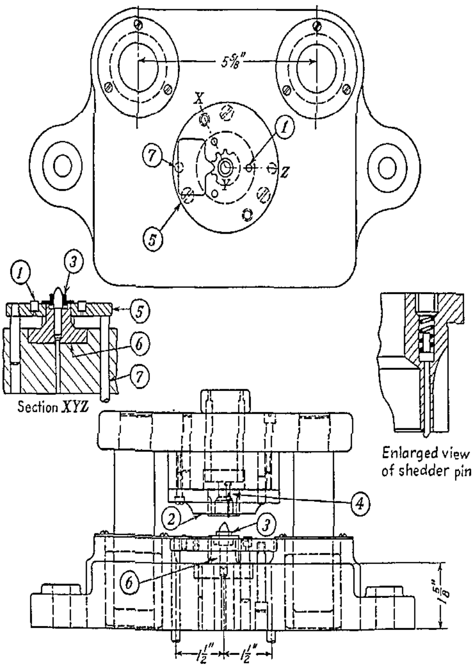


Fig. 5-50. Shaving die for small gears.[3]

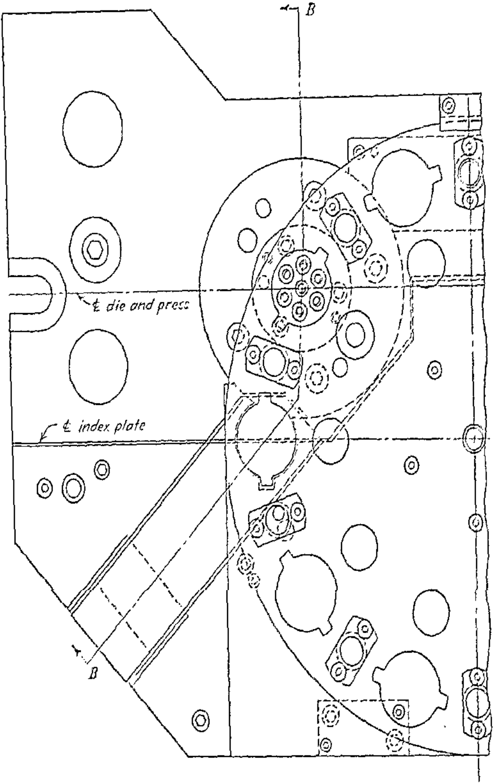


FIG. 5-51. Plan view of die for shaving multiple holes at an angle. *(Oldsmobile Division, General Motors Corp.)*

Die for Shaving Holes at an Angle. The shaving die shown in Fig. 5-51 is designed to shave 12 holes angularly in a 0.278-in.-thick steel disk circumferentially. A 10-station dial feed is incorporated so that six holes may be shaved at a time in each of 2 of the 10 stations (the remaining 8 stations are idle). The six well-lubricated sliding punches and the oil reservoir are shown in Fig. 5-51*A*. The spring-loaded pilot and microswitch assembly prevent operation of the press if the disk is not located properly.

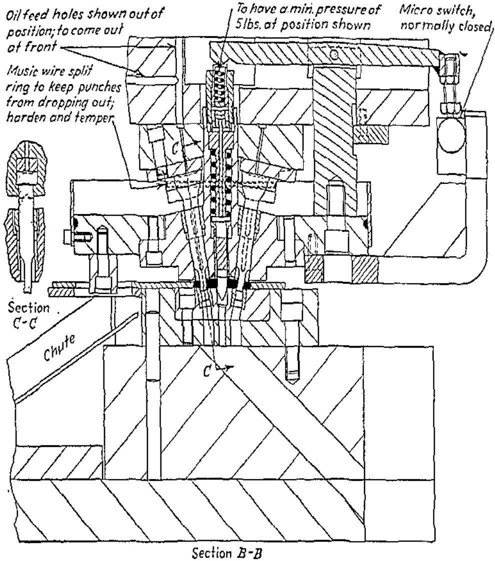


FIG. 5-51A. Section B-B of die shown in Fig. 5-51.

CUTOFF DIES

Cutoff Die for Tubing. A sliding block (Fig. 5-52, *D2*) is actuated by a cam (*D3*) to clamp the work (0.035-in. cold-rolled-steel tubing) before the punch blade descends. The shape and thickness of the blade (*D1*) as well as the contour of the clamping surfaces determine the amount of possible dimpling or distortion of the work.

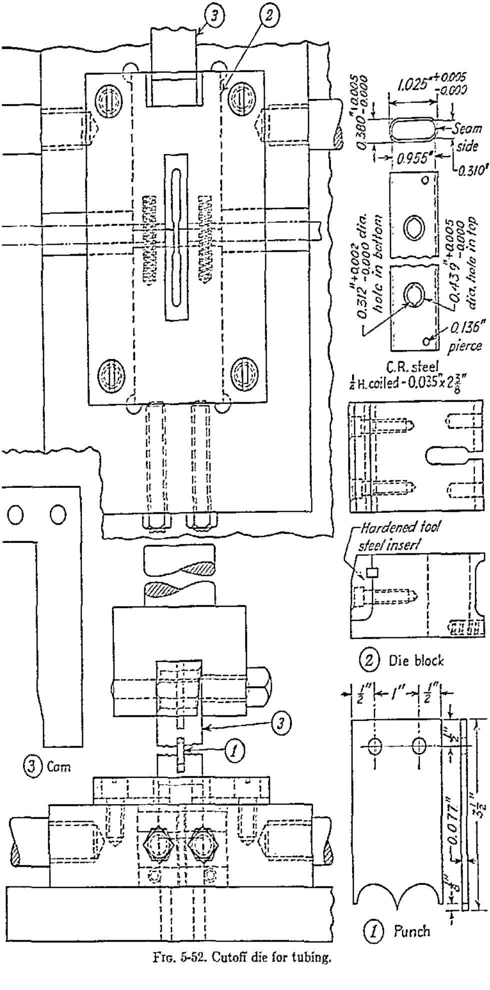


Fig. 5-52. Cutoff die for tubing.

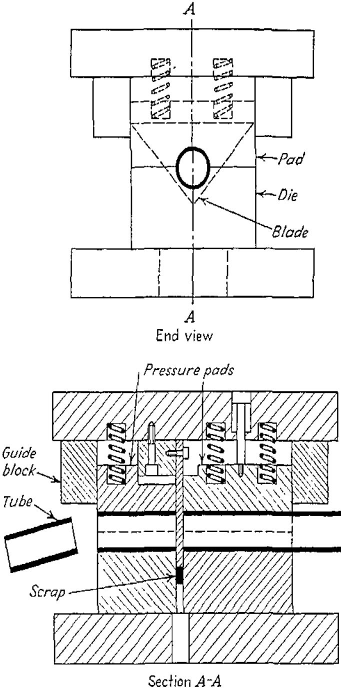


FIG. 5-53. Triangular-blade cutoff die.[15]

Triangular-blade Cutoff Die. Spring-loaded pressure pads closely fit the outside of the tubing and clamp it before the blade descends in the die illustrated in Fig. 5-53. The point of the blade leaves a small indentation at the top of the tubing. The ring slug drops through the die, requiring no scrap cutter.

Cutoff Die for Square Tubing. The die design of Fig. 5-54 incorporates a thin punch with the contour shown. Square tubing is confined and clamped by a spring-loaded pad. The pointed end of the lancing punch pierces the top of the tubing and progressively shears the sides and bottom of the tube as the punch descends. The careful fitting of the punch in the slot ensures the success of this die.

Slug and Shearing Dies. A type of cutoff die, commonly known as a parting or slug die (Fig. 5-55, view *A*), completely trims the outline of both sides or ends of the blank, producing the burr on the same side of the part at both edges. In contrast, the no-scrap shear dies shown at *B* and *C* will produce burr on opposite sides or ends

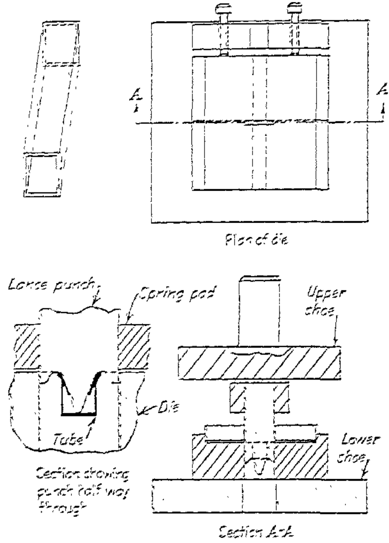


FIG. 5-64. Cutoff die for square tubing. (General Electric Co.)

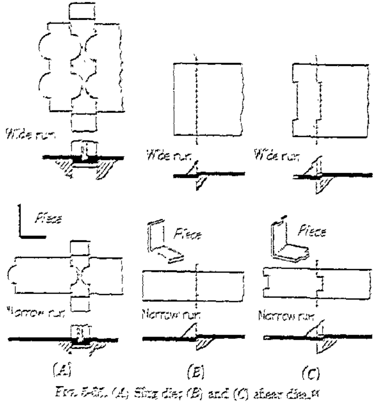


FIG. 5-65. (A) Slug dies; (B) and (C) shear dies.

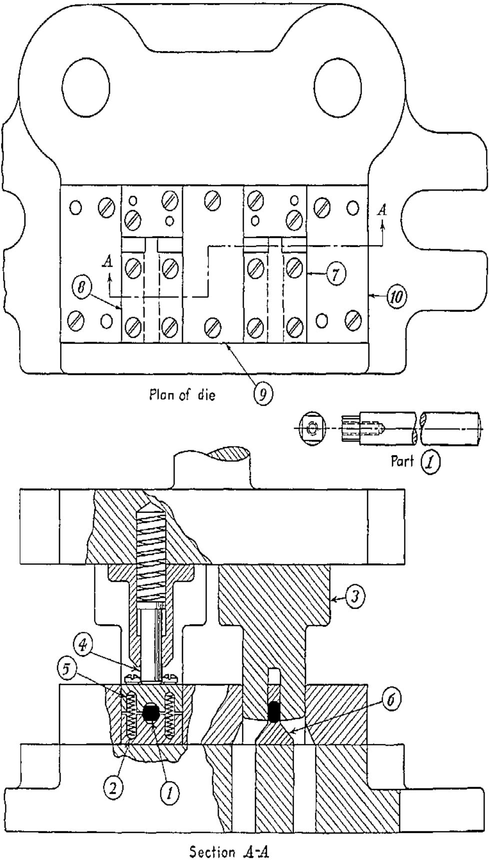


FIG. 5-56. Trimming flats on a round shaft.[8]

of a given part. Wide-run shearing will reduce handling of material strips. But, where parts are to be bent in a subsequent operation, strips are run the narrow way so that the bends will be across the grain.

BROACHING DIES

Die for Trimming Square Ends on a Shaft. A square section is broached on the end of a round bar in two operations in the die illustrated in Fig. 5-56. A heeled punch (*D3*) broaches the first pair of flats in the right-hand nest (*D6*). The part is removed, turned 90°, and inserted by hand in the left-hand nest (*D5*) for the second broaching operation. Springs (*D2*) hold the nests open until the upper nest is forced down by the pin (*D4*) to clamp the work in place. The second operation cannot be done until the first is completed, because of the shape of the nests.

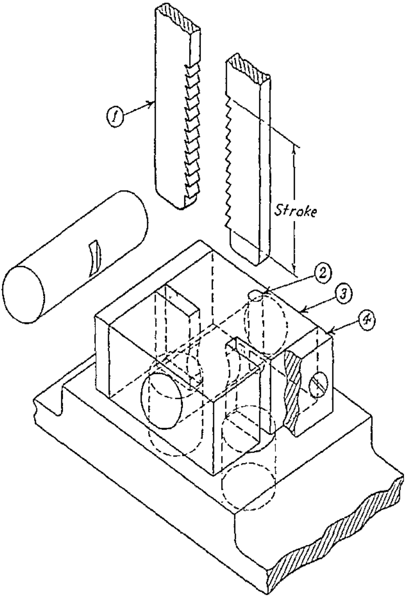


FIG. 5-57. Broaching slots in a round shaft. (*O. H. Mathisen, ASTE.*)

Die for Broaching Slots in a Round Shaft. Toothed broaching blades of high-speed steel (Fig. 5-57, *D1*) cut opposed slots in round rod. The chip is approximately 0.003 in. per tooth. A stop pin (*D2*), a workholder (*D3*), and broaching-blade heel blocks (*D4*) are incorporated.

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SECTION 6

BENDING OF METALS*

Definition and Terminology. Bending is the uniform straining of material, usually flat sheet or strip metal, around a straight axis which lies in the neutral plane and normal to the lengthwise direction of the sheet or strip. Metal flow takes place within the plastic range of the metal, so that the bend retains a permanent set after removal of the applied stress. The inner surface of a bend is in compression; the outer surface is in tension. A pure bending action does not reproduce the exact shape of the punch and die in the metal; such a reproduction is one of forming.

Terms used in bending are defined and illustrated in Fig. 6-1. The neutral axis is the plane area in bent metal where all strains are zero.

Strain Distribution. Circumferential strain on the convex side of a bend is considerably larger and on the concave side almost identical, respectively, to strains calculated from elementary theory, according to Sachs. This explains the decrease in metal thickness with increasing curvature (Fig. 6-2).

Circumferential strains are dependent upon the bend angle (Figs. 6-3 and 6-4). Values in these two graphs are expressed in the so-called natural strain ϵ, not the conventional strain e, which is the absolute change in unit length.

The natural strain ϵ is expressed as follows:

$$\epsilon = \log_e (L - e) \qquad (1)$$

where L = length of bend, in.

The transverse distribution of circumferential strain is shown in Fig. 6-5, which explains the familiar trapezoidal section (Fig. 6-1, section A-A) of a bent strip or bar. The transverse strain is zero if the bend length is sufficiently long. The test piece was in various widths of ½-in. 24ST aluminum. The strain is plotted on the graphs with respect to the center line of each specimen.

The distribution of transverse strains and circumferential strains (ϵ_2 and ϵ_1), as affected by various bend lengths in ½-in.-thick 24ST aluminum, is shown in Fig. 6-6, where the ratios of bend lengths to the stock thickness (L/T) are, respectively, 1, 2, 4, and 8.

Longer bend lengths of a given metal strip of a given thickness are less ductile than the same metal strip of shorter bend lengths (narrow parts), as shown in Fig. 6-7.

BEND RADII

Minimum bend radii vary for the various metals; generally, most annealed metals can be bent to a radius R equal to the thickness t and sometimes to $R = t/2$, for a given angle and bend length. R/t is constant for most metals, but this ratio increases for some aluminum alloys (Fig. 6-8).

The die designer will have to consider suitable gaging, nesting, and piloting methods if narrow parts are to be bent because of the change in cross section at the center of the bend.

* Reviewed by O. D. Lascoe, Department of Manufacturing Processes, Purdue University, and Dr. George Sachs, Director, Metallurgical Research Laboratories, Syracuse University.

The minimum bend radius is affected by bend length (Fig. 6-9); the minimum bend radius is nearly constant when the bend radius is eight or more times the metal thickness.

The minimum bend radius that can be formed in most metals is dependent on the maximum smoothness of the edges, even for very strong metals (Fig. 6-10). Edge

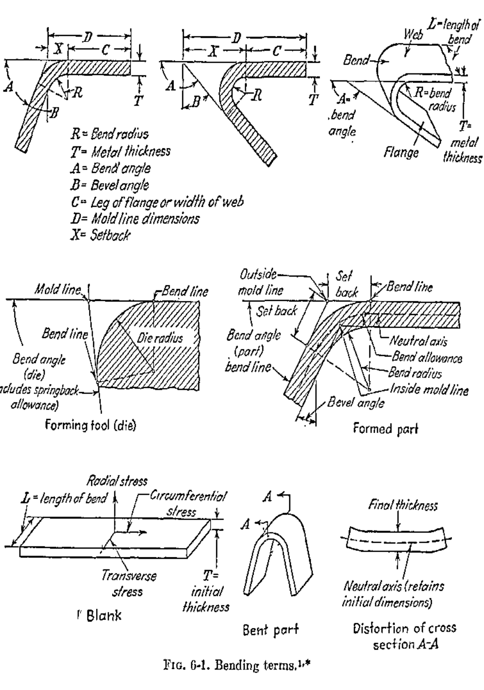


Fig. 6-1. Bending terms.[1,*]

conditions are more pronounced in very short bends in thick metal than for relatively long bends.

Blanking Angle. Directionality in sheet or strip metal limits the magnitude of the bend radius. Blanking angles (the angle between the bend axis and the direction of rolling) as specified by one manufacturer for some metals are listed in Fig. 6-11. Such an angle can govern the orientation of all die elements with respect to the direction of feeding; a blanking angle of 90° allows most but not all metals to be bent to the smallest possible radii.

* Superior numbers relate to References at the end of this section.

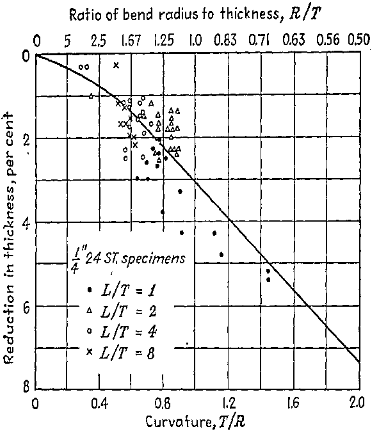


FIG. 6-2. Progressive decrease in thickness with increasing curvature (L/T is the ratio of the length to thickness).[1]

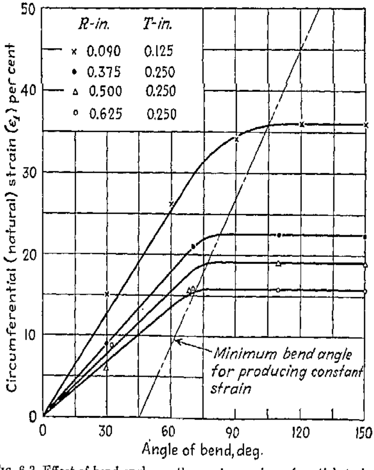
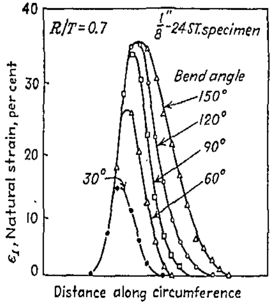


FIG. 6-3. Effect of bend angles on the maximum circumferential strain.[1]



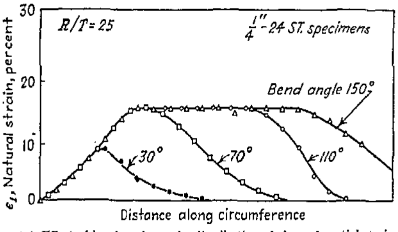


FIG. 6-4. Effect of bend angle on the distribution of circumferential strain.[1]

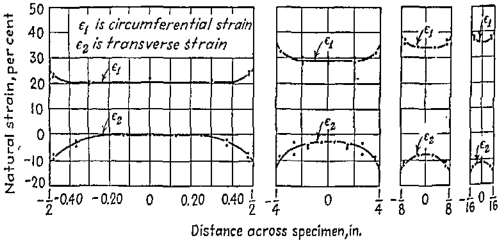


FIG. 6-5. Transverse distributions of strains in bent ⅛-in.-thick 24ST sheet.[1]

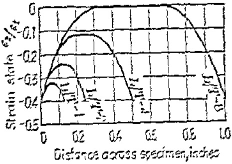


FIG. 6-6. Effect of the bend length on the distribution of strain states in ⅛-in.-thick 24ST sheet.[1]

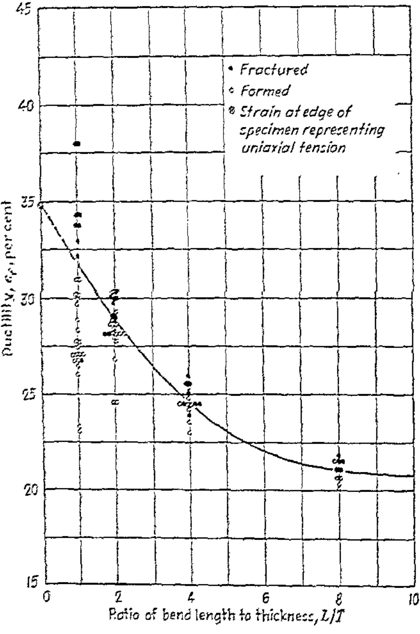


FIG. 6-7. Effect of bend length on ductility.[1]

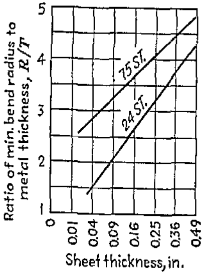


FIG. 6-8. Effect of sheet thickness on minimum bend radii of heat-treated aluminum alloys.[1]

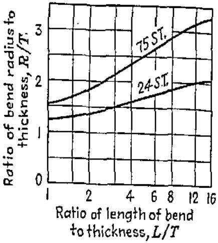


FIG. 6-9. Effect of bend length on minimum bend radii of 0.125-in.-thick heat-treated aluminum alloys.[1]

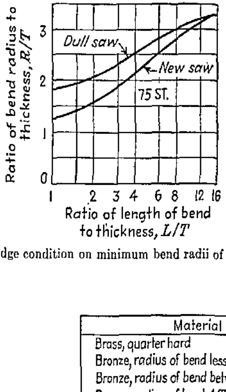
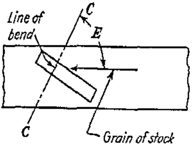


FIG. 6-10. Effect of edge condition on minimum bend radii of an aluminum alloy.[1]



Material	E
Brass, quarter hard	Any
Bronze, radius of bend less than 2 T	90°
Bronze, radius of bend between $2T$-$4T$	65°
Bronze, radius of bend 4 T or more	45°
Copper	Any
Steel, strip A, D, E', or F	Any
Steel, strip B	90°

T=Thickness of stock
E=Minimum angle between line of bend and grain of stock
A=Dead soft CR steel D=HR pickled steel No. 5 temper
B=½ hard CR steel E'=HR pickled steel No. 4 temper
F=¼ hard CR steel

FIG. 6-11. Blanking angles related to bend radii.

BEND ALLOWANCES

The equation for calculating bend allowances is

$$B = \frac{A}{360} \times 2\pi(R + kt) \qquad \text{or} \qquad B = 0.017453A(R + kt) \tag{2}$$

where B = bend allowance (arc length of the neutral axis), in.
A = bend angle, deg
R = bend radius of part, in.
t = metal thickness, in.
k = constant, neutral axis location

A value of 0.5 for k places the neutral axis exactly in the center of the metal; a value generally used for some thicknesses [Eq. (4)]. One manufacturer specifies k according to sheet thickness and inside radius of the bend:

When IR is less than $2t$

$$B = \frac{A\pi}{180}(IR + 0.33t) \tag{3}$$

When IR is $2t$ or more

$$B = \frac{A\pi}{180}(IR + 0.50t) \tag{4}$$

where B = bend allowance (arc length of the neutral axis), in.
IR = inside radius of bend, in.
t = thickness of stock, in.

Bend allowances based on Eq. (2), but using a value of 0.446 for k, are charted in Fig. 6-12, as well as setback allowances.

Example: Given a 90° bend of ⅛ in. radius in 0.040-in. stock, what are values for setback and bend allowance?

Solution: A straight line connecting ⅛ in. on the R scale and 0.040 in. on scale T intersects the B.A. (bend allowance) and S.B. (setback) scales and establishes 0.228 in. and 0.0105 in., respectively, for bend allowance and setback.

On a bend as shown in Fig. 6-13, bend lengths are usually measured from the end of a leg to the opposite side of the bend (l_4 or l_5). The sum of these two measurements will always be greater than the flat length of the piece before it is bent. The blank length necessary to give leg lengths of l_4 and l_5 can be expressed as follows:

$$L = l_4 + l_5 - \left(2 - \frac{\pi}{2}\right)r - \left(2 - \frac{\pi}{2}k\right)t$$
$$= l_4 + l_5 - D \tag{5}$$

where r = inside radius of bend, in.
t = thickness of material, in.
kt = distance from inside of bend to neutral axis
D = setback [see Eq. (14) and Table 6-2]

All these quantities are readily measured except k.

The metal on the inside of the bend compresses, and the metal on the outside stretches. The plane along which no compression or stretching occurs is defined as the neutral axis. In general, it can be stated that metal will stretch more than it will compress. This means that the neutral axis will pull in from the center line of the piece. The sharper the bend (small radius as compared with thickness), the more severe will be the compression, and the neutral axis will pull in closer to the inside surface.

Crane states that k = 0.4. Hinman gives the value of k = ⅓ for mild-tempered sheet metals when the bends are made across the grain and k = ½ where the radius is greater than twice the thickness. Abrahamsen states that, for steel from 10 to 24 gage, $k = 0.2$. Mallett states that $k = 0.446$, or sometimes 0.5.

This formula takes no account of the physical properties of the particular piece of metal being formed or of the condition of the die. The value of k will be influenced by the ductility, yield strength, and possibly the hardness of metal. A rough V die, particularly one with sharp edges, will cause a certain amount of drawing in addition to the straight bending and will result in longer legs l_4 and l_5 than would be the case with a highly polished die with smoothly rounded edges.

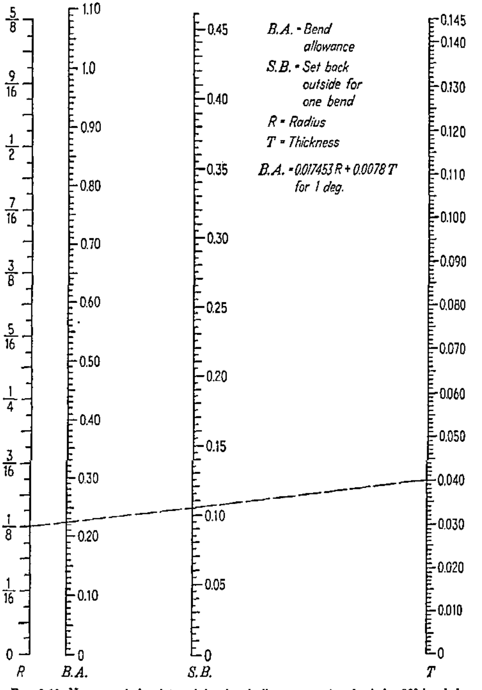


FIG. 6-12. Nomograph for determining bend allowance and setback for 90° bends.[3]

Since k depends upon the ratio of compression to extension for the particular radius and thickness and since this ratio can be determined only by direct measurement, the only way that an accurate value of k can be obtained is to measure it directly. The value of k that should be chosen is one that would give the best results for the range of physical properties in commercial-grade steel and for the average condition of dies.

For precision work where thousandths of an inch are important, the allowance should be determined by experiment. For average work the allowance can be determined assuming that k varies from 1/3 to 1/2 depending upon the ratio of thickness to radius.

Table 6-2 has been compiled on the basis of these values combined with experimental data prepared by the Butler Manufacturing Co. and the Verson Allsteel Press Co. The measurements of bends were made on samples of hot-rolled steel ground to a length of about 1/4 in. and the length was then measured to 0.001 in. with a micrometer caliper. The thickness was similarly measured. The samples were bent on dies especially made for these tests. These dies were carefully made with true angles and radii. After the samples were bent, the lengths of the legs were measured on a surface plate with a height gage. It will be found that the bend allowance depends more on the physical properties of the sample than on the metal from

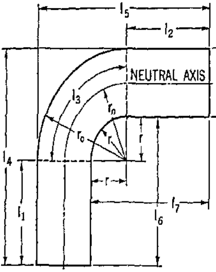


FIG. 6-13. Elements of a 90° bend in sheet metal.[4]

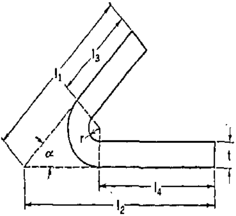


FIG. 6-14. Bend of any angle.[4]

which it is made, *i.e.*, brass and steel of approximately the same physical properties have approximately the same bend allowances.

Often, measurements of bends are made in ways other than from the end of the leg to the opposite side of the bend. Below are given formulas for computing blank lengths for various ways of making measurements.

1. Measurement from end of leg to end of bend (Fig. 6-13):

$$L = l_4 + l_5 - \left(2 - \frac{\pi}{2}\right) r - \left(2 - \frac{\pi}{2} k\right) t = l_4 + l_5 - D \qquad (6)$$

2. Measurement from end of leg to beginning of bend (Fig. 6-13):

$$L = l_1 + l_2 + \frac{\pi}{2} (r + kt) = l_1 + l_2 + E \qquad (7)$$

3. Inside measurements of legs (Fig. 6-13):

$$L = l_6 + l_7 - \left(2 - \frac{\pi}{2}\right) r + \frac{\pi}{2} kt = l_6 + l_7 - F \qquad (8)$$

4. For angles greater or less than 90° (Fig. 6-14):

$$L = l_1 + l_2 - 2(r + t) \cot \frac{\alpha}{2} + \frac{\pi}{180} (r + kt)(180 - \alpha) \qquad (9)$$

5. For angles greater or less than 90°, measured to beginning of bend (Fig. 6-14):

$$L = l_3 + l_4 + \frac{\pi}{180}(180 - \alpha)r + \frac{\pi}{180}(180 - \alpha)kt \tag{10}$$

For $180 - \alpha = 1°$,

$$L = l_3 + l_4 + G \tag{11}$$

For any angle α,

$$L = l_3 + l_4 + G(180 - \alpha) \tag{12}$$

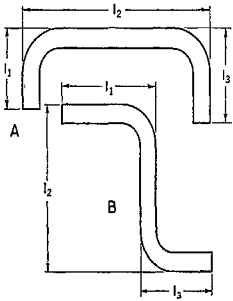


FIG. 6-15. Measurements of multiple bends: (A) double bend; (B) reverse bend.[4]

6. For multiple bends, measure to ends of bends, and deduct D for each bend. For two bends (Fig. 6-15):

$$L = l_1 + l_2 + l_3 - 2D \tag{13}$$

In the above equations

$$D = \text{setback} = 2(r + t) - \frac{\pi}{2}(r + kt) \tag{14}$$

$$E = \text{bend allowance} = \frac{\pi}{2}(r + kt) \tag{15}$$

$$G = \text{bend allowance for } 1° = \frac{\pi}{180}(r + kt) \tag{16}$$

$$F = \text{inside measurement of legs} = 2r - E = 2r - \frac{\pi}{2}(r + kt) \tag{17}$$

$$D + E = 2(r + t) \tag{18}$$

Bend allowances may be found directly from Tables 6-1 and 6-2.

SPRING-BACK

After the bending pressure on metal is released the bend angle decreases and the radius of curvature increases, because the elastic stresses in the metal are also released.

The amount of metal movement, spring-back, depends primarily upon the ratio of the angles A/A_1 (Fig. 6-16) and the temper of the metal.

Spring-back factor K is expressed as

$$K = \frac{A}{A_1} = \frac{R_1 + t/2}{R + t/2} \tag{19}$$

TABLE 6-1. APPROXIMATE LENGTHS OF BEND ALLOWANCES, INCHES, FOR SMALL RADII IN THIN METAL

Inside radius, in.

0.010-in. Metal Thickness

Angle, deg	0.000	0.007	0.010	0.015	0.020	0.025
1	.....	.....	.....	.....	.....	0.001
2	.....	.....	.....	0.001	0.001	0.001
3	.....	0.001	0.001	0.001	0.001	0.002
4	.....	0.001	0.001	0.001	0.002	0.002
5	.....	0.001	0.001	0.002	0.002	0.003
6	.....	0.001	0.001	0.002	0.003	0.003
7	.....	0.001	0.002	0.002	0.003	0.004
8	.....	0.001	0.002	0.002	0.003	0.004
9	.....	0.002	0.002	0.003	0.004	0.005
10	.....	0.002	0.002	0.003	0.004	0.005
20	0.001	0.003	0.005	0.006	0.009	0.010
30	0.001	0.005	0.007	0.009	0.013	0.015
40	0.002	0.007	0.009	0.013	0.017	0.021
50	0.002	0.008	0.011	0.016	0.022	0.026
60	0.003	0.010	0.014	0.019	0.026	0.031
70	0.003	0.012	0.016	0.022	0.030	0.037
80	0.004	0.014	0.019	0.025	0.035	0.042
90	0.005	0.016	0.021	0.028	0.039	0.047

0.016-in. Metal Thickness

Angle, deg	0.000	0.007	0.010	0.015	0.020	0.025
1	.....	.....	.....	.....	.....	0.001
2	.....	.....	0.001	0.001	0.001	0.001
3	.....	0.001	0.001	0.001	0.001	0.002
4	.....	0.001	0.001	0.001	0.002	0.002
5	.....	0.001	0.001	0.002	0.002	0.003
6	0.001	0.001	0.002	0.002	0.003	0.003
7	0.001	0.001	0.002	0.002	0.003	0.004
8	0.001	0.002	0.002	0.003	0.004	0.004
9	0.001	0.002	0.002	0.003	0.004	0.005
10	0.001	0.002	0.003	0.003	0.004	0.005
20	0.002	0.004	0.005	0.007	0.009	0.010
30	0.003	0.006	0.008	0.010	0.013	0.016
40	0.003	0.009	0.010	0.014	0.017	0.021
50	0.004	0.011	0.013	0.017	0.022	0.026
60	0.005	0.013	0.016	0.020	0.026	0.031
70	0.006	0.015	0.018	0.024	0.030	0.037
80	0.007	0.017	0.021	0.028	0.034	0.042
90	0.008	0.020	0.024	0.030	0.039	0.047

0.020-in. Metal Thickness

Angle, deg	0.000	0.007	0.010	0.015	0.020	0.025
1	.....	.....	.....	.....	.....	0.001
2	.....	.....	0.001	0.001	0.001	0.001
3	.....	0.001	0.001	0.001	0.001	0.002
4	.....	0.001	0.001	0.002	0.002	0.002
5	0.001	0.001	0.001	0.002	0.002	0.003
6	0.001	0.001	0.002	0.002	0.003	0.003
7	0.001	0.002	0.002	0.003	0.003	0.004
8	0.001	0.002	0.002	0.003	0.004	0.004
9	0.001	0.002	0.003	0.003	0.004	0.005
10	0.001	0.002	0.003	0.004	0.005	0.006
20	0.002	0.005	0.006	0.008	0.009	0.011
30	0.004	0.007	0.009	0.012	0.014	0.017
40	0.005	0.010	0.012	0.015	0.019	0.022
50	0.006	0.012	0.015	0.019	0.024	0.028
60	0.007	0.015	0.018	0.023	0.028	0.034
70	0.009	0.017	0.021	0.027	0.033	0.039
80	0.010	0.020	0.024	0.031	0.038	0.045
90	0.011	0.022	0.027	0.035	0.042	0.050

0.025-in. Metal Thickness

Angle, deg	0.000	0.007	0.010	0.015	0.020	0.025
1	.....	.....	.....	.....	.....	0.001
2	.....	0.001	0.001	0.001	0.001	0.001
3	.....	0.001	0.001	0.001	0.001	0.002
4	0.001	0.001	0.001	0.002	0.002	0.002
5	0.001	0.001	0.002	0.002	0.002	0.003
6	0.001	0.002	0.002	0.002	0.003	0.003
7	0.001	0.002	0.002	0.003	0.003	0.004
8	0.001	0.002	0.003	0.003	0.004	0.005
9	0.001	0.002	0.003	0.004	0.004	0.005
10	0.001	0.002	0.003	0.004	0.005	0.006
20	0.003	0.005	0.006	0.008	0.010	0.012
30	0.004	0.008	0.009	0.012	0.015	0.017
40	0.006	0.010	0.013	0.016	0.020	0.023
50	0.007	0.013	0.016	0.020	0.024	0.029
60	0.008	0.016	0.019	0.024	0.029	0.035
70	0.010	0.018	0.022	0.028	0.034	0.040
80	0.011	0.021	0.025	0.032	0.039	0.046
90	0.013	0.024	0.028	0.036	0.044	0.052

0.032-in. Metal Thickness

Angle, deg	0.000	0.007	0.010	0.015	0.020	0.025
½	.....	.....	.....	.....	.....	.....
1	.....	.....	.....	.....	0.001	0.001
2	.....	0.001	0.001	0.001	0.001	0.001
3	.....	0.001	0.001	0.001	0.002	0.002
4	.....	0.001	0.001	0.002	0.002	0.003
5	.....	0.002	0.002	0.002	0.003	0.003
6	0.001	0.002	0.002	0.003	0.003	0.004
7	0.001	0.002	0.003	0.003	0.004	0.004
8	0.002	0.003	0.003	0.004	0.004	0.005
9	0.002	0.003	0.003	0.004	0.005	0.006
10	0.002	0.003	0.004	0.005	0.005	0.006
20	0.004	0.006	0.007	0.009	0.011	0.013
30	0.006	0.009	0.011	0.014	0.016	0.019
40	0.008	0.013	0.015	0.018	0.022	0.025
50	0.010	0.016	0.018	0.023	0.027	0.031
60	0.012	0.019	0.022	0.027	0.032	0.038
70	0.013	0.022	0.026	0.032	0.038	0.044
80	0.015	0.025	0.029	0.036	0.043	0.050
90	0.017	0.028	0.033	0.041	0.049	0.057

0.040-in. Metal Thickness

Angle, deg	0.000	0.007	0.010	0.015	0.020	0.025
½	.....	.....	.....	.....	.....	.....
1	.....	.....	.....	.....	0.001	0.001
2	.....	0.001	0.001	0.001	0.001	0.001
3	0.001	0.001	0.001	0.001	0.002	0.002
4	0.001	0.001	0.002	0.002	0.002	0.003
5	0.001	0.002	0.002	0.002	0.003	0.003
6	0.001	0.002	0.002	0.003	0.003	0.004
7	0.002	0.002	0.003	0.003	0.004	0.005
8	0.002	0.003	0.003	0.004	0.005	0.005
9	0.002	0.003	0.004	0.004	0.005	0.006
10	0.002	0.004	0.004	0.005	0.006	0.007
20	0.005	0.007	0.008	0.010	0.012	0.013
30	0.007	0.010	0.012	0.015	0.017	0.020
40	0.009	0.014	0.016	0.020	0.023	0.027
50	0.011	0.017	0.020	0.024	0.029	0.033
60	0.014	0.021	0.024	0.029	0.035	0.040
70	0.016	0.024	0.028	0.034	0.040	0.046
80	0.018	0.028	0.032	0.039	0.046	0.053
90	0.020	0.031	0.036	0.044	0.052	0.060

0.051-in. Metal Thickness

Angle, deg	0.000	0.007	0.010	0.015	0.020	0.025
½	.....	.....	.....	.....	.....	0.001
1	.....	.....	.....	0.001	0.001	0.001
2	0.001	0.001	0.001	0.001	0.001	0.001
3	0.001	0.001	0.001	0.002	0.002	0.002
4	0.001	0.002	0.002	0.002	0.003	0.003
5	0.001	0.002	0.002	0.003	0.003	0.004
6	0.002	0.003	0.003	0.003	0.004	0.005
7	0.002	0.003	0.003	0.004	0.005	0.005
8	0.002	0.003	0.004	0.004	0.005	0.006
9	0.003	0.004	0.004	0.005	0.006	0.007
10	0.003	0.004	0.005	0.006	0.006	0.007
20	0.006	0.008	0.009	0.011	0.013	0.015
30	0.009	0.013	0.014	0.017	0.019	0.022
40	0.012	0.017	0.019	0.022	0.026	0.029
50	0.015	0.021	0.024	0.028	0.032	0.037
60	0.018	0.025	0.028	0.034	0.039	0.044
70	0.021	0.029	0.033	0.039	0.045	0.051
80	0.024	0.034	0.038	0.044	0.052	0.059
90	0.027	0.038	0.042	0.050	0.058	0.066

0.064-in. Metal Thickness

Angle, deg	0.000	0.007	0.010	0.015	0.020	0.025
½	.....	.....	.....	.....	0.001	0.001
1	.....	.....	0.001	0.001	0.001	0.001
2	0.001	0.001	0.001	0.001	0.001	0.002
3	0.001	0.001	0.002	0.002	0.002	0.002
4	0.001	0.002	0.002	0.003	0.003	0.003
5	0.002	0.002	0.003	0.003	0.004	0.004
6	0.002	0.003	0.003	0.004	0.004	0.005
7	0.003	0.003	0.004	0.004	0.005	0.006
8	0.003	0.004	0.004	0.005	0.006	0.006
9	0.003	0.004	0.005	0.006	0.006	0.007
10	0.004	0.005	0.005	0.006	0.007	0.008
20	0.007	0.010	0.011	0.013	0.014	0.016
30	0.011	0.015	0.016	0.019	0.021	0.024
40	0.015	0.020	0.022	0.025	0.028	0.032
50	0.018	0.024	0.027	0.031	0.036	0.040
60	0.022	0.029	0.032	0.038	0.043	0.048
70	0.026	0.034	0.038	0.044	0.050	0.056
80	0.029	0.039	0.043	0.050	0.057	0.064
90	0.033	0.044	0.049	0.057	0.064	0.072

TABLE 6-3. ALLOWANCES FOR BENDS IN SHEET METAL, INCHES

Radius, in.	Allowance*	Thickness of material, in.											
		0.015	0.018	0.020	0.024	0.025	0.030	0.032	0.036	0.040	0.047	0.051	0.060
1/32	D	0.032	0.035	0.038	0.043	0.044	0.052	0.055	0.060	0.065	0.074	0.080	0.091
	E	0.061	0.063	0.065	0.068	0.069	0.070	0.072	0.074	0.077	0.082	0.085	0.091
	F	0.002	−0.001	−0.002	−0.005	−0.006	−0.008	−0.009	−0.012	−0.015	−0.020	−0.022	−0.029
	G	0.00068	0.00070	0.00072	0.00075	0.00076	0.00078	0.00080	0.00083	0.00086	0.00091	0.00094	0.00101
1/16	D	0.045	0.049	0.051	0.056	0.057	0.063	0.066	0.070	0.075	0.084	0.089	0.105
	E	0.110	0.112	0.114	0.117	0.118	0.122	0.123	0.126	0.130	0.135	0.138	0.140
	F	0.015	0.013	0.011	0.008	0.007	0.003	0.002	−0.002	−0.005	−0.010	−0.013	−0.015
	G	0.00122	0.00125	0.00126	0.00130	0.00131	0.00135	0.00137	0.00140	0.00144	0.00150	0.00154	0.00156
3/32	D	0.058	0.062	0.064	0.069	0.071	0.077	0.079	0.084	0.089	0.097	0.102	0.113
	E	0.159	0.161	0.163	0.166	0.167	0.171	0.172	0.176	0.179	0.184	0.187	0.194
	F	0.028	0.026	0.024	0.021	0.021	0.017	0.015	0.012	0.009	0.003	0.000	−0.007
	G	0.00177	0.00179	0.00181	0.00184	0.00185	0.00190	0.00191	0.00195	0.00198	0.00204	0.00208	0.00216
1/8	D	0.072	0.076	0.078	0.083	0.084	0.090	0.093	0.097	0.102	0.111	0.116	0.126
	E	0.208	0.210	0.212	0.215	0.216	0.220	0.222	0.225	0.228	0.233	0.236	0.243
	F	0.042	0.040	0.038	0.035	0.034	0.030	0.028	0.025	0.022	0.017	0.014	0.006
	G	0.00231	0.00234	0.00236	0.00239	0.00240	0.00244	0.00246	0.00250	0.00253	0.00259	0.00263	0.00270
5/32	D	0.085	0.089	0.091	0.096	0.097	0.104	0.106	0.111	0.116	0.124	0.129	0.140
	E	0.257	0.260	0.261	0.264	0.265	0.269	0.270	0.274	0.277	0.282	0.286	0.292
	F	0.055	0.053	0.051	0.048	0.047	0.043	0.042	0.039	0.036	0.030	0.027	0.020
	G	0.00286	0.00288	0.00290	0.00294	0.00294	0.00299	0.00300	0.00304	0.00308	0.00314	0.00317	0.00325
3/16	D	0.099	0.102	0.105	0.110	0.111	0.117	0.119	0.124	0.129	0.138	0.142	0.153
	E	0.306	0.309	0.310	0.313	0.314	0.318	0.320	0.323	0.327	0.331	0.335	0.342
	F	0.069	0.066	0.065	0.062	0.061	0.057	0.055	0.052	0.049	0.044	0.040	0.034
	G	0.00340	0.00343	0.00345	0.00348	0.00349	0.00353	0.00355	0.00358	0.00362	0.00368	0.00372	0.00379
7/32	D	0.112	0.116	0.118	0.123	0.125	0.130	0.133	0.138	0.142	0.151	0.156	0.167
	E	0.355	0.358	0.359	0.362	0.363	0.367	0.369	0.372	0.375	0.380	0.384	0.391
	F	0.082	0.080	0.078	0.075	0.074	0.070	0.069	0.066	0.062	0.057	0.054	0.047
	G	0.00395	0.00398	0.00399	0.00403	0.00404	0.00408	0.00410	0.00413	0.00417	0.00423	0.00426	0.00434

TABLE 6-2. ALLOWANCES FOR BENDS IN SHEET METAL, INCHES (*Continued*)

Radius, in.	Allowance*	Thickness of material, in.											
		0.015	0.018	0.020	0.024	0.025	0.030	0.032	0.036	0.040	0.047	0.051	0.060
1/4	*D*	0.126	0.129	0.132	0.136	0.138	0.144	0.146	0.151	0.156	0.164	0.169	0.180
	E	0.404	0.407	0.408	0.412	0.412	0.416	0.418	0.421	0.424	0.430	0.433	0.440
	F	0.096	0.093	0.092	0.088	0.088	0.084	0.082	0.079	0.076	0.070	0.067	0.060
	G	0.00449	0.00452	0.00454	0.00457	0.00458	0.00462	0.00464	0.00468	0.00471	0.00477	0.00481	0.00488
9/32	*D*	0.139	0.143	0.145	0.150	0.151	0.157	0.160	0.164	0.169	0.178	0.183	0.194
	E	0.454	0.456	0.458	0.461	0.461	0.465	0.467	0.470	0.473	0.479	0.482	0.489
	F	0.109	0.107	0.105	0.102	0.101	0.097	0.096	0.092	0.089	0.084	0.081	0.074
	G	0.00504	0.00507	0.00508	0.00512	0.00513	0.00517	0.00519	0.00522	0.00526	0.00532	0.00535	0.00543
5/16	*D*	0.152	0.156	0.158	0.163	0.164	0.170	0.173	0.178	0.183	0.191	0.196	0.207
	E	0.503	0.505	0.507	0.510	0.511	0.514	0.516	0.519	0.522	0.528	0.531	0.538
	F	0.122	0.120	0.118	0.115	0.114	0.110	0.109	0.106	0.103	0.097	0.094	0.087
	G	0.00558	0.00561	0.00563	0.00566	0.00567	0.00571	0.00573	0.00577	0.00580	0.00586	0.00590	0.00598
11/32	*D*	0.166	0.169	0.172	0.177	0.178	0.184	0.186	0.191	0.196	0.205	0.209	0.220
	E	0.552	0.554	0.556	0.559	0.560	0.564	0.565	0.568	0.571	0.577	0.580	0.587
	F	0.136	0.133	0.132	0.129	0.128	0.124	0.122	0.119	0.116	0.111	0.107	0.100
	G	0.00613	0.00616	0.00617	0.00621	0.00622	0.00626	0.00628	0.00631	0.00635	0.00641	0.00644	0.00652
3/8	*D*	0.179	0.183	0.185	0.190	0.191	0.197	0.200	0.205	0.210	0.218	0.223	0.234
	E	0.601	0.603	0.605	0.608	0.609	0.613	0.614	0.617	0.620	0.626	0.629	0.636
	F	0.149	0.147	0.145	0.142	0.141	0.137	0.136	0.133	0.130	0.124	0.121	0.114
	G	0.00667	0.00670	0.00672	0.00675	0.00676	0.00681	0.00682	0.00686	0.00689	0.00695	0.00699	0.00707
7/16	*D*	0.206	0.210	0.212	0.217	0.218	0.224	0.227	0.232	0.236	0.245	0.250	0.261
	E	0.699	0.701	0.703	0.706	0.707	0.711	0.712	0.716	0.719	0.724	0.727	0.734
	F	0.176	0.174	0.172	0.169	0.168	0.164	0.163	0.160	0.156	0.151	0.148	0.141
	G	0.00777	0.00779	0.00781	0.00784	0.00785	0.00790	0.00791	0.00795	0.00798	0.00804	0.00808	0.00816
1/2	*D*	0.233	0.236	0.239	0.244	0.245	0.251	0.254	0.258	0.263	0.272	0.276	0.287
	E	0.797	0.800	0.801	0.804	0.805	0.809	0.810	0.814	0.817	0.822	0.826	0.832
	F	0.203	0.200	0.199	0.196	0.195	0.191	0.190	0.186	0.183	0.178	0.174	0.168
	G	0.00886	0.00888	0.00890	0.00894	0.00895	0.00899	0.00900	0.00904	0.00908	0.00914	0.00917	0.00925

Tests conducted and data prepared by H. L. Smith and R. J. Gabler.
* See accompanying text for explanation of types *D*, *E*, *F*, and *G* allowances. See Table 6-1 for small-radius allowances in thin metal.

TABLE 6-2. ALLOWANCES FOR BENDS IN SHEET METAL, INCHES *(Continued)*

Radius, in.	Allowance*	Thickness of material, in.											
		0.064	0.072	0.075	0.081	0.090	0.102	0.105	0.125	0.134	0.156	0.187	0.250
1/32	D	0.097											
	E	0.094											
	F	−0.031											
	G	0.00104											
1/16	D	0.110	0.102	0.124	0.132	0.144	0.159	0.163	0.189				
	E	0.143	0.149	0.151	0.155	0.161	0.170	0.172	0.186				
	F	−0.018	−0.024	−0.026	−0.030	−0.036	−0.045	−0.047	−0.061				
	G	0.00159	0.00165	0.00168	0.00172	0.00179	0.00189	0.00191	0.00217				
3/32	D	0.118	0.128	0.131	0.142	0.157	0.173	0.177	0.203	0.214	0.243	0.283	0.365
	E	0.198	0.204	0.206	0.208	0.210	0.219	0.221	0.235	0.241	0.257	0.278	0.322
	F	−0.010	−0.016	−0.019	−0.021	−0.023	−0.031	−0.033	−0.047	−0.054	−0.069	−0.091	−0.135
	G	0.00219	0.00226	0.00229	0.00231	0.00234	0.00243	0.00246	0.00261	0.00268	0.00285	0.00310	0.00359
1/8	D	0.131	0.141	0.145	0.152	0.163	0.177	0.181	0.216	0.228	0.256	0.297	0.378
	E	0.247	0.253	0.255	0.260	0.267	0.277	0.279	0.284	0.290	0.306	0.327	0.372
	F	0.003	−0.003	−0.005	−0.010	−0.017	−0.027	−0.029	−0.034	−0.040	−0.056	−0.077	−0.122
	G	0.00274	0.00281	0.00283	0.00289	0.00296	0.00307	0.00310	0.00316	0.00323	0.00340	0.00364	0.00413
5/32	D	0.145	0.154	0.158	0.166	0.176	0.091	0.195	0.219	0.230	0.270	0.310	0.392
	E	0.296	0.302	0.304	0.309	0.316	0.326	0.328	0.346	0.350	0.355	0.376	0.421
	F	0.017	0.010	0.008	0.004	−0.004	−0.013	−0.015	−0.031	−0.038	−0.042	−0.064	−0.108
	G	0.00328	0.00335	0.00338	0.00343	0.00351	0.00362	0.00364	0.00382	0.00389	0.00394	0.00429	0.00468
3/16	D	0.158	0.168	0.172	0.179	0.190	0.204	0.208	0.232	0.243	0.277	0.324	0.405
	E	0.345	0.351	0.353	0.358	0.365	0.375	0.377	0.393	0.400	0.410	0.426	0.470
	F	0.030	0.024	0.022	0.017	0.010	0.000	−0.002	−0.008	−0.015	−0.042	−0.051	−0.095
	G	0.00383	0.00390	0.00392	0.00398	0.00406	0.00416	0.00419	0.00436	0.00444	0.00463	0.00473	0.00522
7/32	D	0.172	0.181	0.185	0.192	0.203	0.218	0.221	0.246	0.257	0.283	0.329	0.419
	E	0.394	0.400	0.402	0.407	0.414	0.424	0.426	0.442	0.449	0.466	0.490	0.519
	F	0.044	0.037	0.035	0.030	0.023	0.014	0.013	−0.004	−0.011	−0.029	−0.053	−0.081
	G	0.00437	0.00444	0.00447	0.00452	0.00460	0.00471	0.00473	0.00491	0.00498	0.00518	0.00544	0.00577

TABLE 6-2. ALLOWANCES FOR BENDS IN SHEET METAL, INCHES (Continued)

Radius, in.	Allowance*	Thickness of material, in. 0.064	0.072	0.075	0.081	0.090	0.102	0.105	0.125	0.134	0.156	0.187	0.250
¼	D	0.185	0.195	0.198	0.206	0.217	0.231	0.236	0.250	0.270	0.297	0.350	0.432
	E	0.443	0.449	0.452	0.456	0.463	0.470	0.475	0.491	0.498	0.515	0.524	0.568
	F	0.057	0.051	0.048	0.044	0.037	0.027	0.025	0.000	0.002	−0.015	−0.024	−0.068
	G	0.00492	0.00499	0.00502	0.00507	0.00515	0.00525	0.00529	0.00545	0.00553	0.00572	0.00582	0.00671
9/32	D	0.198	0.208	0.212	0.219	0.230	0.244	0.248	0.272	0.284	0.310	0.304	0.446
	E	0.492	0.498	0.501	0.505	0.512	0.522	0.524	0.540	0.547	0.564	0.573	0.617
	F	0.071	0.064	0.062	0.057	0.050	0.040	0.038	0.022	0.016	−0.002	−0.010	−0.054
	G	0.00546	0.00554	0.00556	0.00561	0.00569	0.00580	0.00583	0.00600	0.00608	0.00627	0.00637	0.00686
5/16	D	0.212	0.222	0.225	0.232	0.243	0.258	0.262	0.286	0.297	0.324	0.377	0.459
	E	0.541	0.548	0.550	0.554	0.562	0.571	0.573	0.589	0.596	0.613	0.622	0.666
	F	0.084	0.078	0.076	0.070	0.063	0.054	0.052	0.036	0.029	0.012	0.003	−0.041
	G	0.00601	0.00608	0.00611	0.00616	0.00624	0.00634	0.00637	0.00654	0.00662	0.00681	0.00691	0.00740
11/32	D	0.225	0.235	0.239	0.246	0.257	0.271	0.275	0.299	0.310	0.337	0.383	0.472
	E	0.590	0.597	0.599	0.604	0.611	0.620	0.622	0.635	0.645	0.662	0.670	0.715
	F	0.097	0.091	0.089	0.084	0.077	0.067	0.065	0.049	0.042	0.025	0.008	−0.028
	G	0.00656	0.00663	0.00665	0.00670	0.00678	0.00689	0.00691	0.00709	0.00717	0.00736	0.00754	0.00795
⅜	D	0.239	0.248	0.252	0.259	0.270	0.285	0.288	0.313	0.324	0.350	0.389	0.480
	E	0.639	0.646	0.648	0.653	0.660	0.669	0.672	0.687	0.694	0.712	0.730	0.764
	F	0.111	0.104	0.102	0.097	0.090	0.081	0.078	0.063	0.056	0.038	0.014	−0.014
	G	0.00710	0.00717	0.00720	0.00725	0.00733	0.00743	0.00746	0.00763	0.00771	0.00790	0.00817	0.00860
7/16	D	0.266	0.275	0.279	0.286	0.297	0.312	0.315	0.340	0.351	0.377	0.416	0.502
	E	0.737	0.744	0.746	0.751	0.758	0.767	0.770	0.785	0.792	0.810	0.834	0.873
	F	0.138	0.131	0.129	0.124	0.117	0.108	0.105	0.090	0.083	0.065	0.041	0.002
	G	0.00819	0.00826	0.00829	0.00834	0.00842	0.00852	0.00855	0.00872	0.00880	0.00899	0.00926	0.00970
½	D	0.292	0.302	0.306	0.313	0.324	0.338	0.342	0.366	0.377	0.404	0.442	0.518
	E	0.836	0.842	0.844	0.849	0.856	0.866	0.868	0.884	0.891	0.908	0.932	0.982
	F	0.164	0.158	0.156	0.151	0.144	0.134	0.132	0.116	0.109	0.092	0.068	0.018
	G	0.00928	0.00935	0.00938	0.00943	0.00951	0.00962	0.00964	0.00982	0.00989	0.01008	0.01035	0.01090

where A = bend angle of part, deg
A_1 = bend angle of part during bending, deg
R = part radius, in.
R_1 = die radius, in.

Higher values than those calculated are found in actual practice (Fig. 6-17), due to variations in work-hardening rates, die clearances, and the chemical composition of a particular metal. Variations from the calculated angle may be as high as ±2°.

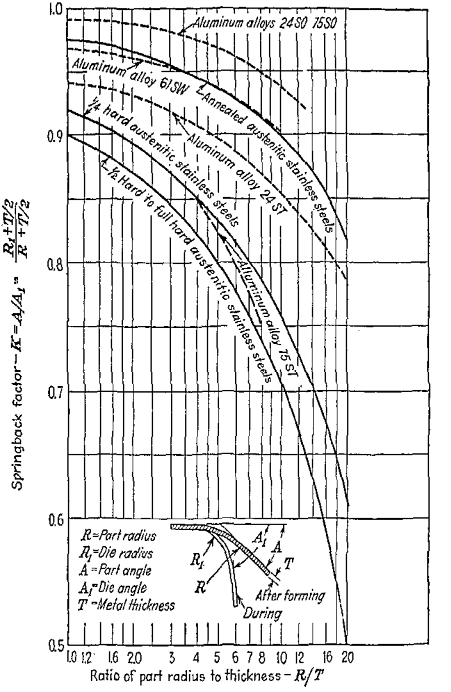


FIG. 6-16. Spring-back data for aluminum alloys and stainless steels.[1]

Spring-back allowances for 90° bends in 24SO and 75SO aluminum are listed in Table 6-3, to be incorporated in form blocks used in hydraulic rubber-pad presses.

For angles other than 90°, the spring-back allowance for 90° will be multiplied by the factors set forth in Table 6-4. To find spring-back allowance for an 80° flange proceed as follows:

From Table 6-3, the spring-back allowance in 24SO Dural sheet 0.040 in. thick for a ⅛ in. bend radius of the flange is 3° for a 90° flange. The 3° allowance is then multi-

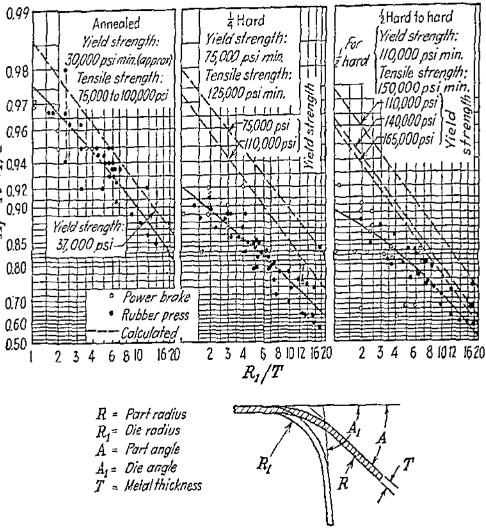


Fig. 6-17. Spring-back data for 18-8 types of stainless steels.[2]

TABLE 6-3. SPRING-BACK ALLOWANCE IN DEGREES FOR 90° BENDS IN 24SO AND 75SO ALUMINUM

Sheet thickness, in.	Bend radius, in.							
	3/32	1/8	3/16	1/4	5/16	3/8	7/16	1/2
0.020	3	4	5½	7½	8½	9	9½	12
0.025	2¾	3¾	5½	6½	8	8¼	8¾	10¾
0.032	2¼	3	4¾	6	6¾	7	7½	9½
0.040	2	3	4	5	6	6¼	6¾	8¾
0.051	2	2½	3½	4	5	5¼	5¾	7½
0.064	1½	2	2¾	3¾	4½	5	5½	6¾
0.081	1	1½	2	2½	3¼	3½	4	4¾
0.094			1¾	2½	3	3¼	3¾	4½
0.125			1½	2	2¼	2¾	3	3¾

Courtesy of Emerson Electric Co.

plied by 0.8, the factor opposite 80° in Table 6-4. The product, 2.4°, is the spring-back allowance for an 80° angle.

Spring-back allowances for 90° bends in 24ST stock are listed in Table 6-5. To obtain the spring-back allowance for angles other than 90°, the allowance for 90° should be multiplied by the factors shown in Table 6-4.

TABLE 6-4. SPRING-BACK FACTORS IN BENDING ALUMINUM TO OTHER ANGLES THAN 90°

Angle, deg	24SO and 75SO aluminum	24ST aluminum
60	0.6	0.7
65	0.6	0.7
70	0.7	0.8
75	0.7	0.8
80	0.8	0.9
85	0.8	0.9
95	1.05	1.02
100	1.05	1.05
105	1.1	1.05
110	1.2	1.1
115	1.2	1.1
120	1.3	1.2

Courtesy of Emerson Electric Co.

TABLE 6-5. SPRING-BACK ALLOWANCE IN DEGREES FOR 90° BENDS IN 24ST ALUMINUM

Sheet thickness, in.	Bend radius, in.							
	3/32	1/8	3/16	1/4	5/16	3/8	7/16	1/2
0.020	10	12	15½	19	22½	24	27¼	33½
0.025	8¾	10½	14	16¾	17¾	21	23	28½
0.032	7¾	8¾	12	14½	16¾	17¾	19¼	24
0.040	7¼	8¼	10¾	12¾	14½	15¼	17	20½
0.051			9	10½	12¼	13	14½	16¾
0.064			8	9¾	11¼	12	12¾	15
0.081					9½	10½	11¼	13
0.094					8¾	9¾	10½	12

Courtesy of Emerson Electric Co.

Tables 6-3 to 6-5, inclusive, are based upon the results of thousands of tests and should be accurate to within 2° for average operating conditions on a hydraulic press with an 8-in. rubber pad having a Shore durometer hardness of 60 to 70.

The operating pressure of the press was 2,500 tons and a 1-in. throw pad having a Shore durometer hardness of 60 to 70 was located over the blanks on the form blocks during the forming operations.

Tables 6-3 to 6-5, inclusive, were calculated from tests on straight flanges. In view of the many possible contours of curved flanges, it is difficult if not impossible to predetermine accurately the spring-back allowance for such flanges. As a practical working basis, Tables 6-3 to 6-5, inclusive, for straight flanges can be employed as a guide for determining the spring-back allowances for curved flanges. However, the exact spring-back allowance for curved flanges must be developed by trial and error.

An empirical equation[2] for predicting angular deviation in curved flanges is

$$X = 100AC + \frac{0.095(A - B)}{0.0005} D + EG + F \tag{20}$$

where X = total degrees of angular deviation (spring-back)
A = punch and die setting (clearance when closed), in.
B = minimum stock thickness, in.

C = factor for die setting at maximum stock thickness
D = factor for difference between die setting and minimum stock thickness
E = factor for hardness variation
F = constant for difference between die setting and minimum stock thickness
G = difference between high and low points of Rockwell B scale in the stock specifications

Values of factors C, D, E, and F for certain materials are listed in Table 6-6.

Example: To form a 90° angle in 0.032-in. half-hard steel, with a thickness variation of plus 0.003 in. and minus 0.002 in., Rockwell range of B71 to 82, and a die setting of 0.035, substitute the known values in the formula and find the angular deviation to be 2.4°.

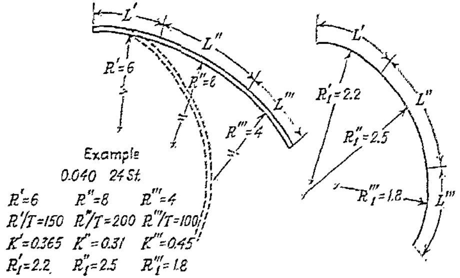


FIG. 6-18. Graphical method for determining form-block contours.[1]

Form-block Contours. A graphical method of determining the contour of form blocks to compensate for spring-back has been developed (Fig. 6-18). The part is divided into a few lengths, L', L'', etc., each possessing an approximately common radius R', R'', R'''. These radii are determined graphically, and the ratios R/t (t = metal thickness) are found. The spring-back factors K', K'', K''' are taken from Fig. 6-16. Die radii $R_1' = K'R'$, $R_1'' = K''R''$, $R_1''' = K'''R'''$ are then calculated.

TABLE 6-6. DEVIATION FACTORS FOR SPRING-BACK IN CURVED FLANGES[1]

Material (half hard only)	Factor C*	Factor D*	Factor E*
Steel	0.08	0.19	0.05
Brass	Zero	0.13	0.04
Aluminum	0.12	0.12	Zero

Material	If minimum stock thickness is	Factor F*
Steel	More than 95% of the punch-and-die setting	0.50
Steel	Less than 95% of the punch-and-die setting	1.40
Brass	More than 95% of the punch-and-die setting	0.80
Brass	Less than 95% of the punch-and-die setting	2.00
Aluminum	Any thickness	0.50

* Factors for use in Eq. (26).

L' is laid out on the perimeter of a circle of radius R_1', L'' on a circle of radius R_1'', and L''' on a circle of radius R_1'''. These three segments are faired, or smoothly blended, in agreement with the desired part contour.

For such large radii as are shown in Fig. 6-18, the data derived from Figs. 6-16 and 6-17 would be inapplicable. Instead, the spring-back must be determined from special tests on the workpiece material.

BENDING PRESSURES

The amount of pressure required depends upon the thickness of the stock, the length of the bend, the width of the die, whether a lubricant is used, and the amount of

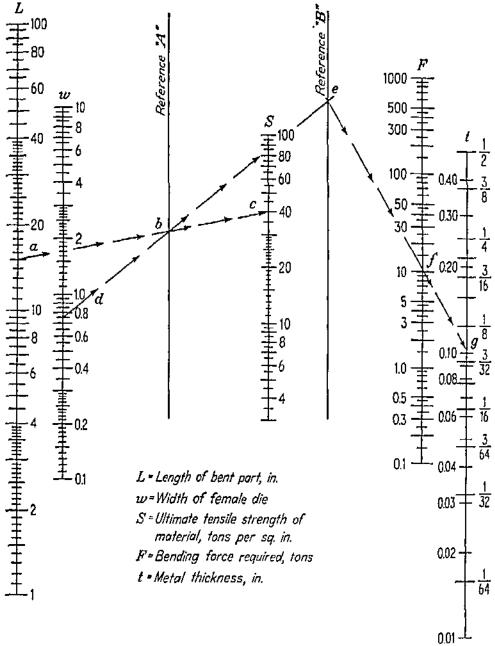


Fig. 6-19. Nomograph for determining bending pressures in V dies.[5]

wiping, ironing, or coining present. V dies in which the punch does not bottom (air-bending), commonly used in press brakes, require minimum pressures (Table 6-7).

For U-ing and channel bending, the pressures required will be approximately twice those listed; for edge bending, the pressures will be about one-half those listed.

TABLE 6-7. PRESSURE IN TONS PER LINEAR FOOT FOR BENDING MILD STEEL[a]

Width of female die opening (in.), columns 5/16 to 2:

Gage	Decimal	5/16	3/8	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 1/2	1 3/4	1 7/8	2
20	0.0359	1.96	1.65	1.13	0.89									
18	0.0478	...	2.8	2.04	1.83	1.32								
16	0.0598	...	5.6	3.75	2.64	2.14	1.79	1.53						
14	0.0747	...	...	5.62	4.61	3.37	2.85	2.48	2.16	1.92				
13	0.0897	...	...	...	8.42	5.15	4.24	3.65	3.19	2.79				
12	0.1046	...	...	...	9.83	7.0	5.98	4.8	4.2	3.8	3.1			
11	0.1196	...	...	...	...	11.1	9.1	6.8	5.9	5.25	4.2	3.5	3.3	3.0
10	0.1345	...	...	...	...	...	10.5	8.8	7.6	6.7	5.4	4.5	4.2	3.9
9	0.1495	...	...	...	...	...	15.0	11.8	9.6	8.5	6.8	5.7	5.3	4.9
3/16	0.187	...	...	...	...	...	...	...	18.6	14.0	11.2	9.4	8.6	8.0
7/32	0.218	...	...	...	...	...	...	...	...	22.4	15.8	13.1	12.4	11.3
1/4	0.250	...	...	...	...	...	...	...	...	...	24.4	17.8	16.2	14.9
9/32	0.281	...	...	...	...	...	...	...	...	...	...	26.5	21.0	19.7
5/16	0.312	...	...	...	...	...	...	...	...	...	...	...	30.4	26.2
11/32	0.343	...	...	...	...	...	...	...	...	...	...	...	...	34.5
3/8	0.375	...	...	...	...	...	...	...	...	...	...	...	...	...
13/32	0.406	...	...	...	...	...	...	...	...	...	...	...	...	...
7/16	0.437	...	...	...	...	...	...	...	...	...	...	...	...	...
15/32	0.468	...	...	...	...	...	...	...	...	...	...	...	...	...
1/2	0.500	...	...	...	...	...	...	...	...	...	...	...	...	...
17/32	0.531	...	...	...	...	...	...	...	...	...	...	...	...	...
5/8	0.625	...	...	...	...	...	...	...	...	...	...	...	...	...
11/16	0.687	...	...	...	...	...	...	...	...	...	...	...	...	...
3/4	0.750	...	...	...	...	...	...	...	...	...	...	...	...	...
13/16	0.812	...	...	...	...	...	...	...	...	...	...	...	...	...
1	1.000	...	...	...	...	...	...	...	...	...	...	...	...	...

Width of female die opening (in.), columns 2 1/4 to 16:

Gage	Decimal	2 1/4	2 1/2	2 5/8	2 3/4	3	3 1/4	3 1/2	3 3/4	4	4 1/2	5	5 1/4	5 1/2	6	6 1/2	7	7 1/2	8	8 1/2	9	12	16
20	0.0359																						
18	0.0478																						
16	0.0598																						
14	0.0747																						
13	0.0897																						
12	0.1046																						
11	0.1196																						
10	0.1345																						
9	0.1495	4.3	3.8																				
3/16	0.187	6.9	6.3	5.9	5.6	5.0																	
7/32	0.218	9.8	8.6	8.1	7.7	7.0	6.4	5.9															
1/4	0.250	13.0	11.5	10.9	10.3	9.3	8.5	7.8	7.3	6.7													
9/32	0.281	16.9	14.8	14.0	13.3	12.0	11.0	10.5	9.36	8.7	7.6												
5/16	0.312	21.5	18.6	18.0	16.5	15.0	13.7	12.6	11.6	10.8	9.5	8.4											
11/32	0.343	28.1	23.3	21.7	20.5	18.3	16.8	15.5	14.2	13.2	11.5	10.3	9.8	9.2									
3/8	0.375	36.6	28.4	26.5	24.8	22.5	20.2	18.6	17.2	16.1	13.9	12.5	11.7	11.1	10.1								
13/32	0.406	...	38.7	33.8	30.2	26.6	24.2	22.2	20.5	19.0	16.5	14.7	13.9	13.2	12.0	11.0							
7/16	0.437	...	...	42.8	41.0	31.7	28.7	26.3	24.2	22.4	19.6	17.2	16.3	15.5	14.1	12.9	11.8						
15/32	0.468	...	...	...	47.0	39.5	33.6	30.4	28.0	26.0	22.6	20.0	19.0	17.9	16.2	14.8	13.7	12.8					
1/2	0.500	...	...	...	...	48.0	41.6	35.5	32.5	29.9	26.0	23.0	21.8	20.6	18.6	17.0	15.7	14.5	13.5				
17/32	0.531	...	...	...	...	...	51.2	43.7	37.5	34.3	29.7	26.2	24.8	23.6	21.4	19.4	17.9	16.5	15.4	14.4			
5/8	0.625	...	...	...	...	...	...	...	61.3	52.8	43.2	37.3	35.2	33.2	30.1	27.7	25.3	23.2	21.6	20.3	19.0		
11/16	0.687	...	...	...	...	...	...	...	...	69.2	55.5	46.8	43.5	41.0	37.1	33.7	31.0	28.5	26.5	24.9	23.3		
3/4	0.750	...	...	...	...	...	...	...	...	...	73.5	60.8	53.2	49.7	44.8	41.0	37.4	34.6	32.2	30.0	28.0	20.2	
13/16	0.812	...	...	...	...	...	...	...	...	...	...	77.5	68.0	60.5	53.5	48.6	44.5	41.2	38.0	35.6	33.3	24.0	
1	1.000	...	...	...	...	...	...	...	...	...	...	...	...	...	97.8	83.0	71.0	64.8	59.8	55.8	51.9	37.2	27.0

[a] Data courtesy of the Verson Allsteel Press Co.

Bending pressures for other metals as compared with mild steel on chart, are as follows: Soft brass, 50% of pressure shown. Soft aluminum, 50% of pressure shown. Aluminum alloys heat-treated, same as steel. Stainless steel, 50% more than steel. Chrome molybdenum, 100% more than steel.

Pressures in boldface type are for dies with female openings approximately 8 × metal thickness, with radius on male die equal to metal thickness, and are considered ideal for right-angle bending.

Bending pressures can also be obtained from a suitable chart (Fig. 6-19). The chart is based on

$$F = \frac{KLSt^2}{W} \tag{21}$$

where F = bending force required, tons
K = die-opening factor: varies from 1.20 for a die opening of 16 times metal thickness, to 1.33 for a die opening of 8 times metal thickness
L = length of bent part, in.
S = ultimate tensile strength, tons per sq in.
t = metal thickness
W = width of the V, channel, or U-ing lower die, in.

To prevent the chart from becoming too complex, a die-opening factor of 1.33 was used in all cases.

Ultimate strengths S for various materials are:

Metal	*Tons per Sq. In.*
Aluminum and alloys	6.5–38.0
Brass	19.0–38.0
Bronze	31.5–47.0
Copper	16.0–25.0
Steel	22.0–40.0
Tin	1.1– 1.4
Zinc	9.7–13.5

The use of Fig. 6-19 for deriving bending pressures is valid for V-shaped dies only. For channel forming and U forming, multiply the result by 2. In forming a channel with flat bottom, a blankholder is necessary. Multiply blankholder area in square inches by 0.15 and add to the bending force derived from Fig. 6-19.

Example: A 15-in.-long 0.10-in.-thick, ¾-in.-wide steel strip is to be bent in a V-shaped die. What bending force is necessary if the steel has 40 tons tensile strength?

Solution: Enter Fig. 6-19 at 15 in. on the L scale and draw line *abc* through 40 tons per sq in. ultimate tensile strength on the S scale. Next, draw *dbe* from 0.75 in. on the die width, scale W, to the intersection of the first line with reference axis A. Extend to intersect reference axis B at e. Connect point e and 0.10-in. metal thickness *efg*. At f read bending force as 11 tons.

Hemming Pressures. Hemming pressures, including seaming pressures, will generally amount to seven times the forming pressures required for 90° bends and may be as high as a ratio of 40:1, dependent upon stock thickness, tensile strength, size of area to be flattened or hemmed, and tightness of the hem.

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SECTION 7

BENDING DIES*

PRESS-BRAKE DIES

A stamping operation sometimes classified as either bending or forming may actually include both, as exemplified in the press-brake dies shown in Fig. 7-1.

1. *90° Forming Dies.* In Fig. 7-1*A* is shown a typical 90° forming die, which is one of the most common dies used in press brakes. Most 90° dies are bottoming dies and, in using them, characteristics of bottoming must be remembered. In general, the radius of the bend should be not less than the thickness of the material, and the V-die opening should be eight times the metal thickness. High-tensile materials require larger radii and wider V's than this, and plates over ½ in. thick also require V-die openings of more than eight times the metal thickness.

2. *Acute-angle or Air-forming Dies.* The dies shown in Fig. 7-1*B* are known as "acute-angle" dies because of the acute angle they can form, and also as "air-forming" dies because they usually do not bottom but form in the air. They may be used for 90° bends where accuracy is not too important. They may also be used to form a wide range of both acute and obtuse angles simply by adjusting the ram of the press, which in turn determines how far the punch enters the die.

3. *Gooseneck Dies.* In Fig. 7-1*C* is shown a typical gooseneck or return flanging die. These are essentially simple V-bend dies with clearance for return flanges. Care must be taken in using these dies because they are usually cut beyond the center line and can easily be bent by overloading.

4. *Offset Dies.* An offset can be formed by making two bends with a 90° or acute-angle die. However, for long runs or sharp offsets, dies of the type shown in Fig. 7-1*D* are generally used. The pressures required are sometimes dangerously high, being from four to eight times that for a single bend, depending on the nature of the offset. Where each bend is more than 90°, these dies are usually referred to as Z dies.

5. *Hemming Dies.* The edges of a sheet are sometimes hemmed or turned over to provide stiffness and a smooth edge. Hemming can be done in two operations, starting with an acute-angle die and finishing with a flattening die such as shown in Fig. 7-1*E*. However, most hemming is done on regular hemming dies, which are two-stage dies combining an acute-angle die with some sort of flattening arrangement. One type is shown in Fig. 7-1*F*. Pressures required will vary greatly with thickness of the hem and the degree of flatness.

6. *Seaming Dies.* Seams in sheets or tubes can be made in a variety of ways. A set of dies for making simple seams is shown in Fig. 7-1*G*.

7. *Radius Dies.* These dies are usually employed where the radius exceeds four times the thickness of the material. Such bends can be made with a V die machined to less than 90° and a full-radius punch. However, better results are usually obtained by means of spring-loaded dies such as that shown in Fig. 7-1*H*. Instead of spring pads, rubber pads may be used. The angle of bend is adjusted by varying the distance that the punch enters the die. Punches with different radii may be used with the same die to get different radii on the bend. The inside radius on air bends is com-

* Reviewed by Jay Bowen, Chief Engineer, McReynolds Die & Tool Co.

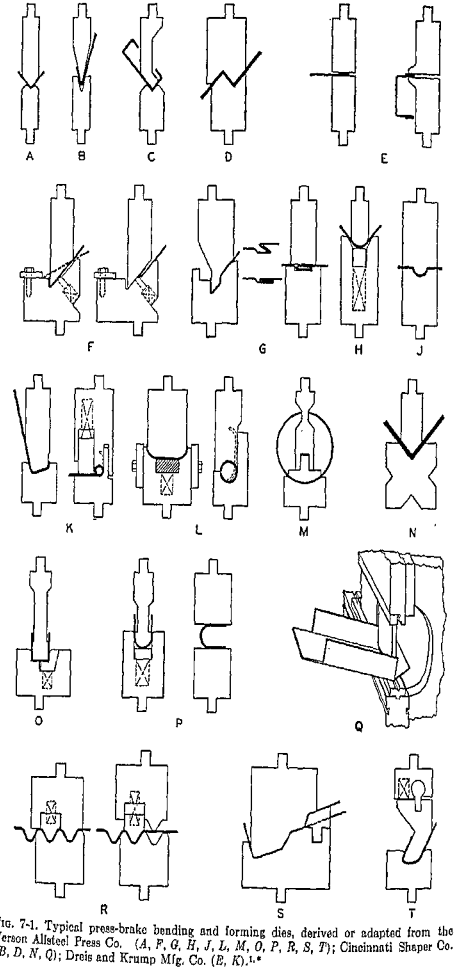


FIG. 7-1. Typical press-brake bending and forming dies, derived or adapted from the Verson Allsteel Press Co. (*A, F, G, H, J, L, M, O, P, R, S, T*); Cincinnati Shaper Co. (*B, D, N, Q*); Dreis and Krump Mfg. Co. (*E, K*).[1,*]

* Superior numbers relate to References at the end of this section.

monly controlled by the die opening. This inside radius, with normal dies, is very nearly five thirty-seconds of the die opening.

8. *Beading Dies.* Beads are used as a stiffening means in flat sheets and sometimes permit the use of thinner material than would be possible otherwise. Beads are of two general types: open beads extending from edge to edge of the sheet, and closed or blind beads that fade out in the sheet. Open beads are usually formed by simple dies such as that shown in Fig. 7-1*J*. Closed beads, on the other hand, require the use of spring pressure pads at the ends, which fade out to minimize wrinkling of the metal.

9. *Curling Dies.* These provide a curl or coiled-up end to the piece. Hinge dies make use of a curling operation. The curl may be centered, or it may be tangent to the sheet as shown in Fig. 7-1*K*.

10. *Tube- and Pipe-forming Dies.* These are similar to curling dies. The edges of the metal must be bent as a first operation. The piece will then roll up properly. Figure 7-1*L* shows a two-operation die for forming *small* tubes. For larger tubes, a bumping die such as in Fig. 7-1*M* is necessary. For accurate work such bumped tubes should be sized over a sizing mandrel. Seams can be formed on the edges of these tubes before they are rolled.

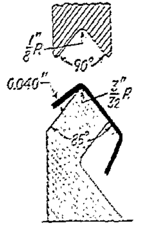


FIG. 7-2. V die for accurate setting of a bend angle.[4]

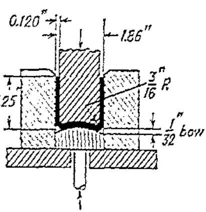


FIG. 7-3. Square beading with bowed spring pad to prevent distortion of the web.[4]

11. *Four-way Die Blocks.* For small production runs or for a job shop, the four-way die block as shown in Fig. 7-1*N* is quite useful and represents a material saving in tool cost.

12. *Channel-forming Dies.* Channels may be formed in gooseneck dies or in single-stroke channel dies as shown in Fig. 7-1*O*. Such dies are commonly made with a spring-pressure pad release of some sort to eject the formed part from the die. Strippers are sometimes provided to strip the part from the punch.

13. *U-bend Dies.* U-bend forming is similar to channel forming, but spring-back is usually more pronounced and means must be provided to overcome it. One way of accomplishing this is shown in Fig. 7-1*P*.

14. *Box-forming Dies.* While boxforming consists of simple angle bending, there are problems peculiar to the nature of the work. In general, a high punch and a low die are required as seen in Fig. 7-1*Q*. Sometimes the punch is cut into sections so that the side of the box can come up between them. Certain shapes of boxes may be formed on horn presses.

15. *Corrugating Dies.* Corrugating dies can be provided to produce a variety of corrugations. From one to four corrugations are made at a single stroke. Figure 7-1*R* shows such a die.

16. *Multiple-bend Dies.* Multiple-bend dies offer an infinite variety of possibilities. Commonly used on large production runs, one die can accomplish, in a single stroke, an operation that would require several operations with single-bend dies. Figure 7-1*S* shows such a die. Such a die requires much greater forming pressures than do dies for the individual operations.

17. *Rocker-type Dies.* Rocker-type dies can be used to form parts that would be impossible with a die acting only vertically. A typical example is shown in Fig. 7-1*T*.

REPRESENTATIVE PRESS-TYPE BENDING DIES

Typical die designs to compensate for spring-back are shown in Figs. 7-2 and 7-3. Variations in sheet temper and thickness cannot be exactly calculated; hence the desired bend angle in the part may be secured by handwork.

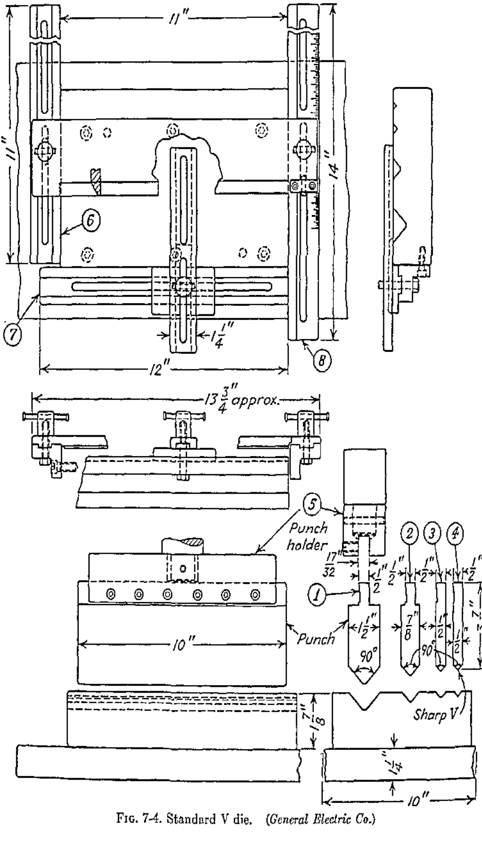


FIG. 7-4. Standard V die. (*General Electric Co.*)

Flexible V-die Design. A practical V die has four sizes of punches (Fig. 7-4, $D1$, $D2$, $D3$, and $D4$*), with sliding gages $D6$, $D7$, and $D8$ to allow flexibility in the positioning and forming of various-sized blanks into V bends up to approximately 90°. A punch of the desired size is placed in the holder $D5$, and the mating V die is located in line for performing the bending operation.

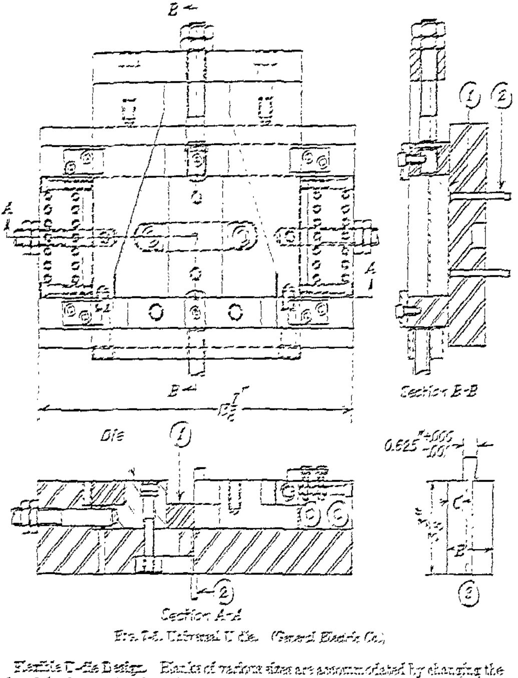


Fig. 7-5. Universal U die. (General Electric Co.)

Flexible U-die Design. Blanks of various sizes are accommodated by changing the size of the die opening through the insertion of "floaters," Fig. 7-5, ($D1$) into the die block. These are steel blocks 4¾ in. long and ½ in. thick, and varying in width from 0.211 to 2.242 in. in increments of 0.062 in. Punches ($D3$), of various widths are used to bend the work into U or channel shapes. Possible combinations of floaters and punches provide a wide range of thicknesses and sizes of workpieces that can be bent. The floaters also function as ejectors actuated through ejector pins ($D2$).

U Die. The vertical punch ($D1$, Fig. 7-6) contacts and slightly indents the stock held by the guides ($D5$). Pivoted jaws ($D2$) iron out the detent and, with a radius equal to stock thickness, produce a 90° bend. Pivot radii R_2 are ½ in. Clearance on the punch, to allow for spring-back, depends on thickness and type of stock.

* D indicates detail number on drawing.

Bending and Flattening Die Design. Two spring-loaded pivoted arms, forced outward by a diamond-shaped punch, bend the first flaps on the part through 90°, and retract to allow the vertical punch to flatten both flaps (Fig. 7-7), completing the finished seam. Spring-loaded holddowns position and prevent movement of the part during the bending and flattening operation. Previous operations on this part cut it to length and shape, and also slot and form the two flanges along the sides of the cutout as shown.

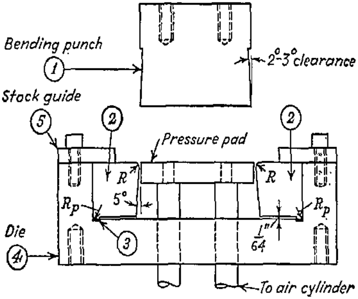


FIG. 7-6. U die with pivoted jaws.[4]

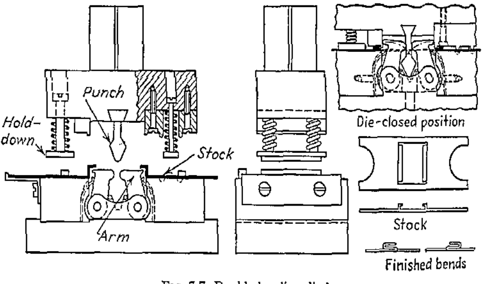
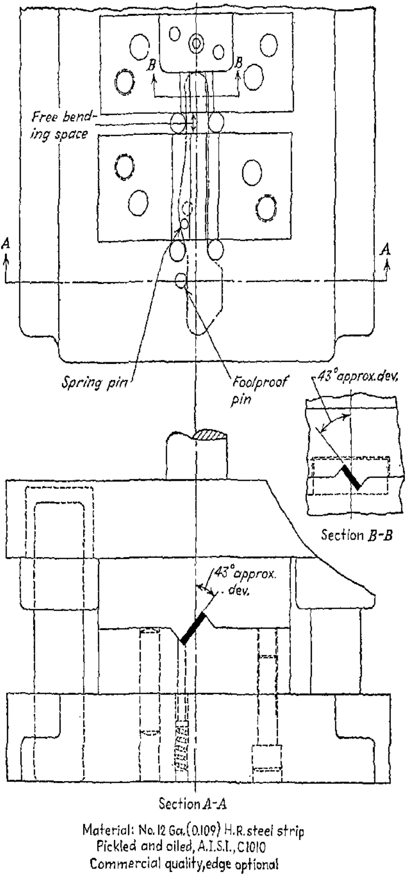


FIG. 7-7. Double-bending die.[3]

Twisting Die. Hot-rolled SAE 1010 12-gage steel strip is twisted (bent in air) to form an angle of 90° in the die shown in Fig. 7-8. To compensate for spring-back angles in the two sections of the die and of the corresponding punch sections are specified as approximately 43° with the vertical. An ejector and gage pins are incorporated.

Rotary Twisting Die. A plunger with a helical groove (*D2, D3*, Fig. 7-9) revolves and twists the work through 90° through the engagement of a hardened pin in the groove on the downward movement of the ram. On the upstroke, a cam (*D4*) prevents plunger movement until it is disengaged from the part, when the stop (*D5*) con



Material: No. 12 Ga. (0.109) H.R. steel strip
Pickled and oiled, A.I.S.I., C1010
Commercial quality, edge optional

Fig. 7-8. Twisting die. (*Harig Mfg. Co.*)

tacts the cam, allowing the spring (*D7*) to return the plunger to its original position. The work is held in position by the lever (*D6*), which, along with a stationary block, has a slot to position and prevent rotation of the part. The finished part is shown as *D1*.

Rotary Bending Dies. Two cam surfaces on the end of the punch (*D3*, Fig. 7-10) rotate a ring (*D1*) counterclockwise by contacting the cam rollers (*D2*) so that the piece part (a carpenter's brace handle made of ⅜-in. cold-rolled steel rod) is bent

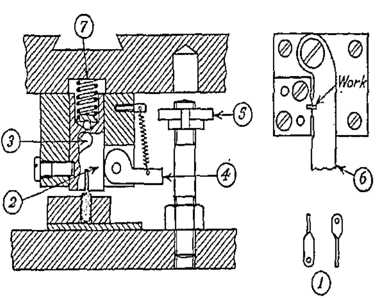


FIG. 7-9. Rotary twisting die.[5]

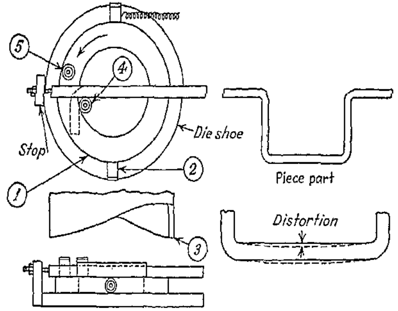


FIG. 7-10. Rotary bending die.[6]

between two hardened rollers (*D4* and *D5*). A conventional press setup provided too much spring-back to allow free turning of the hand grip sleeve.

Bending and Setting a Straight Flange. There is some wiping action as the flange of the workpiece is bent to a 90° angle (Fig. 7-11). A sliding punch (*D1*) is cam-actuated to "set" the 0.406-in. dimension. Stock of uniform thickness (0.040 in.) must be used; otherwise, the die can be wrecked. The part is positioned by the nest plates (*D2* and *D3*). This die could be classified as either a bending or forming die since both actions are used.

Cam-actuated Double-flanging Die. An H-shaped cutout is made in the blank to provide tabs which, when bent 90°, produce a flange extending above and below the surface of the finished part as seen in Fig. 7-12. The section through the bending die shows the reliefs cut in the pressure pad to allow these tabs to swing downward as the flange is being bent upward.

The blank is positioned in the die by the nesting blocks fastened to the sliding die blocks *D1* and is supported by the pressure pad. The flange is bent upward as the forming punch pushes the blank down between the sliding die blocks. The space

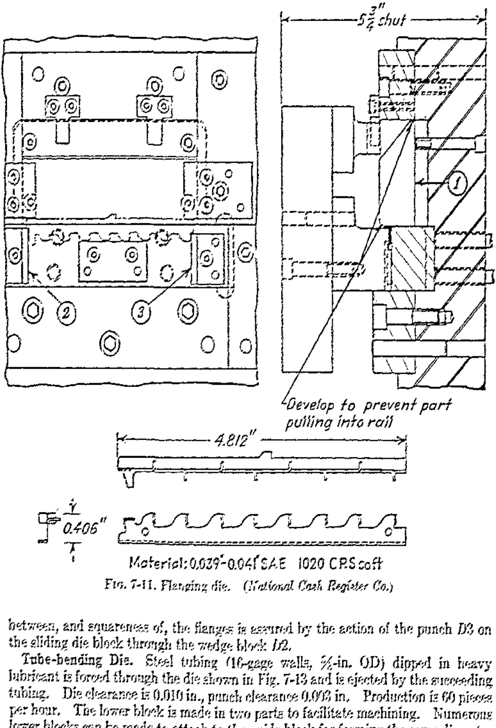


FIG. 7-11. Flanging die. (*National Cash Register Co.*)

between, and squareness of, the flanges is assured by the action of the punch *D3* on the sliding die block through the wedge block *D2*.

Tube-bending Die. Steel tubing (16-gage walls, ⅝-in. OD) dipped in heavy lubricant is forced through the die shown in Fig. 7-13 and is ejected by the succeeding tubing. Die clearance is 0.010 in., punch clearance 0.003 in. Production is 60 pieces per hour. The lower block is made in two parts to facilitate machining. Numerous lower blocks can be made to attach to the guide block for forming the same diameter tubing to different radii, thus making a more universal tool.

Die for Hemming an Auto Fender. An auto fender, with a 90° flange, is clamped against the die section (Fig. 7-14, *D5*) by a spring-loaded hold-down (*D8*) as the punch block (*D2*) descends. A sliding punch (*D7*) is forced to the left by the cammed plunger (*D*1) and the cammed block (*D*12), so that the flange is bent to the left at a 45° angle. A vertical punch (*D*9) descends to flatten the flange against a die block (*D*6) and to flatten it back on itself just after the sliding punch is forced to the right by the cammed plunger and the cammed block (*D*11) is not essential in providing correct timing for the vertical and sliding punch movement. The timing of the right-

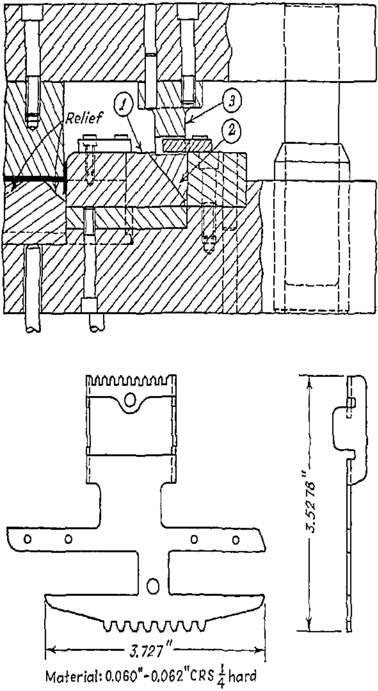


Fig. 7-12. Cam-actuated double-flanging die. (*National Cash Register Co.*)

hand or return movement of the sliding punch must be such that the sliding punch does not obstruct the downward movement of the flattening punch. A wear plate (*D*4) is fitted to the plunger, which slides between two die members (*D*3 and *D*13).

Flanging and Hemming Die. A flanged part is placed between a spring-loaded pad and an air pad (Fig. 7-15, *D*1, *D*2), and an angular flange (*D*5) is bent by the punch (*D*3). The hem is flattened by the action of the lower die member (*D*4) after the

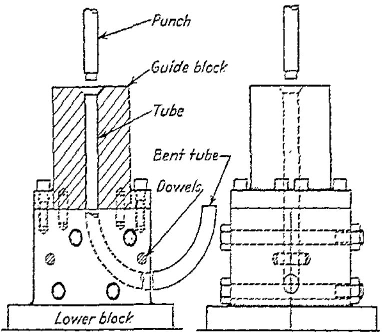


FIG. 7-13. Tube-bending die.[7]

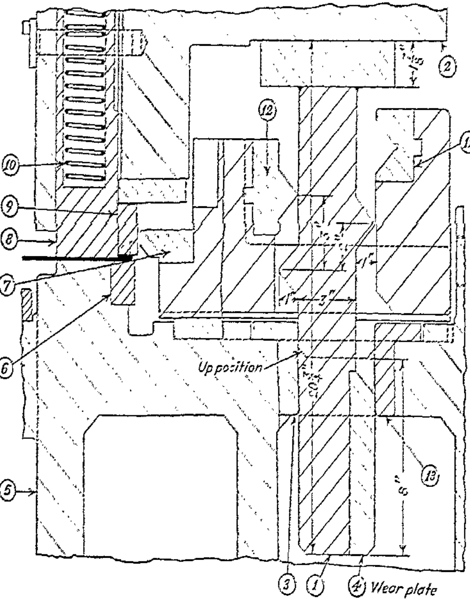


FIG. 7-14. Hemming die.

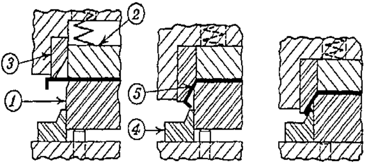


FIG. 7-15. Flanging and hemming die.[8]

air pad compresses. If the angular flange were nearly horizontal it would buckle instead of being flattened.

References

1. American Society of Tool Engineers: "Tool Engineers Handbook," McGraw-Hill Book Company, Inc., New York, 1949.
2. Sachs, G.: "Principles and Methods of Sheet-metal Fabricating," Reinhold Publishing Corporation, New York, 1951.
3. Hahl, H.: Double-bending Die Set Forms Small Channels, *Am. Machinist*, Aug. 4, 1952.
4. Mather, D. L.: Forming Die, *The Tool Engineer*, January, 1952.
5. Lee, L. L.: A Simple Twisting Die, *Am. Machinist*, Apr. 18, 1926.
6. Budnick, J.: Rotary Punch Bends Brace Handles, *Am. Machinist*, June 12, 1950.
7. Riley, F. E.: Press Tool Bends Tubing, *Am. Machinist*, July 28, 1949.
8. Cory, C. R.: "Die Design Manual," Part II, 1948.

SECTION 8

METAL MOVEMENT IN FORMING*

Forming. Forming is a metalworking process in which the shape of the punch and die is directly reproduced in the metal with little or no metal flow. Forming, bending, or drawing actions may be combined in a die; a die is classified according to the predominating action.

Forming Limits. Conventional mechanical tests used to accept or reject a given metal do not determine forming limits exactly, although they may be generally indicative as to type and extent of feasible forming operations.

The decision to use a form die, instead of a draw die, will depend considerably upon the part shape, for which the geometrical criteria are stated in Sec. 2.

The use of a draw die may be indicated if the use of a form die would (1) cause the metal to tear because of excessive tensile strain, or (2) form objectionable wrinkles because of an excess of metal.

Forming limits depend also on the metalworking method; a double-action die may successfully fabricate a certain part, where a single-action die could not.

Forming Stress. Forming limits are functions of various stress distributions and amounts; these stresses are also treated in Secs. 6 and 10. All stresses can be resolved into either tensile or compressive type for any single metalworking operation or combinations thereof. Analysis of combined stresses in a multiple operation can be quite difficult.

FORMING OF STRETCH AND SHRINK FLANGES

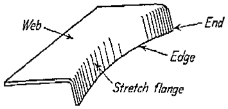
Figure 8-1 shows the two basic types of flanges—stretch and shrink. The reverse-type flange is a combination of these two. Any stretch flange can be considered as a segment of a flanged hole.

In stretch flanging, tensile strain increases from zero at the flange "break" line (axis of bending) to a maximum at the flange edge; for that reason, any tearing will start from the flange edge. The amount of tensile strain increases with (1) increasing forming angles and (2) increasing flange heights. Ability to withstand strain without tearing increases with the metal thickness and is also affected by the composition and treatment of the material and by its edge smoothness.

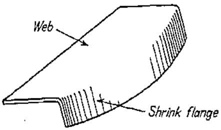
In shrink flanging, the tendency to wrinkle increases from zero at the flange break line to a maximum at the flange edge. Generally, wrinkling will be avoided if the flanging operation can be done in the same direction as that of the flange movement, so that any excess flange metal is ironed or "wiped" out to the edge of the flange as added flange height. To get such ironing or wiping effect, the blank may have to be tipped so that the flange is vertical in the die. Wrinkles cannot be forcibly spanked out of thin-gage flanges, but large wrinkles can sometimes be distributed into a greater number of small, unobjectionable wrinkles or may be changed into folds of metal.

Critical Strain. The distribution and the magnitude of strains in the forming of stretch and shrink flanges are mainly functions of the part shape.

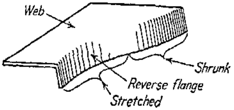
*Reviewed by C. R. Cory, Engineer in Charge of Die Engineering, Fisher Body Division of General Motors Corp., and Dr. George Sachs, Director, Metallurgical Research Laboratories, Syracuse University.



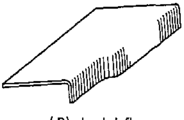
(*A*) Stretch flange



(*B*) Shrink flange



(*C*) Reverse flange



(*D*) Joggled flange

FIG. 8-1. Basic types of flanges.[1,*]

Referring to elements in Fig. 8-2, the critical strain e is defined as the ratio of flange movement a to the radius of curvature $(c \pm w)$:
For stretch flanges:

$$e = \frac{a}{c - w} \tag{1}$$

For shrink flanges:

$$e = \frac{a}{c + w} \tag{2}$$

where e = strain, in.
a = flange movement, in.
c = part radius at inner bend line, in.
w = developed flange width, in.

Note that the denominator in the above equations is, respectively, the difference or sum of the part radius c at the inner bend line and the developed flange width w, at the center of the flange. In many instances where the bend radius is small, an

* Superior numbers relate to References at the end of this section.

approximate value for the flange movement is given in Eq. (3), assuming that the bend radius and metal thickness are zero, and that there is no change in flange width:

$$c = w(1 - \cos\alpha) \tag{3}$$

where α = bend angle, deg

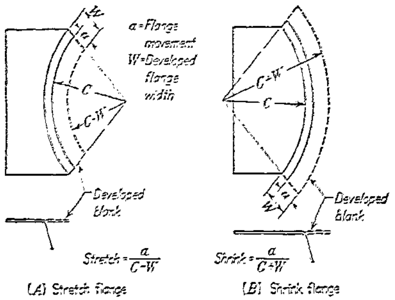


FIG. 8-2. Nomenclature for contoured flanges.[1]

For 90° bend angles, the critical strain is approximately:[1]
For stretch flanges:

$$\epsilon = \frac{w}{c - w} \tag{4}$$

For shrink flanges:

$$\epsilon = -\frac{w}{c + w} \tag{5}$$

The limiting strain for a stretch or shrink flange, derived from Eqs. (1), (2), and (3), is defined by Eq. (6):

$$\epsilon = \frac{1 - \cos\alpha}{(c/w) \pm 1} \tag{6}$$

where the sign in the denominator is minus for a stretch flange and plus for a shrink flange.

Influence of Edge Condition. The condition of a flange edge subjected to stretching can considerably affect the forming limit, and to a greater extent with aluminum than with steel. It is seen in Fig. 8-3, that for a given segment angle, 24SO aluminum alloy with edges polished can be stretched 20 per cent or more without any difficulty. It is also seen that, for a given edge condition, permissible stretch is reduced as the segment angle increases.

Spring-back Allowance. In forming contoured flanges, the metal tends to spring back toward its original flat condition, and a compensating angular allowance must therefore be provided on the form block or punch. The usual amount of such allowance is 2° for steel, 3° for SO aluminum, and 6° for ST aluminum.

It can happen that, in addition to the spring-back, there will be a distortion or "bowing" in the lengthwise direction of the flange. In a stretch flange, with attendant elastic shrink, the bowing will be concave; for a shrink flange, there will be elastic stretch and *convex* bowing. The magnitude of bowing in 24ST aluminum has been investigated and may be determined from Fig. 8-4. Steel parts do not generate so much lengthwise spring-back as aluminum parts.

Because of the several factors involved, such as the kind and condition of material, and amount of stretch or shrink, final determination of spring-back must generally be left to die tryout.

Flange-edge Thickness Changes. The forming of stretch or shrink flanges is always accompanied by change in metal thickness at the flange edge, thickness being

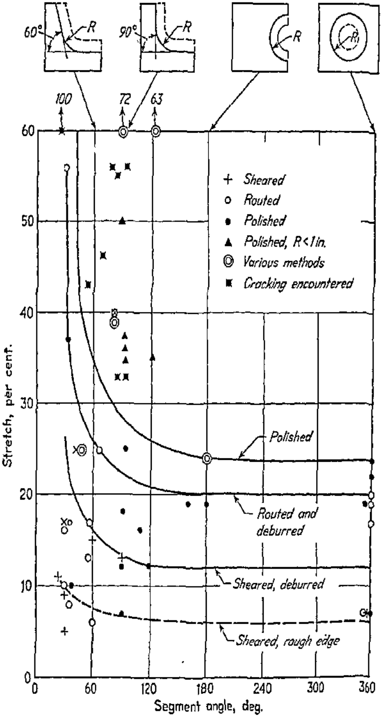


FIG. 8-3. Stretch values as a function of edge condition and segment angle, for 24SO aluminum flanged parts.[1]

decreased for a stretch flange and increased for a shrink flange. This thickness change is usually insignificant, especially in the case of steel parts. Generally die tryout is necessary for accurate determination, but an approximation is

$$\text{Thickness change } \Delta T = \pm \frac{Te}{2} \qquad (7)$$

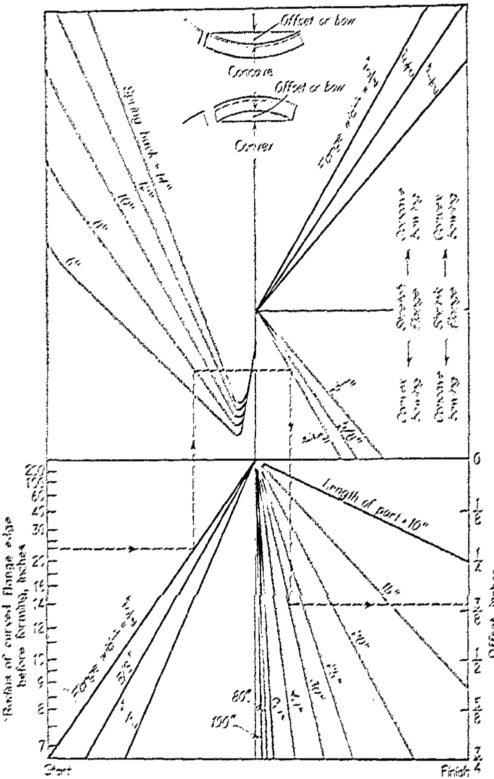


FIG. 8-4. Bowing in 24ST aluminum as a function of spring-back, part length, and flange radius and width.[1]

The plus sign indicates an increase, and the negative sign a decrease in metal thickness.

FLANGING OF HOLES

Holes in sheet metal with surrounding flanges of various shapes are frequently termed "extruded," "countersunk," "burred," or "dimpled" holes. However, they are all holes with stretch flanges.

Dimpling. A dimple is a small conical flange around a hole in sheet metal; it is a stretch flange encircling the hole. Two or more sheets riveted together, using dimples, provide a 40 per cent stronger joint than a conventional riveted joint, provided that the ram coin-dimpling process is used in forming the dimples (Figs. 8-5 and 8-6) around previously pierced holes. The ram coin-dimpling operation introduces pressure in the direction of the thickness of the sheet to reduce internal stresses and thereby increase the amount of strain to fracture the sheet. This process has superseded conventional dimpling for aluminum and stainless-steel parts; no coining action is present in the latter method.

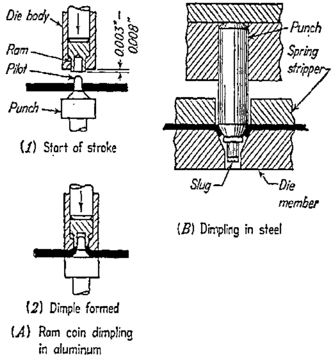


FIG. 8-5. Dimpling methods.[3]

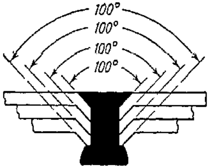


FIG. 8-6. Proper nesting of ram-coin-dimpled sheets.[3]

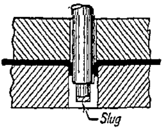


FIG. 8-7. Hole flanging with a two-step punch.

The critical strain e in a dimple is

$$e = \left(\frac{D}{d} - 1\right)(1 - \cos \alpha) \tag{8}$$

where D = rivethead diameter, in.
d = hole diameter, in.
α = bend angle, deg

Dimpling, confined mainly to air-frame fabrication, is done in dies heated to 600°F, for some aluminum alloys, using portable or stationary dimpling machines.

For steel parts, holes are characteristically pierced, and the dimples are formed by one punch in a single stroke, as shown in Fig. 8-5*B*. The size of the piercing point on the punch is somewhat smaller than the size of the hole in the finished part. The hole in the die member may be $\frac{1}{32}$ in. larger than the point size, since piercing occurs before the metal is entirely forced down to the countersunk shape of the die member.

90° Hole Flanging. Forming a flange around a previously pierced hole at a bend angle of 90° (the most common operation) is nothing more than the formation of a stretch flange at that angle and Eq. (4) applies for the critical strain.

A 90° hole flange can be pierced and flanged in one stroke, using a two-step punch as shown in Fig. 8-7.

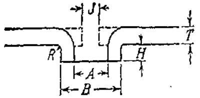


FIG. 8-8. Elements of a hole flanged for tapping: J, diameter of original pierced hole; T, thickness of stock; R, bend radius of flange; A, ID of hole flange; B, OD of hole flange; H, width of flange.

One manufacturer has standardized flange widths (Fig. 8-8, dimension H) for holes to be tapped in low-carbon-steel stamping stock, as follows:

$B = A + \frac{5T}{4}$ when T is less than 0.045 in.

$B = A + T$ when T is more than 0.045 in.

$H = T$ when T is less than 0.035 in.

$H = \frac{4T}{5}$ when T is 0.035 to 0.050 in.

$H = \frac{3T}{5}$ when T is more than 0.050 in.

$R = \frac{T}{4}$ when T is less than 0.045 in.

$R = \frac{T}{3}$ when T is more than 0.045 in.

$$J = \sqrt{\frac{TB^2 + 4TA^2 + 4HA^2 - 4HB^2}{9T}} \tag{9}$$

References

1. Sachs, G.: "Principles and Methods of Sheet-metal Fabrication," Reinhold Publishing Corporation, New York, 1951.
2. Krivobok, V. N., and G. Sachs: "Forming of Austenitic Chromium-nickel Stainless Steels," *The International Nickel Co., Inc.*, New York, 1948.
3. Luedde, J., and D. Boekemeier: "Dimpling Manual," McDonnell Aircraft Corp., 1952.

SECTION 9

FORMING DIES*

Simple Flanging Dies. Figure 9-1 shows a die for simultaneously forming and stretch-flanging a right-hand and a left-hand part from 24SO clad aluminum alloy, 0.064 in. thick, in a 250-ton double-action hydraulic press. The previously developed blank was annealed at 650°F, with edges polished at *A* and *B* to prevent cracks from forming. Deformations were: stretch, 43 per cent at *A*, 55 per cent at *B*, 12 per cent at *C*; decrease in thickness, 22 per cent at *A*, 28 per cent at *B*, 11 per cent at *C*.

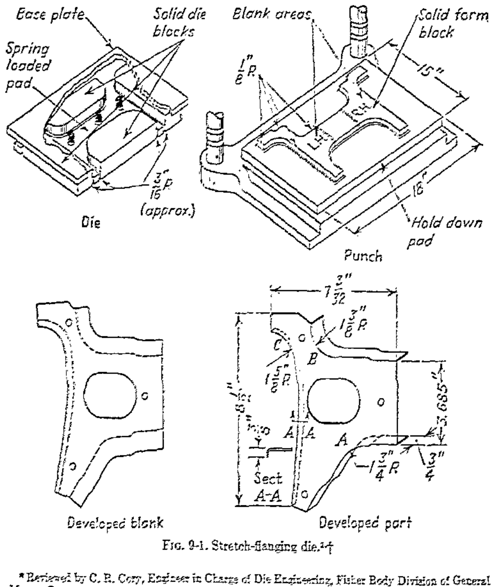


Fig. 9-1. Stretch-flanging die.[1]†

* Reviewed by C. R. Cory, Engineer in Charge of Die Engineering, Fisher Body Division of General Motors Corp.

† Superior numbers relate to References at the end of this section.

The spring-loaded pad attached to the inverted die holds the web of the blank as the solid die blocks form the flanges down. Gages or nests for this elementary die are not shown. It is not capable of high production, and the finished part is removed by hand. A high-production design would incorporate a pressure pad attached to the lower shoe and an automatic stripper (such as stripping hooks) to remove the part from the solid form blocks.

Figure 9-2 shows tooling for shrink-flange forming of a part from 24SO clad aluminum alloy, 0.032 in. thick, in a 40-ton crank press. The part is produced from a developed flat blank. The major shrink strain at the closed end of flange was 25 per cent, necessitating use of deep-drawing technique. Pressure is supplied by a spring pad and pins from a cushion.

Drawing and/or stretching of the metal may occur in the die, depending upon the amount and location of the net hold-down pressure exerted.

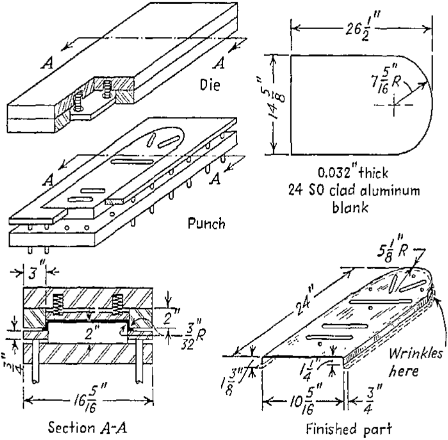


FIG. 9-2. Shrink-flanging die.[3]

Die designs for the forming of curved flanges commonly incorporate a spring or pneumatic pad for clamping the web, to prevent slippage or distortion. Sometimes, adequate clamping pressure can be secured by forming right-hand and left-hand parts in the same blank, and subsequently trimming them apart (Fig. 9-3).

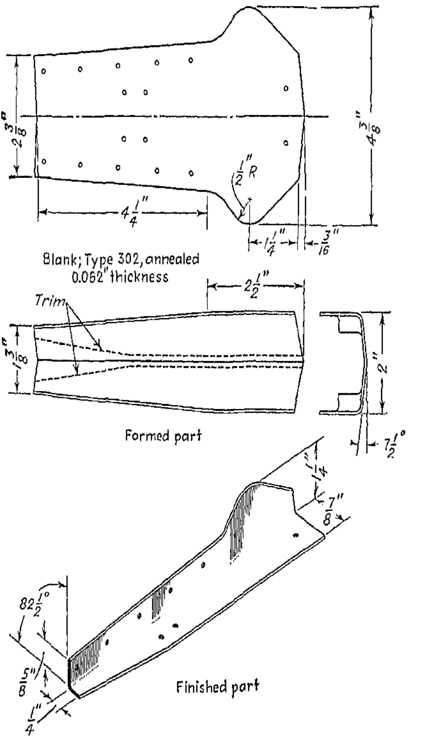


FIG. 9-3. A right-hand and left-hand part laid out for simultaneous forming of stretch flanges.[2]

Flanging an Automotive Part. A design for the quantity forming of a slightly bowed and tabbed flange is shown in Fig. 9-4. Gage pins (*D*6*) enter the holes in the

* *D* indicates detail number on drawing.

blank, and gages (*D*7) position the blank and prevent its slipping. The flange (*D*1) and its tab (*D*2) are formed upward and outward by the punch (*D*4) against the die (*D*3) as the punch forces the pad (*D*5) down. Pressure is supplied to the pad through air pins (*D*8) by a die cushion. The part falls out of the back of the die used in an inclinable press.

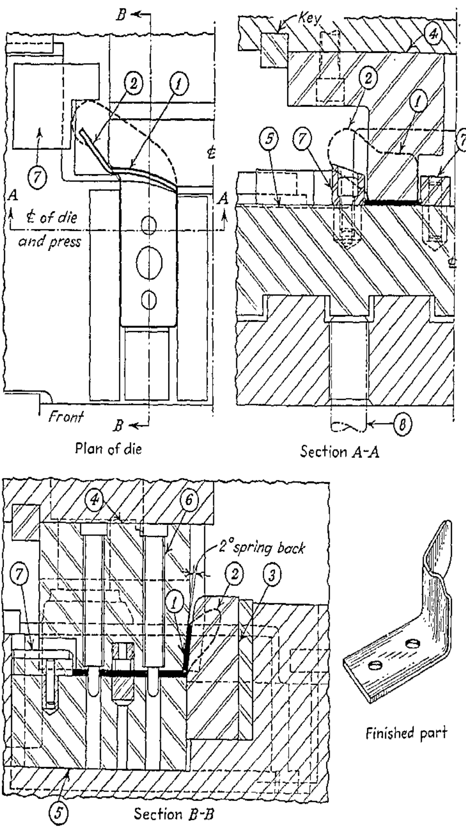
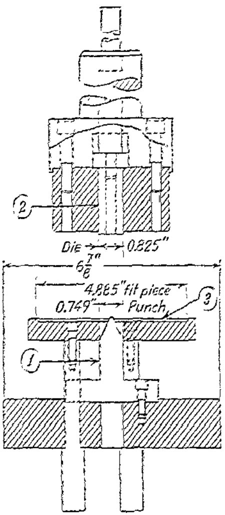


FIG. 9-4. Forming a tabbed flange. (*C. R. Corp.*)

Hole-flanging Die. The formation of a $\frac{5}{16}$-in. hub (ID of 0.748 in.) or circular flange around a $\frac{1}{4}$-in.-diameter hole is accomplished in the die shown in Fig. 9-5. The inverted flanging punch (*D*1) (0.7495 in. diameter) enters the hole in the workpiece (a fan of 0.037-in.-thick, deep-drawing hot-rolled steel).

Slitting and forming of the blades, as well as spot welding the fan back, are done in subsequent operations. A die cushion actuates the stripper (*D*3) and the part is removed by a knockout (*D*2).



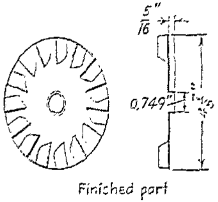


FIG. 9-5. Hole-flanging die. (*Century Electric Co.*)

Flanging Large Flat Parts. The forming of flanges around the periphery of refrigerator doors, home-freezer lids, and similar parts is frequently done in dies equipped with a number of cams. The cam action shown in Fig. 9-6 is not in the same direction as the action of the vertical forming punch. Cam return (not shown) is by spring action or by the positive return stroke of the driver.

Double-cam Flanging Die. The die shown in Fig. 9-7 has, in addition to the outside cam, an inner cam which collapses when the die is open. The inside cam action is required whenever the part is locked on the punch by interfering flanges, offsets, or shapes.

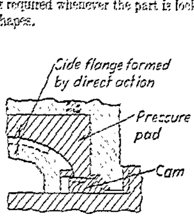


FIG. 9-6. Cam flanging die.[4]

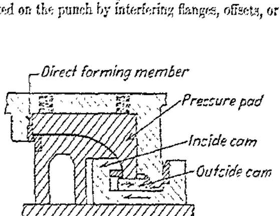


FIG. 9-7. Internal and external cam flanging die.[4]

Forming a Flanged Cylinder. A circular flat blank (0.0375-in. deep-drawing hot-rolled steel) with an OD of 1$^{15}/_{16}$ in. and an ID of $^{21}/_{32}$ in. is formed into a flanged cylinder in the die shown in Fig. 9-8. A double-action press, equipped with a rubber die cushion, performs a combined drawing and flanging operation. The circular blank is loaded in the nest (*D*1) and centered on the pin on the lower knockout (*D*3). The outer ram of the double-action press descends to lower the spring pad (*D*4) and draw sleeve (*D*5). The spring pad grips the blank as the draw sleeve draws the part to the 1.4145-in. dimension. The part is then gripped between the draw sleeve and the step in the die and the inner punch (*D*6) descends to draw the 1.1785-in. dimension and complete the part.

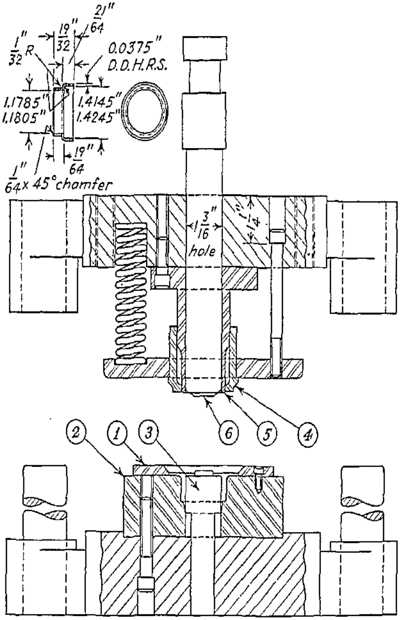


FIG. 9-8. Hole-flanging die. (*Century Electric Co.*)

Flanging Shim Stock. Two-inch strip shim stock 0.003 in. thick is blanked and pierced by 0.069-in.-diameter nail punches (*D*1, *D*5) which also forms flanges around the hole to a height of 0.036 in. (Fig. 9-9).

The holes are pierced without the cutting of any slugs, by the use of a four-sided tapered point on the punches. The 0.069-in. flanged holes shrink to a diameter of 0.067 in. after the flanges are formed and the punches withdraw. Spring-loaded ejector pins (*D*2, *D*6) are used in this die design, which achieves piercing and flanging in opposite directions by the use of a lever (*D*3) actuated by a pin (*D*4).

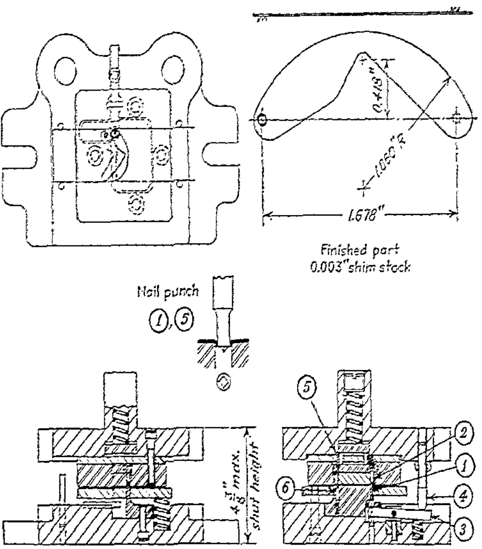


FIG. 9-9. Flanging holes in opposite directions. (*Harig Mfg. Corp.*)

Forming an Inward and a Straight Flange. An inward flange is formed by a cam forming member sliding on a horizontal surface of the die shoe in the die shown in Fig. 9-10. The cam driver, with a driving angle equal to or greater than the angle of the flange to be formed, forces the cam flanging member inward as the air-pressure pad is

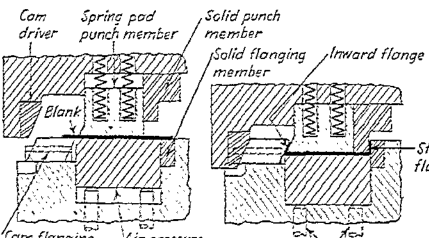


FIG. 9-10. Forming an inward and a straight flange. (*C. R. Cory.*)

forced down. The punch is split into two parts: a spring-loaded punch, and a solid punch, which forms the straight flange, a design that prevents the part from sticking to the split punch. On the upstroke the pad travels upward carrying the flanged part above both the solid flanging member and the cam flanging member so that the finished part can be removed.

Return Flanging Die. The dies shown in Figs. 9-11 and 9-11*A*, for flanging a freezer-lid panel, are notable for their low required shut height of 16 in., as compared with 24 in. required by conventional design.

The 20-gage cold-rolled-steel part (previously pierced, drawn, and redrawn) is placed in the die with its flanges down. The die incorporates a spring pad traveling ahead of any action. Six side and end cam drivers (*D*6) and four corner cam drivers (Fig. 9-11, *D*7) arrive simultaneously, pulling all the center collapsible sections outward. The cam drivers dwell while the outer cam slide flange sections travel inwardly, thus forming the four flanges under at one press stroke.

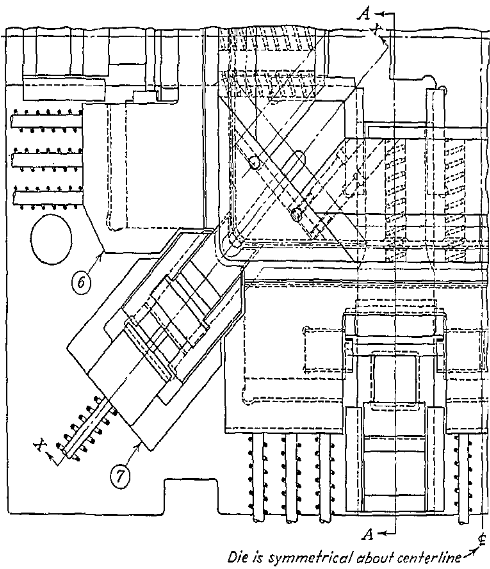


Fig. 9-11. Quarter-plan view of die for flanging a freezer-lid panel.[15]

On the upstroke, the outer cam slides move outward after the inner collapsible sections recede under spring pressure toward the center of the die, permitting the part to be unloaded. Figure 9-11*A* shows the cam drivers (*D*1) and the corresponding external and internal collapsible or retracting forming members (*D*2, *D*3) for the rounded corners of the lid. Similar sets of forming members (*D*4, *D*5) flange the straight sides of the lid. This die in a 150-ton mechanical press attended by two operators produces 120 pieces per hour.

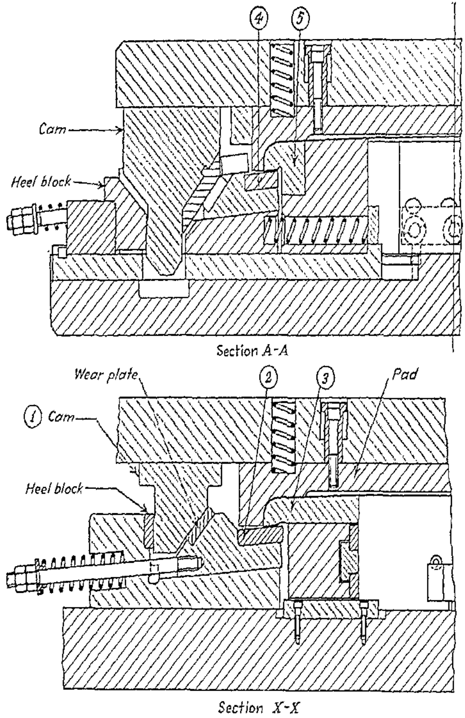


FIG. 9-11*A*. Section views of die in Fig. 9-11.

Roller Die for Flanging Inwardly. The swiveling die members (*D*1) in the die shown in Fig. 9-12 are rollers which flange 0.031-in. copper blanks (1$\frac{3}{16}$ in. by $\frac{5}{8}$ in.) placed between the locating pins (*D*2). The work is bent to form the completed clip by the revolving rollers, actuated by the punch (*D*3). The part is slid endwise off the punch.

Typical Standard Cam Forming Die. Cam-actuated forming-die designs are standard designs with many manufacturers; Fig. 9-13 illustrates a typical design. Either spring shedder pins or conventional strippers are incorporated (not shown) if the flange angle is close to 90°. The die can be wrecked if stock thickness is not uniform.

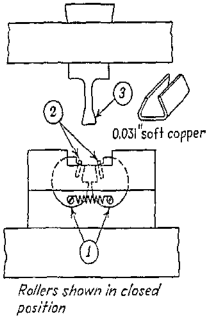


FIG. 9-12. Swiveling-roller die for flanging.

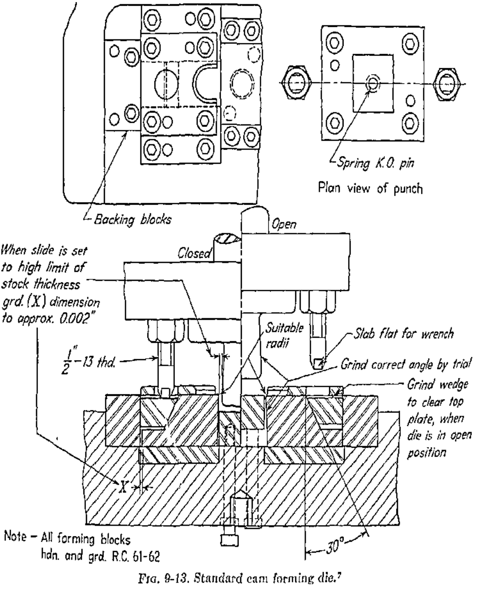


FIG. 9-13. Standard cam forming die.[7]

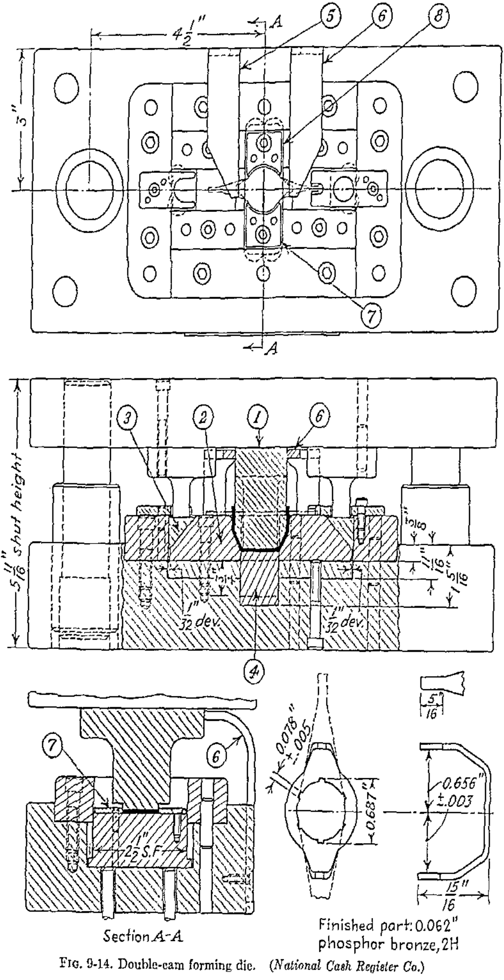


FIG. 9-14. Double-cam forming die. (*National Cash Register Co.*)

Double-cam Forming and Setting Die. After the vertical punch (Fig. 9-14, *D*1) has completed its forming function, horizontal punches (*D*2) actuated by two cams (*D*3) set the legs of the part. A floating member (*D*4) with a vertical travel of 3/4 in. (*A*) limits cam movement through pad action to allow for thickness variations in the part (0.062-in. phosphor bronze, 2H). Legs are set to ±0.003 in. from the center line. Nest plates (*D*7, *D*8) position the part, and it is removed by stripping brackets (*D*5, *D*6).

Die for Press-brake Flanging. Flanges and joggles in aluminum strip (0.072-in. Alclad 75SW) are formed in the press-brake die shown in Fig. 9-15. The blanks are heat-treated and stored at approximately 0°F so that they will not age-harden before forming is completed. An insert (*D*6) in the joggle die (*D*2), in conjunction with a pressure pad (*D*4), the flange die (*D*3), and the punch (*D*5), form the flanges and joggles. The part is positioned at each end by locating pins (*D*1) and removed by the stripper (*D*7).

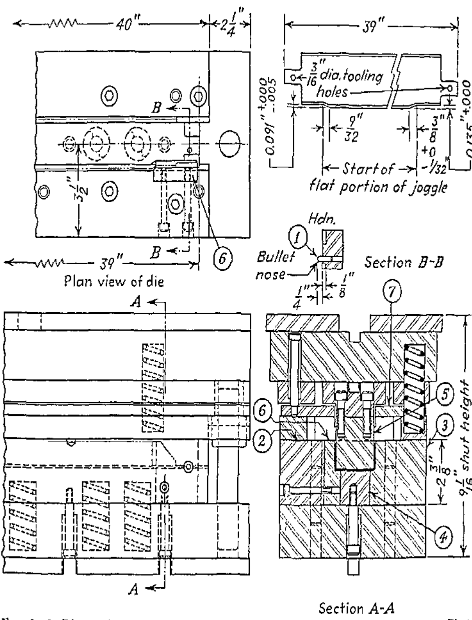


FIG. 9-15. Die for joggle and flange forming in a press brake. (*The Emerson Electric Mfg. Co.*)

Embossing and Flanging Die for Channel. The die shown in Fig. 9-16 performs the first (embossing) and third (flanging) operations in producing a channel structural member of 0.064-in. 3S half-hard sheet aluminum. A second (trimming) operation is performed in a die not shown. The embossing is done with a long shim block (*D*1) inserted between the die shoe and the embossing die. The third (flanging or channel-forming) operation is performed with the shim block (*D*1) removed (section *B-B*), permitting the punch member to enter the lower die member to form the channel sides.

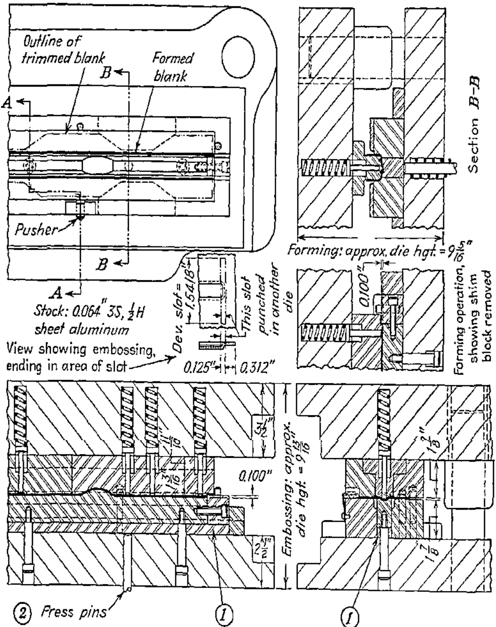


FIG. 9-16. Flanging and embossing die. (*Harig Mfg. Corp.*)

Overform Flanging Die. The part, of 0.050-in. cabinet sheet steel, is overformed from a flat blank positioned by suitable nests (not shown) in the die illustrated in Fig. 9-17. The pressure pad (*D*2) is actuated by pressure pins (*D*1). The 90° flange is formed in another similar die, followed by a restrike operation to set the angle and dimensions of the 90° flange.

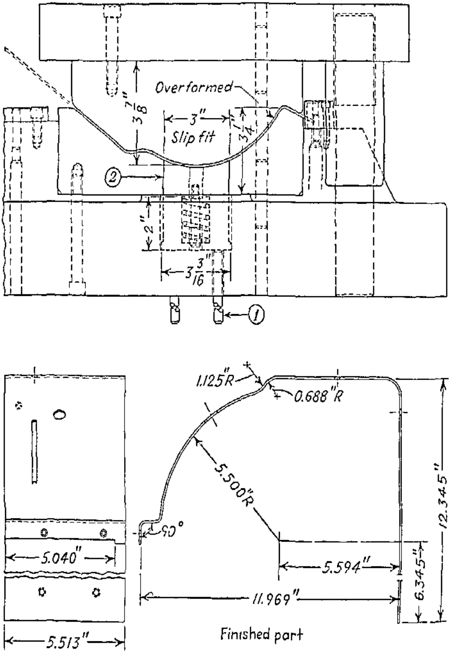


FIG. 9-17. Overform flanging die. (*National Cash Register Co.*)

Forming Permanent Magnets. Magnet steel (0.320 by 0.320 in. by 5¼ in. long) is formed between hinged form blocks (*D*1) and the punch (*D*2, Fig. 9-18) into a U shape, after the blank is placed between the gages (*D*3). A cam-actuated knockout (*D*4) strips the work from the vertical punch and is retracted by springs (*D*5). The part is snapped to the right and comes to rest around the two locating pins (*D*6). The U-shaped blank is sized, on the next press stroke, between the flattening punch and die (*D*7, *D*8).

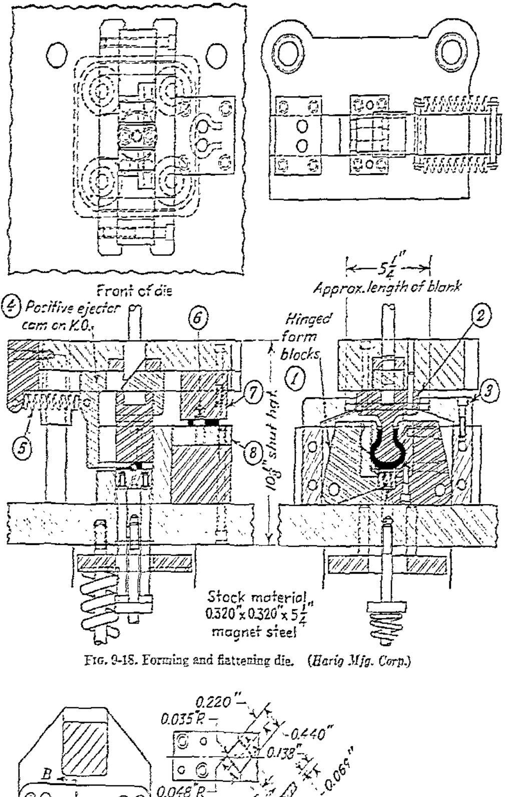


FIG. 9-18. Forming and flattening die. (*Harig Mfg. Corp.*)

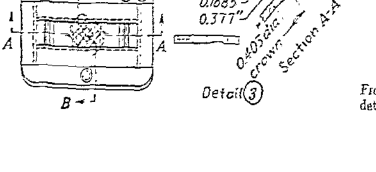


FIG. 9-19B. Sliding punch detail for die of Fig. 9-19.

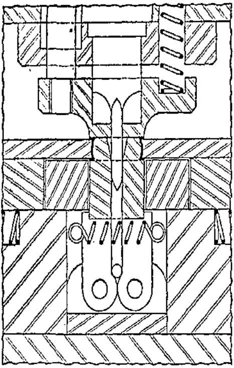


Fig. 9-19A. Enlarged view of punches in the die of Fig. 9-19.

Hand-operated Forming Die. A small square bobbin (a coil form) of 0.010-in.-thick metal is formed from a square tube in the die shown in Fig. 9-19. An expanding punch (*D*1) forces two hinged punches (*D*4) apart which expand the tube against two sliding punches (*D*3) actuated by two cams (*D*5). An upper flange approximately 0.007 in. wide is formed between the upper punch and member (*D*2) and a lower flange is formed between the sliding punches and the shoulder of the hinged punches. This small die set is hand-operated.

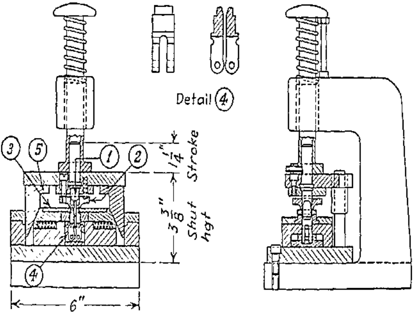


Fig. 9-19. Hand-operated flanging and forming die. (*Harig Mfg. Corp.*)

Die Forming of Gold Sheet. A blank made from 0.028-in.-thick 14K gold is placed in a nest (Fig. 9-20, *D*9). As the ram descends, the part is U-formed by the spring-loaded punch (*D*6). Near the bottom of the stroke, this punch dwells while the double-faced cam (*D*1) forces two slides (*D*4, *D*5) inwardly to offset the part. A cam-actuated knockout (*D*3) strips the part from the punch and ejects it toward the rear of the die. The knockout has a spring return (*D*7, *D*8).

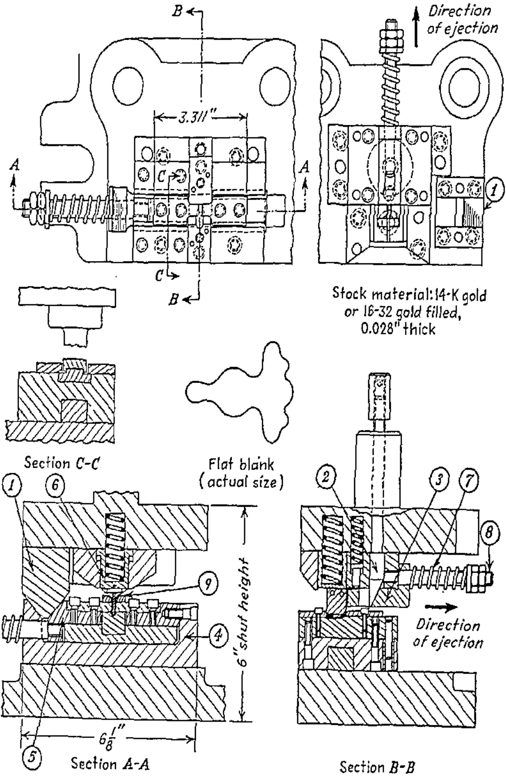


FIG. 9-20. Single-cam double-slide forming die. (*Harig Mfg. Corp.*)

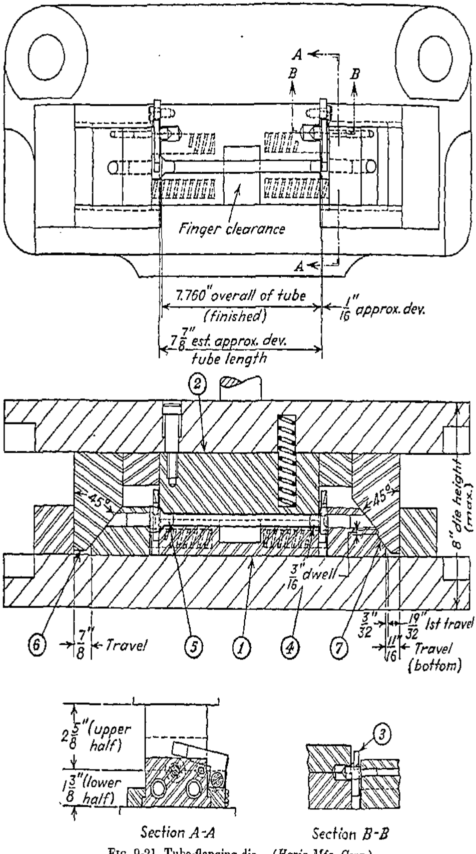


FIG. 9-21. Tube-flanging die. (*Harig Mfg. Corp.*)

Die Design for Tube Flanging. Steel tubing is clamped by a die member (D1) and a spring-loaded pad (D2) in the die shown in Fig. 9-21. Retracting gages (D3) return automatically after the tubing is flanged and expanded on the right and left ends, respectively, by suitable punches (D4, D5), which are actuated by cams (D6, D7). Note that the right-hand flanging die is cammed into the part and then dwells for 1/16 in. of the press stroke so that the left-hand flanging die can completely enter the part; then both dies can continue on in, flanging the tube on both ends.

Forming and Flattening Operations on Tubing. The die shown in Fig. 9-22 is used with a die cushion to form stainless steel preformed tubing and also to flatten a section by a swaging operation. Fractures at the corners have resulted from the use of nonhomogeneous stock.

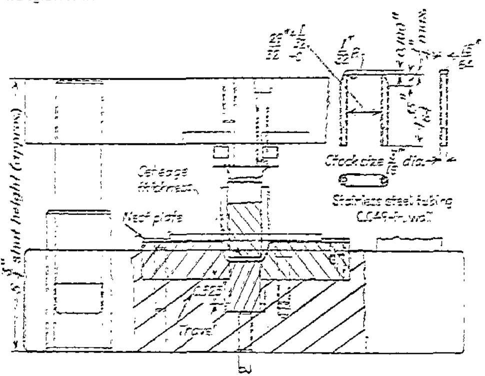


Fig. 9-22. Forming and swaging die. (National Cash Register Co.)

Forming Die for Motor Frame Foot. A developed blank (Fig. 9-23A) is engaged by two pilots incorporated in the forming die of Fig. 9-23. The second and final forming of the part is completed in a die of identical design except that punch and die radii are smaller and that it is equipped with suitable punches and die inserts (shown in Fig. 9-23) for forming welding projections. The part is trimmed and slotted in two subsequent operations.

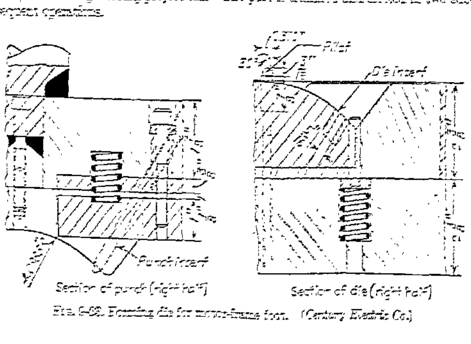
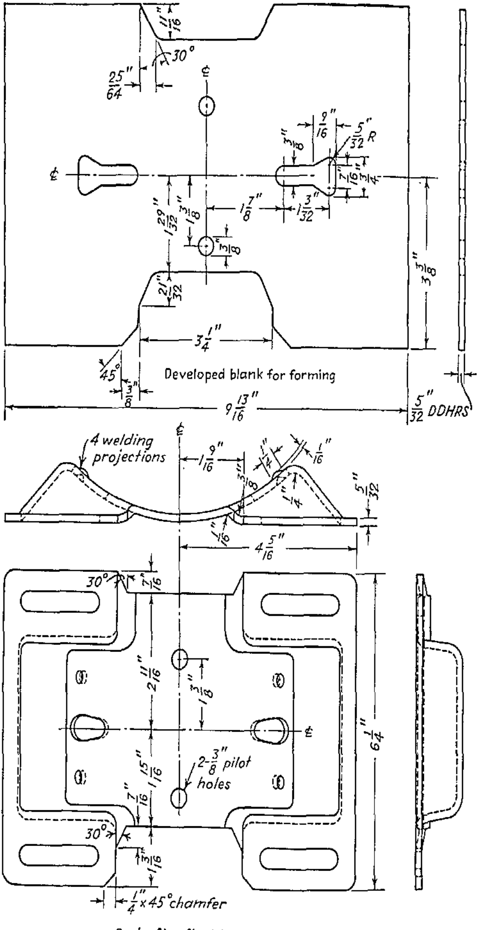


Fig. 9-23. Forming die for motor-frame foot. (Century Electric Co.)



Part after final forming

Fig. 9-23A. Developed blank and part formed in the die of Fig. 9-23.

CURLING DIES

Curling the edge or edges of a flat or curved sheet, tube, or shell is essentially a flanging operation; it consists of an expansion of the metal followed by its reduction. The term reduction is not to be confused with its use in connection with drawing operations.

Curling-punch Design. The diameter of the groove in a curling punch should equal the curl diameter of the part. The groove diameter should not be less than $\frac{1}{16}$ in. for

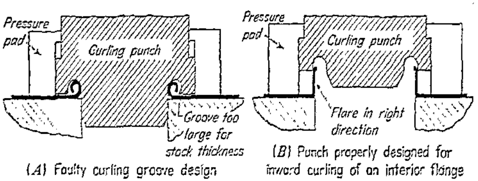


Fig. 9-24. Curling-groove design.[6]

a stock thickness of 0.010 in.; the groove diameter should not be less than $\frac{1}{8}$ in. for 0.018-in. stock thickness, according to Mills. Crane states that the curl diameter should be from 10 to 20 times metal thickness. When the groove is too large, the curl forms to its own diameter (*A*, Fig. 9-24).

Burr and Flare Direction. The optimum condition of a shell or tube for curling occurs when both its burr and flare are in the direction of curling.

Outward curling of a shell periphery is the easiest curling operation, particularly if the shell has been drawn in a single-action die.

Inward curling on an interior flange (*B*, Fig. 9-24) is easier to accomplish, when the flare is inward, than an outward curling.

Die-design principles for the inward curling of shallow and deep shells are shown in Fig. 9-25. If the piece edge has been nipped, or has a flare in the right direction, the use of a tapered plug may be unnecessary.

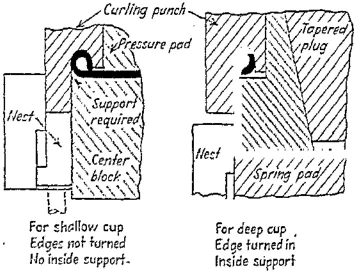


Fig. 9-25. Die-design principles for inwardly curling shallow and deep shells.[6]

Inward Curling of a Deep Shell. This operation is achieved in the die of Fig. 9-26, *which is equipped with an expander (D1) that slides on the top surface of a supporting* plug (*D*2). A heavy spring (*D*5) presses against a tapered plug (*D*3) to provide dwell for holding the expander open before the curling punch engages the work. After the curling punch has cleared the work on the upstroke, a spring (*D*6) causes the expander to dwell until it is collapsed by the upward movement of the curling steel. The light spring (*D*4) merely retains the supporting plug (*D*2).

Curling a Can Cover. A heel on the curling punch (Fig. 9-27, *D*1) supports the inside of the work (a can cover) which is to be curled outwardly. A pocket in the die supports the outside of the work, which is stripped by an adjustable-spring counterbalanced knockout and oil-seal breaker pins (*D*2). During the working stroke, the part is gripped between the lifting plate and the knockout. On the upstroke the lifting plate ensures positive part movement upward with the punch so that it can be ejected.

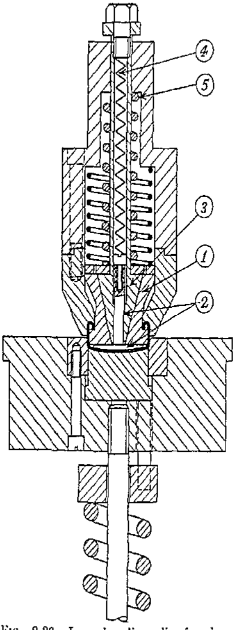


Fig. 9-26. Inward-curling die for deep shells.[6]

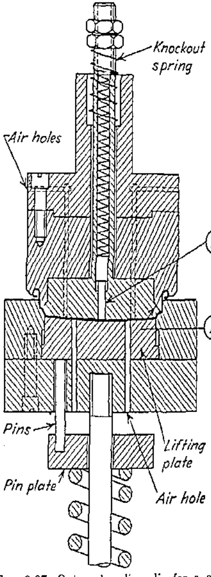


Fig. 9-27. Outward-curling die for a can cover.[6]

Die for Forming Partial Curls. Two partial curls are formed in 0.012-in.-thick 8H phosphor bronze in the die shown in Fig. 9-28, by cam-actuated punches (*D1*, *D2*). The part is gaged into location without manual adjustment. The hand ejector mechanism, pushing the part out from the back of the die, functions only when the part is fully formed. Note that the part has been nipped to facilitate producing the curl on the right-hand side.

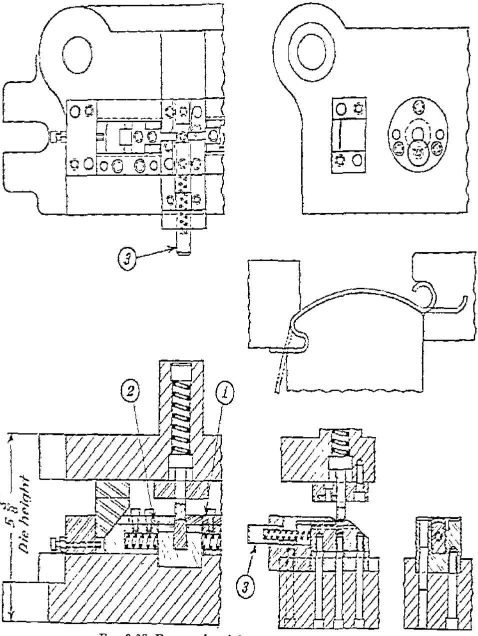


FIG. 9-28. Form-and-curl die. (*Harig Mfg. Corp.*)

Curling and Flanging Die with Retractable Holding Jaws. A holding clamp (Fig. 9-29, *D1*) opened by a plunger *D2* allows a curl to be formed on one end of the part by a curling punch *D3*. A flanging punch *D4* flanges the sides of the part (a pen clip of 0.020-in.-thick base metal).

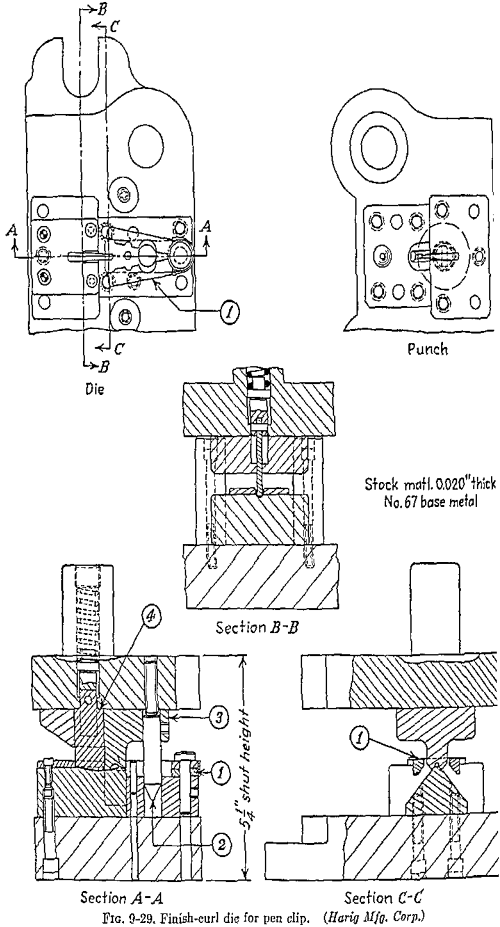


FIG. 9-29. Finish-curl die for pen clip. (*Harig Mfg. Corp.*)

Hinge-forming Die. A revolving lower curling steel (Fig. 9-30, *D1*) is loaded while in the horizontal position. The part to be curled is located over two locating pins (*D4*) and backed up by a support plate (*D3*). The anvil block (*D8*) has a slot to provide clearance for the locating pins (*D4*). This anvil block is free to move in a vertical direction and is held against its upper stops by springs (*D9*). On the downstroke a plunger (*D2*) swings the lower curling steel (*D1*) to a vertical position. The lower curling steel is then forced against the anvil (*D8*) by the heel (*D5*) on the die block (*D6*). The upper curling die then contacts the anvil and drives it downward, curling the part as it goes. The entire force of the curling operation is carried by the support plates (*D3*) which must be securely doweled in place. Since the work is loaded and unloaded in a horizontal position and away from the closing members of the die, this design provides for operator safety.

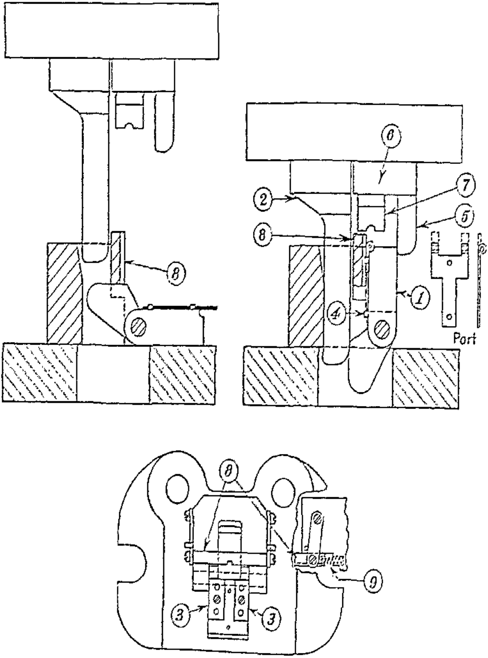


Fig. 9-30. Hinge-forming die.[5]

Curling Channel Edges. Slots in a typewriter part (Fig. 9-31) are gang-milled after three die operations curl the edges. The first operation (not shown) forms the flat blank into a channel shape, with radii equal to one-half of the ID of the final curl (0.1575 in.). The part is placed, legs down (view *A*) in a nest consisting of a split die and cam-actuated forming punches. The spring-loaded plunger (*D*1) forces the part and the expanding die steels (*D*2) downward. The die steels are expanded by an adjustable wedge (*D*3) and hold the part while the outer die halves are cammed in to form the start of the inward curl. The curl is completed by a solid die and a conventional curling punch (view *B*).

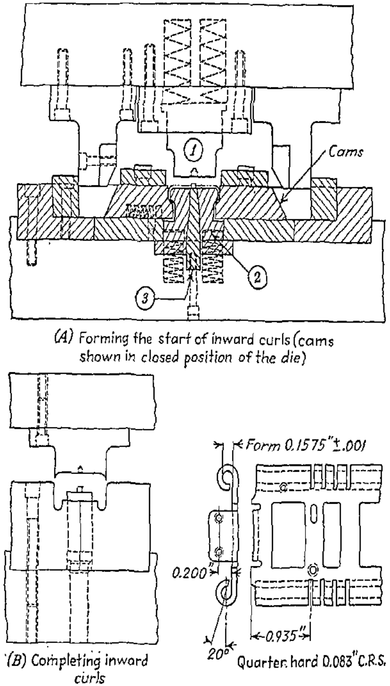


FIG. 9-31. Dies for curling channel edges.[8]

Inward Curling of a Shallow Part. This operation will distort and bulge the curl (Fig. 9-32, *A*) if any of the following conditions are present: the curling punch is too loose or too tight; there is too much or too little material; the pressure pad does not clamp the work before the curling punch engages the work; or the flange of the workpiece has high spots. Rubber suction cups, assisted by spring-loaded pins, lift the part from the die and a knockout removes the part from the cups.

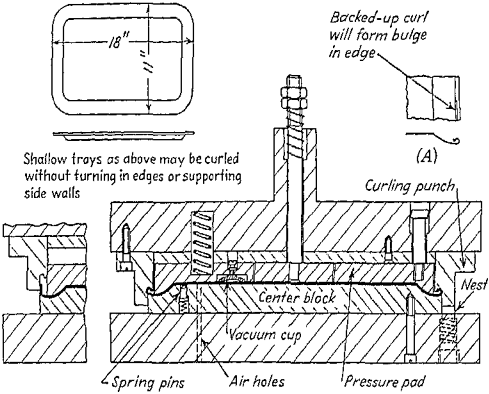


FIG. 9-32. Inward-curling die for shallow parts.[6]

Wiring Dies. Strictly speaking, a wiring die is a curling (or false-wiring) die in which a wire is inserted in the edge to be curled either by hand or by a suitable spring pad, so that the part edge is curled around the wire. Such an operation is simply *forming a shrink flange which can be formed without wrinkles provided that the flange width is less than ten times the metal thickness*; it is commonly done on annealed metals such as the wiring of pails, pots, and similar utensils.

Seaming Dies. Seaming dies usually join or crimp straight or curved flanges together, although it may be an operation of hemming only (Fig. 7-14), in which case the flange is bent back upon itself and flattened to give the part increased strength.

Longitudinal Seaming of Tubes. Horn-type die designs for seaming round tubes are shown in Fig. 9-33. The edges of the tube are bent and hooked together before it is slid on the horn. A slot is machined in the die and the punch is radiused for inside seaming. The outside-seaming die is provided with a smooth horn and a suitable slot in the punch.

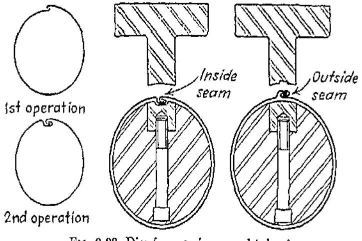


FIG. 9-33. Dies for seaming round tubes.[9]

"Zipper" Closing and Seaming Die. A preformed U-shaped blank (0.036-in.-thick steel) with bent edges (Fig. 9-34, section *A-A*) is formed into a cylinder and the edges are lock-seamed in the die shown. The driving shoulder of the arborlike punch forces the blank inside the guide plates and into the die block. Chilled-iron inserts (sections *C-C* to *G-G*) fold and seam the edges. Rollers (sections *H-H* and *I-I*) flatten the seam. The finished tube is forced out of the die by the following workpiece. The special vertical hydraulic press used has a 44-in. (maximum) stroke.

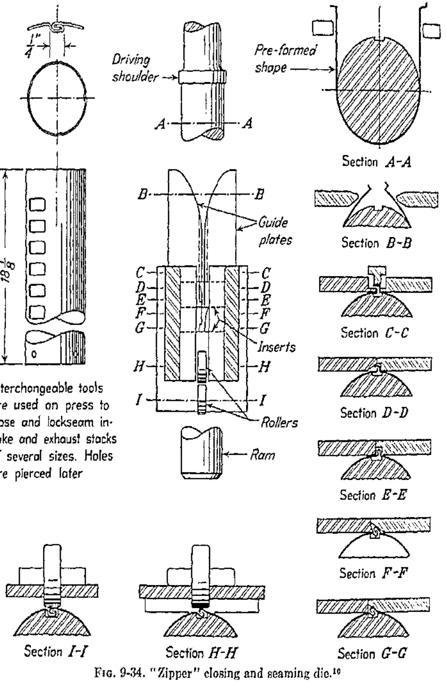


FIG. 9-34. "Zipper" closing and seaming die.[10]

BEADING DIES

Beads are rather shallow recesses in a metal sheet, usually rounded troughs of uniform width which may be either straight or curved. The possible depth and contour of beads that can be successfully formed depend upon the permissible amount of stretching of the metal and the method of forming.

Pure stretching is defined as a process in which a shape is obtained by an increase in surface area with a corresponding reduction in thickness, the strain being restricted to the metal in the immediate vicinity of the shaped sections of the part. The ideal example of such stretching is the forming of a bead in a flat blank. The maximum stretch to which a metal can be subjected depends upon its thickness, its temper, and the contour and dimensions of the bead. The average stretch found in a die-formed bead (of a circular contour, with comparatively sharp radii at the edges) can be measured approximately by the increase in contour length from the flat into the curved cross section. The average stretch values (for such beads) required to obtain a certain depth-to-width ratio, neglecting the radii, are given in Fig. 9-35, for austenitic stainless steels.

Beads and bosses with a circular contour (small recesses having shapes varying between that of a short bead and of a spherical contour) can be formed in 24SO and 75SO aluminum if their depth does not exceed 20 per cent of their width, since these alloys have a stretching limit of 10 per cent. The stretching limit of alloys 52SO and 61SW is nearly 20 per cent, allowing the formation of bead depths almost 30 per cent of the width. The forming limits of low-carbon steels are about the same as for these alloys; limits for the copper alloys approach 40 per cent, the value for the austenitic stainless steels.

The formation of beads, corrugations, bosses, and similar recesses in parts of certain types is practical and feasible only by drawing (Sec. 11), by rubber forming (Sec. 13), or by special methods or certain combinations thereof (Sec. 17). Suitable techniques and die designs are included in the sections listed.

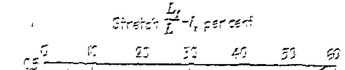


FIG. 9-35. Stretch values for beads in austenitic stainless steels.

Press-brake Beading Dies. A typical die for this operation is shown in Fig. 7-1*J*; a die for corrugating (forming multiple beads) in Fig. 7-1*R*.

"Piano" Corrugating Die. A corrugation (consisting of four bends in the metal) can be formed as a single operation but is a tedious operation if many corrugations (parallel beads) are to be formed. If more than one corrugation is to be formed simultaneously, rupture will occur unless the corrugation is shallow. A "piano" die (Fig. 9-36), having one or more spring-loaded punches and a rigid punch, progressively forms one corrugation at a time, thereby confining any stretching to the cross section of one corrugation, and allowing metal to be "sucked in" from the unformed portion of the sheet.

Beading a Doubly Curved Part. The part shown in Fig. 9-37, having a pronounced double curvature, is first formed to that curvature, and the beads are formed in a second operation. The beads are formed in a double-action press so that there is both a drawing and stretching action in their formation.

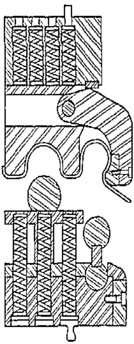


FIG. 9-36. "Piano" corrugating die.[1]

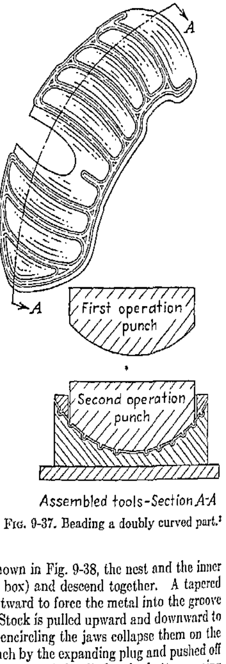


FIG. 9-37. Beading a doubly curved part.[1]

Beading a Rectangular Box. In the die shown in Fig. 9-38, the nest and the inner expanding jaws hold the part (a rectangular box) and descend together. A tapered expanding plug drives the expanding jaws outward to force the metal into the groove in the nest, thus forming an external bead. Stock is pulled upward and downward to form the bead. Coil springs in two grooves encircling the jaws collapse them on the upstroke. The work is stripped from the punch by the expanding plug and pushed off the jaws by a centrally located spring pin and out of the die by the bottom spring stripper.

Beading a Can Cover. A can cover is supported on the inside by the spring-loaded plug in the die shown in Fig. 9-39. Downward pressure is applied by the hardened ring to prevent buckling of the can walls and to roll-form the bead outward at the corner of the cover. On the upstroke, the work is forced from the punch by the plug. A spring-loaded pin pushes the work downward and off the knockout.

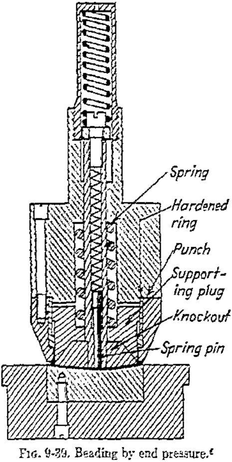


FIG. 9-39. Beading by end pressure.[4]

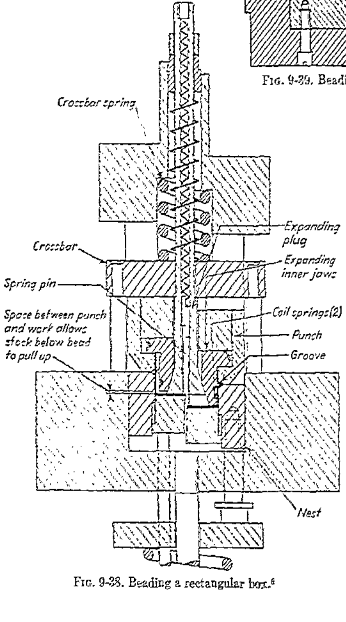


FIG. 9-38. Beading a rectangular box.[6]

Nib-forming Die. The punch closes the interlocking jaws from the outside, and the center plug closes them from the inside, to form a nib as shown in Fig. 9-40. The spring-loaded jaws are released before the punch ascends, since the jaws are housed in a cage which slides up and down in the punch.

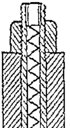
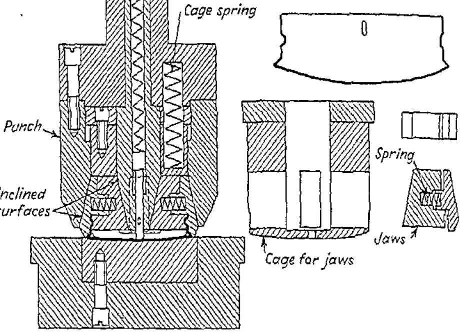



FIG. 9-40. Nib-forming die.[6]

FORMING CYLINDRICAL PARTS

Forming Thin Metal Cylinders. Metal cylinders can be formed complete in one press stroke by U-forming a blank over a spring-supported horn and then driving the horn into a U-shaped die to complete the operation. To perform this operation suc-

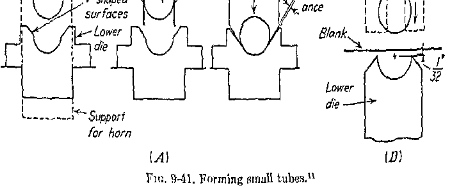


FIG. 9-41. Forming small tubes.[11]

cessfully, the metal must be thin enough so that it can be U-formed on spring pressure, and the proportion of tube diameter to tube length must be such that the horn will have sufficient rigidity to allow the forming of the part.

Forming Tubes with Butt Joints. A typical die for forming small short tubes (*A*, Fig. 9-41) first bends the blank into a U shape on a spring-supported horn, utilizing a concave punch with sharp edges extending 1/32 in. below center to allow for wear. The punch and horn continue down as a unit, and the tube is finish-formed in the lower die. It may be more convenient to feed the blank under the horn; the inverted die design (view *B*) can be then used.

Tube-forming Die with Retractable Arbor. Figure 9-42 shows a die with arbor for forming a tubular end to an OD of 0.250 in. on 0.031-in. stainless-steel strip. Forming is done between the inverted punch (*D2*) and the die (*D3*). The left end of the arbor (*D1*) slides in the retaining block (*D6*) and is held above (*D2*) by the spring assembly (*D7*). As the die closes, the spring pad (*D5*) contacts the arbor, forcing it downward and U-forming the blank. As the die continues to close, this pad holds the stock down and the die completes the curling operation. A hand-operated lever (*D4*) forces the arbor to the left and out of the formed tube.

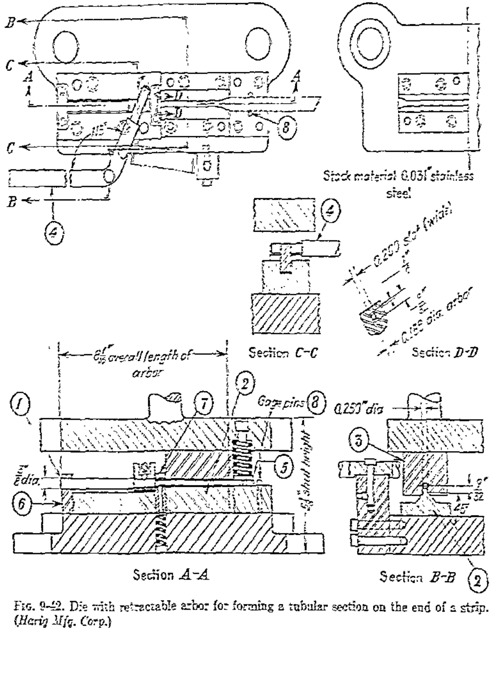


FIG. 9-42. Die with retractable arbor for forming a tubular section on the end of a strip. (*Herig Mfg. Corp.*)

Cam-actuated Arbor or Horn-type Forming Die. A preformed rounded channel-shaped blank (0.025-in. 1010 cold-rolled steel) is formed into an electric-iron-plug receptacle in the die shown in Fig. 9-43. The work is formed around an arbor (*D*1) by cam-actuated forming punches (*D*2) as it is clamped in position by a spring-loaded plunger (*D*3). A vertical spring-loaded punch (*D*4) snaps up after the two sliding punches are home, to set the part. Ejection is manual; these elements are shown: *D*5, *D*6, *D*7, and *D*8.

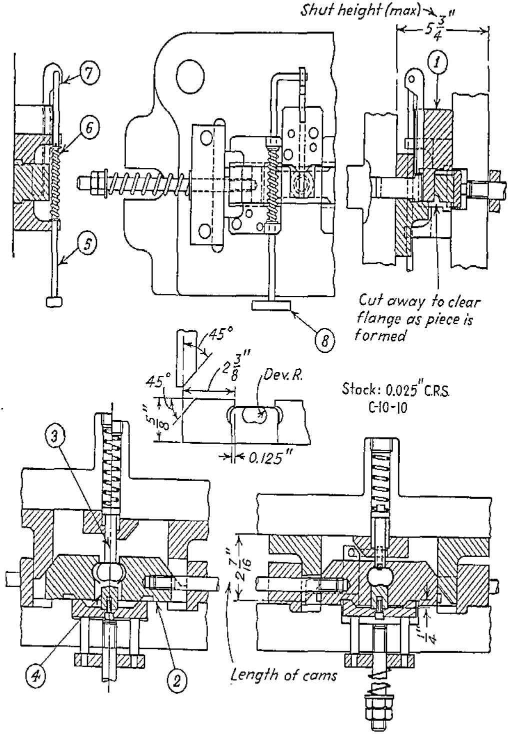


FIG. 9-43. Mandrel-type cam-actuated forming die. (*Harig Mfg. Corp.*)

Forming a Clamp Ring. Forming a hose clamp ring can be done in two die operations. The blank is first formed (*A*, Fig. 9-44) with the proper allowance for spring-back on the punch and die radius. The distance X is found by the equation

$$X = (\text{ID} + t)1.414$$

where ID = inside diameter of the ring, in.
t = stock thickness, in.

The part is held by the nests (D1) and lower and upper spring-loaded clamping plungers (D3, D2); the latter extend beyond the punch radius to position the part before forming starts. The first-formed part is then final-formed around a mandrel (view B), being gripped by a clamping plunger (D4) during this operation. The finished part is stripped from the mandrel by hand.

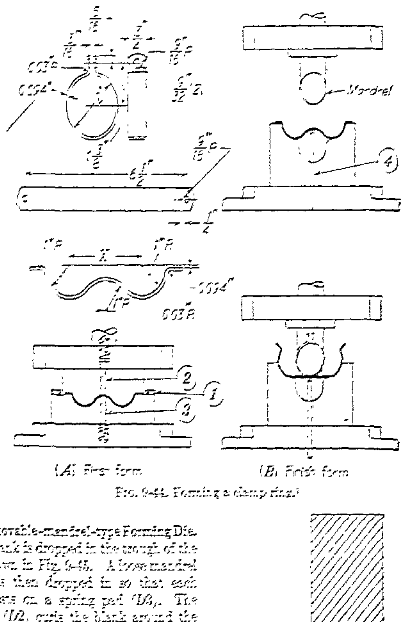
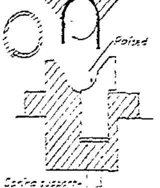
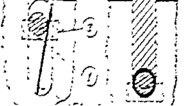


Fig. 9-44. Forming a clamp ring.[1]

Removable-mandrel-type Forming Die. The blank is dropped in the trough of the die shown in Fig. 9-45. A loose mandrel (D1) is then dropped in so that each end rests on a spring pad (D3). The punch (D2) curls the blank around the





mandrel and spanks it to a round shape. The mandrel is removed and the part stripped from it by hand.

Forming Lapped-joint Tubes. For forming a tube with a lap joint, the design shown in Fig. 9-41 can be changed so that the longer branch of the U-formed blank strikes a raised section of the die, forcing the branch against the horn (Fig. 9-46). The shorter branch is formed outside to overlap. The raised die section is spring-supported. The bottom of the horn or mandrel is slotted to accommodate the overlapping joint. If desired, one overlapping flap could be designed with raised nibs for projection welding.

Forming a Yoked Tube. A yoked tube of mild steel (0.0625 in. thick) is formed around a mandrel (Fig. 9-47, *D*2) by hinged punches (*D*1). The blank is positioned by guides (*D*3) and gage pins (*D*6). Vertical punch travel is limited by stop blocks (*D*7) after the squeezing action by contact with the 30° angle of the die (*D*5) is completed. The latch (*D*4) supports the mandrel at the back of the die but is opened when a blank is inserted and returned by a spring (*D*8). Yokeless tubes can be formed by reducing the distance between the guide blocks (*D*3), and designing the hinged punches so that their ends will meet under the mandrel at the end of the downstroke.

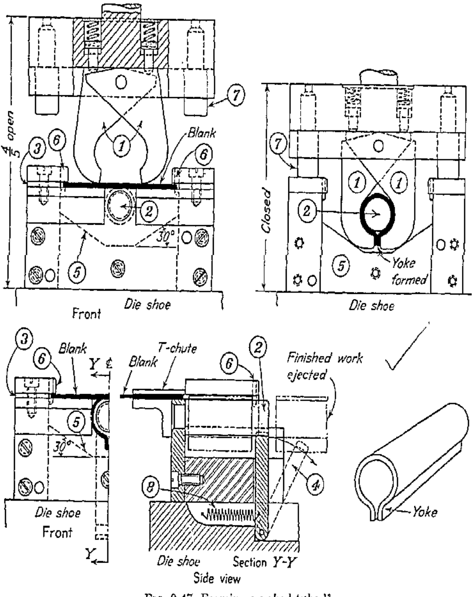


Fig. 9-47. Forming a yoked tube.[12]

Forming Dies with Movable Horns. An inexpensive gravity-fed inverted die design for an inclined press is shown in Fig. 9-48. The pivoted horn is supported during the forming action by the spring-loaded C block. No stripper is provided since the cylindrical parts slide off by gravity. This inverted die is economical to build.

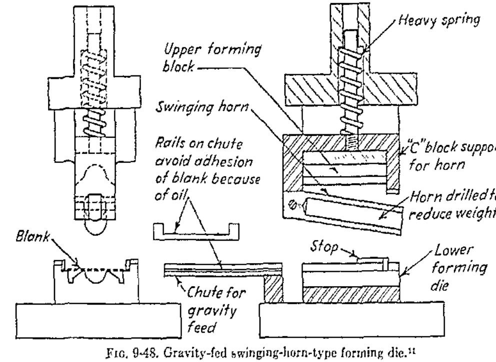
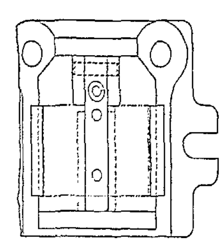


Fig. 9-48. Gravity-fed swinging-horn-type forming die.[11]



A hinged lift horn or mandrel (Fig. 9-49, *D*1) is used to form a tube of rectangular cross section from preformed 0.034-in. annealed steel. The horn forms two corners only as it slides down into the die against the force exerted by the die cushion through the pins (*D*2). Pins (*D*3) push the horn and pad down while allowing the part to fold around the horn.

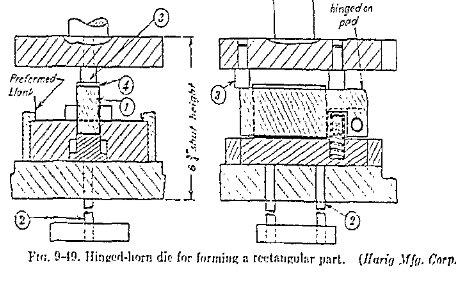
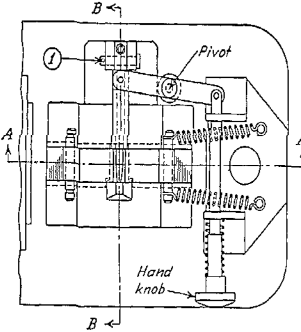


Fig. 9-49. Hinged-horn die for forming a rectangular part. (*Harig Mfg. Corp.*)

Another die design uses a pivoted mandrel with its pivot (Fig. 9-50, *D*1) located at the back of the die. A fountain-pen nib is formed around the horn by two spring-loaded horizontal sliding punches (*D*3) cam-actuated, in conjunction with the vertical punches (*D*2, *D*5). A hand-operated ejector strips the finished nib off the arbor and out the front of the die. As the die closes, the spring-loaded plunger (*D*8) forces the mandrel (*D*9) down and U-forms the part against the pad (*D*2). The sliding punches (*D*3) are then cammed in to form the part around the mandrel. Then while the cams dwell the upper punch (*D*5) closes the part and at the bottom of the stroke the sliding punches are again cammed in to re-strike the part and make it round.



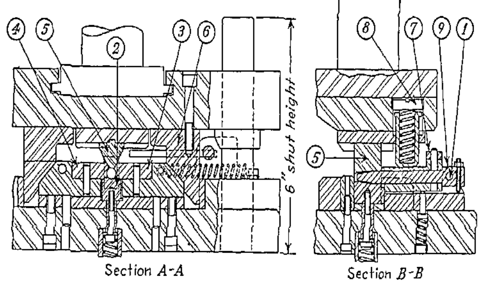


FIG. 9-50. Pivoted-arbor forming die for a fountain-pen nib. (*Harig Mfg. Corp.*)

FIG. 9-51*A*. Detail and product for die of Fig. 9-51.

Low-grade steel is formed into a core for rolls of cash-register paper strip (Fig. 9-51, A). The slight indentation made by the blade (D2) is of no importance in this inexpensive but high-production part, but it nullifies spring-back. The die incorporates a typical floating mandrel (D1) in which a flat blank is placed between the nests (D3)

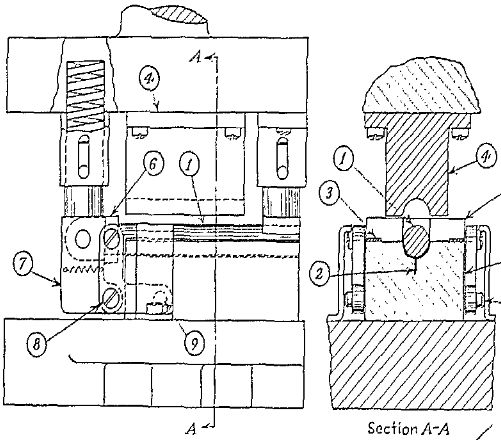


FIG. 9-51. Floating-arbor tube-forming die.[5]

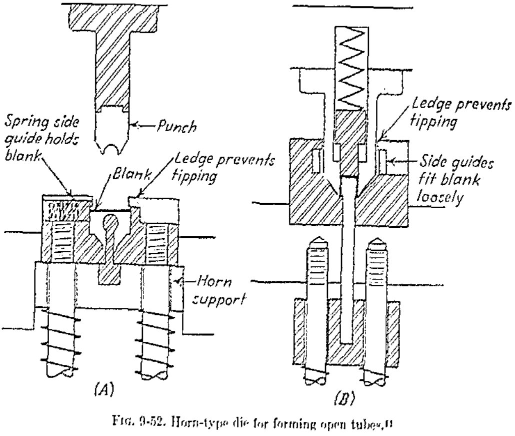


FIG. 9-52. Horn-type die for forming open tubes.[11]

and formed around the mandrel by the punch (*D4*) and die (*D5*). Stripping is automatic through the movement of the stripping collar (*D6*), which is actuated by the bell cranks (*D7*) pivoted at *D8*. On the upstroke, the studs (*D9*) contact the upper part of the bracket, forcing the stripping collar to the right and allowing the operator to remove the finished core from the mandrel.

Forming Open Tubes. Forming open tubes (Fig. 9-52) allows the use of a webbed horn. In both dies, the blanks are retained by guides and ledges to prevent tipping. At *A* the left-hand guide is spring-loaded; at *B* the blank fits the guides loosely.

Another die design for forming open tubes, using a vertical mandrel, is shown in Fig. 9-53. The flat blank is placed in a slot in the cover of the die. The first form cam forces the first punch toward the front, forming the blank into a U shape. Further descent of the ram retracts the first form punch; the mandrel (pin) descends, and the two second form punches are forced inward by the two side-acting second form cams to form the finished open tube. The vertical shouldered mandrel forces the work through the die to size and iron it. Shoulders on the second form punches act as strippers.

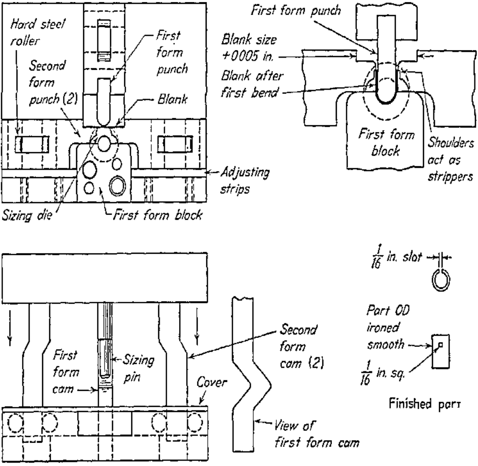


FIG. 9-53. Vertical mandrel die for forming open tubes.[13]

FORMING RINGS, CLIPS, AND SIMILAR PARTS

Ring-forming Die. A flat blank is placed in the disappearing nests (Fig. 9-54, *D1*) and is formed into a U shape around the upper half of the mandrel (*D2*). Four pins (*D6*), actuated by a die cushion, hold the blank between the mandrel and the upper punch. The inverted U-formed blank is carried down by the mandrel and the upper forming punch (*D4*) to where the ends of the blank are closed by the lower punch (*D5*) to form the finished ring. Air-actuated stripping pins (*D3*) push the ring from the mandrel on the upstroke. This die is identical in principle to the die shown in Fig. 9-42.

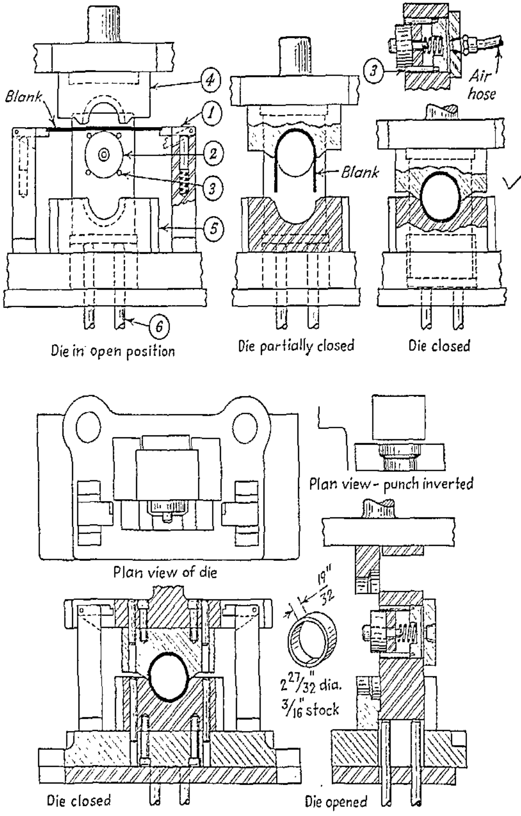


FIG. 9-54. Ring-forming die. (*Toledo Pressed Steel Co.*)

Forming a Flattened Ring. A channel-shaped blank is placed under the forming anvil (Fig. 9-55, *D*1) with the ends of the blank resting on two grooved rolls (*D*2), which are mounted on cranks (*D*5). As the ram descends, the part (with flanges down) is held tightly between the bottom of the anvil (mandrel) and the top of the die. Racks (*D*3) attached to the punch then engage pinions (*D*4) to turn the cranks. The rolls are forced around the anvil to form the flattened ring around it; one rack is timed ahead of the other to permit one end of the ring (a rope guide for a clothesline pulley) to lap over the other.

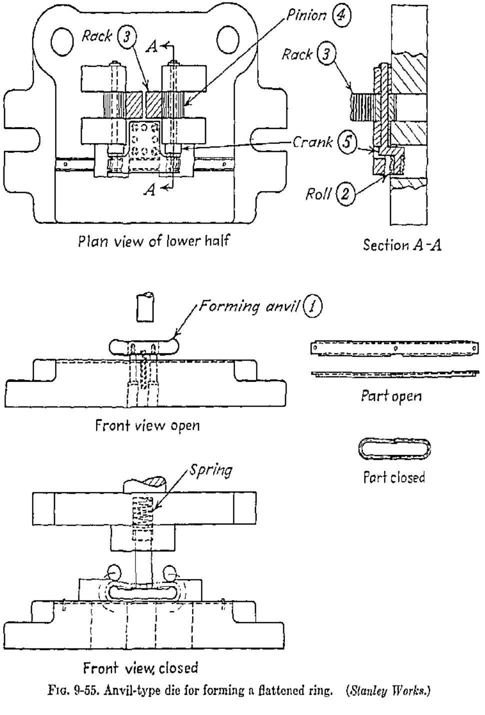


Fig. 9-55. Anvil-type die for forming a flattened ring. (*Stanley Works.*)

Forming a Phosphor Bronze Clip. A relieved forming punch (Fig. 9-56, *D*1) forms the ears on a phosphor bronze blank (0.014 in. thick) with clearance of stock thickness only. The bottom of the part is embossed to a depth of 0.031 in. and to a diameter of 0.139 in. by an embossing punch or pin (*D*3). The spring-loaded pad (*D*4) for the pin travels ¼ in. against the pins (*D*8), equal to the depth of the die (*D*5). The blank is placed in a suitable nest *D2*. The finished part is ejected by a sliding ejector *D4*, which strips the clip from the hornlike forming punch; the ejector is actuated by a knockout rod *D5*. The punch *D1* is spring-mounted so that after it has U-formed and embossed the part, it can dwell while the form punch *D7* continues downward and bends the angle on the tab at the rear of the part.

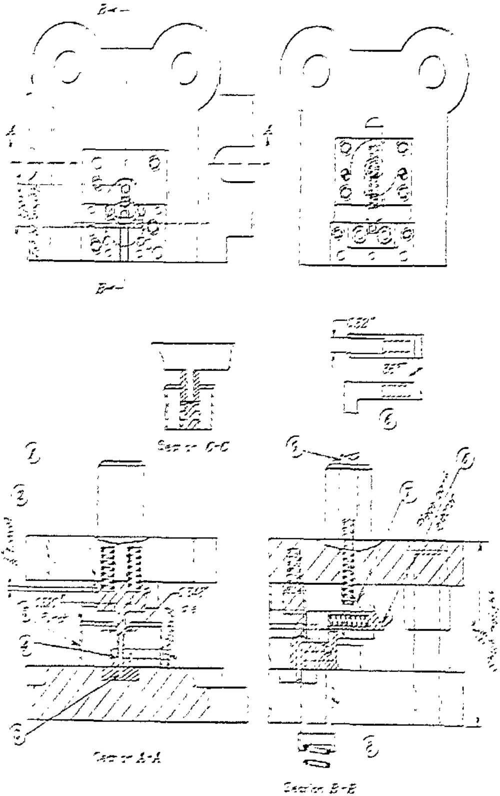


Fig. 6-56. Forming a phosphor bronze clip using a relieved punch. (Hart Mfg. Corp.)

Toggle-action Forming Die. Another forming-die design, using toggle joints to actuate horizontal forming punches or plates, is shown in Fig. 6-57. A flat blank is placed in the nest, and small clips and cylindrical parts are formed around the mandrel after the blank becomes U-shaped in the die or lower plate. This design is a variation of the conventional cam or wedge die with sliding horizontal punches.

Forming Die with Air Actuation. Clips, cylinders, and rings are formed in the die of Fig. 9-58, in which air at 80 psi is used instead of springs to return the horizontal forming punches (*D*1). The same air pressure actuates the pressure pin (*D*2).

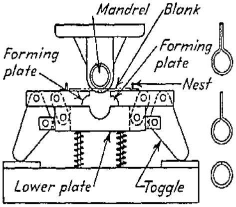


Fig. 9-57. Toggle-action forming die.[16]

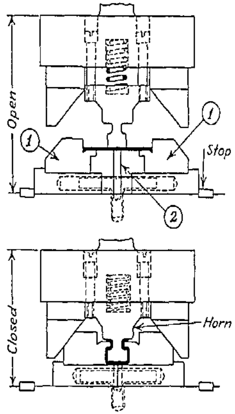


Fig. 9-58. Air-actuated forming die.[14]

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SECTION 10

DISPLACEMENT OF METAL IN DRAWING*

Drawing is a process of cold forming a flat precut metal blank into a hollow vessel without excessive wrinkling, thinning, or fracturing. The various forms produced may be cylindrical or box-shaped with straight or tapered sides or a combination of straight, tapered, or curved sides. The size of the parts may vary from ¼ in. diameter or smaller, to aircraft or automotive parts large enough to require the use of mechanical handling equipment.

Metal Flow. When a metal blank is drawn into a die, a change in its shape is brought about by making the metal flow on a plane parallel to the die face, in such a manner that its thickness and surface area remain about the same as the blank. Figure 10-1 shows schematically the step-by-step flow of metal in circular shells. The units within one pair of radial boundaries have been numbered and each unit moved progressively toward the center in three steps. If the shell were drawn in this manner, and a certain unit area examined after each depth shown, it would show (1) a size change only as the metal moves toward the die radius; (2) a shape change only as the metal moves over the die radius. Observe that no change takes place in area 1, and the maximum change is noted in area 5.

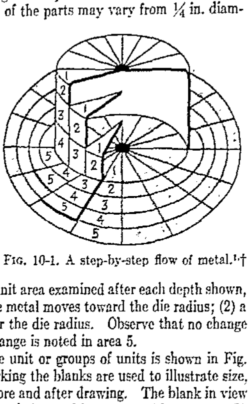

FIG. 10-1. A step-by-step flow of metal.[1,†]

The relative amount of movement in one unit or groups of units is shown in Fig. 10-2*A* and *B*, in which two methods of marking the blanks are used to illustrate size, shape, and position of the units of area, before and after drawing. The blank in view *A* is marked with radial lines and concentric circles, and in view *B* with squares. If, after these blanks are marked and drawn, sections are cut out of the shell, flattened, and compared with the original triangular portions, a change in shape of the triangular pieces will be found. The illustration shows that the inner portion of the triangle which becomes the base of the shell remains unchanged throughout the operation. The portion which becomes the side wall of the shell is changed from an angular figure to a longer parallel-sided one as it is drawn over the die radius, from which point no further change takes place. The particular areas observed have been enlarged and superimposed upon each other, respectively, to show more clearly their size, shape, and position before and after drawing.

The general change in circular draws, due to flow, may be summarized as follows:

1. Little or no change in the bottom area because no cold work was done in this area.

2. All radial boundaries of the units of area remain radial in the bottom area. The units in the top flange area remain radial until they move over the die radius; they

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† Superior numbers relate to References at the end of this section.

then become parallel and assume dimensions equal to their dimensions at the point where they move over the die radius.

3. There is a slight decrease in surface area and increase of thickness in the units involving maximum flow. The increase in thickness is limited to the space between the punch and die.

4. The flow lines on a circular shell indicate that the metal movement is uniform on all diameters.

Flow in Rectangular Shells. The drawing of a rectangular shell involves varying degrees of flow severity. Some parts of the shell may require severe cold working and others simple bending. In contrast to circular shells in which pressure is uniform on all diameters, some areas of rectangular and irregular shells may require more pressure than others. True drawing occurs at the corners only; at the sides and ends metal movement is more closely allied to bending. The stresses at the corner of the shell are compressive on the metal moving toward the die radius and are tensile on the

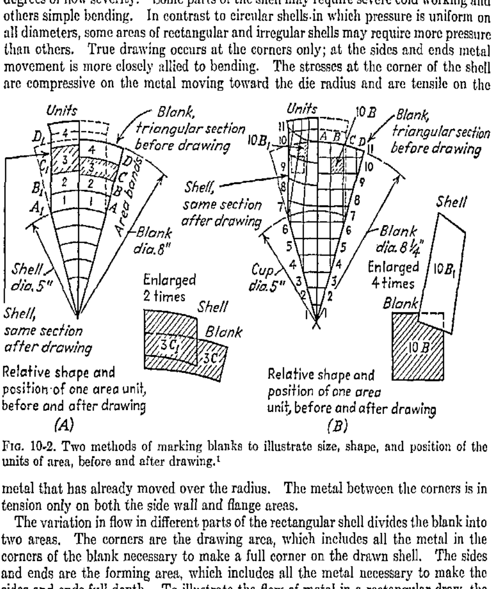
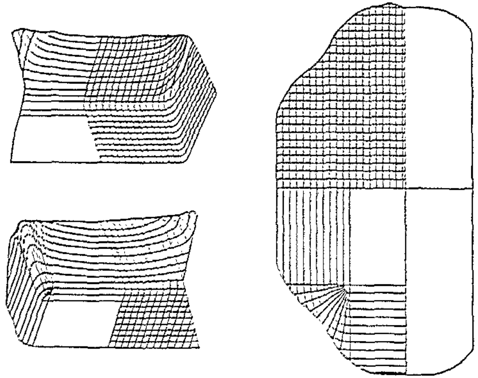


FIG. 10-2. Two methods of marking blanks to illustrate size, shape, and position of the units of area, before and after drawing.[1]

metal that has already moved over the radius. The metal between the corners is in tension only on both the side wall and flange areas.

The variation in flow in different parts of the rectangular shell divides the blank into two areas. The corners are the drawing area, which includes all the metal in the corners of the blank necessary to make a full corner on the drawn shell. The sides and ends are the forming area, which includes all the metal necessary to make the sides and ends full depth. To illustrate the flow of metal in a rectangular draw, the developed blank in Fig. 10-3B has been divided into unit areas by two different methods. In Fig. 10-3A the corners of the shell drawn from the blank in view B are shown. The upper view is the corner area which was marked with squares, and the lower view is the corner area which was marked with radial lines and concentric circles. The severe flow in the corner areas is clearly shown in the lower view by the radial lines of the blank being moved parallel and close together, and the lines of the concentric circles becoming farther apart the nearer they are to the center of the corner and the edge of the blank. The relatively parallel lines of the sides and ends show that little or no flow occurred in these areas. The upward bending of these lines indicates the flow from the corner area to the sides and ends to equalize the height where these areas on the blank were blended to eliminate sharp corners.

Control of Flow. The shaping of a shell necessitates severe plastic working of the metal; therefore the elimination of any condition which tends to retard the flow is necessary in order to minimize the stresses to which the metal is subjected. In any one location of the blank, if the metal is very thin and a sufficiently wide area is free to move away from the tools, the metal may buckle rather than shrink. These buckles are called "wrinkles" if they occur at the edges of the blank and "puckers" if they appear in any other part of the blank. The formation of wrinkles in the flange area is to be expected since the direction of the stresses is circumferential; therefore, this wrinkling must be controlled because it may adversely affect normal metal flow. The fact that relatively thin metals have a high wrinkling tendency makes it necessary to use higher blankholding pressures on such draws than on draws with relatively thick metals. When the thickness-diameter ratio of the blank is low, high blankholding pressure is required; when this ratio is high, little or no blankholding



(A) (B)

FIG. 10-3. Metal flow in rectangular draws: (A) blank marked before drawing; (B) corner areas after drawing.[1]

pressure is required. Also, as a general rule, as the thickness-diameter ratio of the blank decreases, the reduction percentage should also be decreased, and the tools for these draws must be finished with greater care.

The shape of the shell section governs to some extent whether wrinkles or puckers will be most prevalent under conditions of poor control. Straight-sided shells are typical shapes in which wrinkles would occur, whereas puckers are most likely to appear in domed or tapered shells. If the die radius and/or the punch radius are too large, even though the sides are straight, the conditions come close to domed shapes, and both wrinkles and puckers have a tendency to occur. In Fig. 10-4, the shells are arranged in order of increased blankholder pressures required. *A*, *B*, *C*, and *D* have the same diameters but, because of their shape, require different blankholder pressures to control metal flow. Shell *A* will tend to wrinkle without sufficient pressure; shell *B* will wrinkle and possibly pucker because of the large punch and die radii; shells *C* and *D* would wrinkle and pucker. Shell *E* will tend to pucker because there is very little metal flow, and a very high blankholder pressure will be required to pull the material tightly around the punch.

The dies shown in Fig. 10-5 illustrate (*A*) good control of flow; (*B*) poor control of flow. In the die shown at view *A*, the tool faces are in close contact with the blank at all points, but insufficient blankholder pressure may encourage wrinkles to occur in the shell. At view *B* there is poor control of the metal flow because only the tip of the punch is in contact with the blank, leaving much of the center area of the blank free to pucker. Depending upon the material, increased blankholder pressure may or may not produce a good shell.

Blankholder Pressure. *The amount of blankholder pressure required to prevent wrinkles and puckers is largely determined by trial and error.* The pressure required to hold a blank flat for a cylindrical draw varies from very little to a maximum of

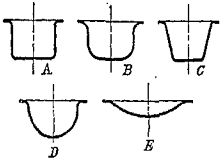


Fig. 10-4. Shells arranged in order of increased blankholder pressure requirements.[1]

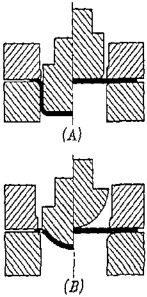


Fig. 10-5. Two drawing tools showing: (*A*) good control of flow; (*B*) poor control of flow.[1]

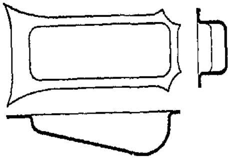


Fig. 10-6. Unbalanced draw, using excess metal to control flow.[1]

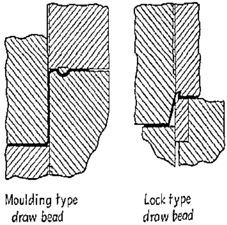


Fig. 10-7. Two common types of draw beads.[2]

about one-third or more of the drawing pressure. On cylindrical draws, the pressure is uniform and balanced at all points around the periphery because the amount of flow at all points is the same. On rectangular- and irregular-shaped shells, the amount of flow around the periphery is not uniform; hence the pressure required varies also. In certain areas where more pressure is required, excess material on the blank (Fig. 10-6) or beads on the blankholder faces may be employed to retard the flow of the metal.

Beads. The beads need not be continuous around the die, and more than one are sometimes placed in areas requiring greater retarding of metal flow. Figure 10-7 shows two common types of draw beads. Draw beads may be mounted in a die in

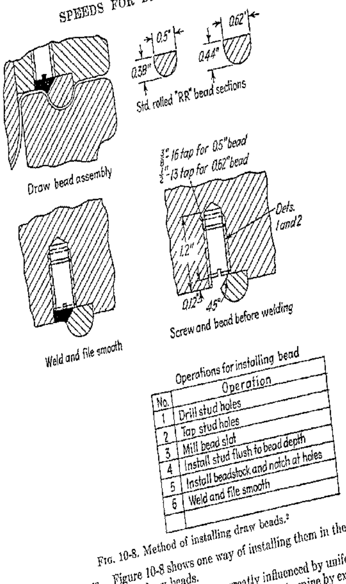


FIG. 10-8. Method of installing draw beads.[2]

several different ways. Figure 10-8 shows one way of installing them in the die. See Sec. 12 for more discussion on draw beads.

Speeds for Drawing. The drawing speeds are greatly influenced by uniformity and physical characteristics of stock. It is usually necessary to determine by experimentation the best speed at which a particular stock can be worked. The metal must be given sufficient time to flow; otherwise fractures are likely to occur. The tentative drawing speeds in Table 10-1 may be used for average conditions, and adjusted up or down to suit the specific application.

TABLE 10-1. TENTATIVE TABLE OF LINEAR VELOCITIES[1]

Material	Drawing, fpm		Ironing or burnishing, fpm
	Single action	Double action	
Aluminum	175	100	
Strong aluminum alloys	...	30–40	
Brass	200	100	70
Copper	150	85	
Steel	55	35–50	25
Steel (in carbide dies)	...	60	
Steel, stainless	...	20–30	
Zinc	150	40	

CYLINDRICAL DRAWS

Development of Blanks. The development of the approximate blank size should be done first (1) to determine the size of a blank to produce the shell to the required depth and (2) to determine how many draws will be necessary to produce the shell. This is determined by the ratio of the blank size to the shell size. Various methods have been developed to determine the size of blanks for drawn shells. These methods are based on (1) mathematics alone; (2) the use of graphical layouts; (3) a combination of graphical layouts and mathematics. The majority of these methods are for use on symmetrical shells.

It is rarely possible to compute any blank size to close accuracy or to maintain perfectly uniform height of shells in production, because the thickening and thinning of the wall vary with the completeness of annealing. The height of ironed shells varies with commercial variations in sheet thickness, and the top edge varies from square to irregular, usually with four more or less pronounced high spots resulting from the effect of the direction on the crystalline structure of the metal. Thorough annealing should largely remove the directional effect. For all these reasons it is ordinarily necessary to figure the blank sufficiently large to permit a trimming operation. The drawing tools should be made first; then the blank size should be determined by trial before the blanking die is made. There are times, however, when the metal required to produce the product is not immediately available from stock and must be ordered at the same time as the tools are ordered. This situation makes it necessary to estimate the blank size as closely as possible by formula or graphically in order to know what sizes to order.

Blank Diameter. The following equations may be used to calculate the blank size for cylindrical shells of relatively thin metal. The ratio of the shell diameter to the corner radius (d/r) can affect the blank diameter and should be taken into consideration.

When d/r is 20 or more,

$$D = \sqrt{d^2 + 4dh} \tag{1}$$

When d/r is between 15 and 20,

$$D = \sqrt{d^2 + 4dh} - 0.5r \tag{2}$$

When d/r is between 10 and 15,

$$D = \sqrt{d^2 + 4dh} - r \tag{3}$$

When d/r is below 10,

$$D = \sqrt{(d - 2r)^2 + 4d(h - r) + 2\pi r(d - 0.7r)} \tag{4}$$

where D = blank diameter
d = shell diameter
h = shell height
r = corner radius

The above equations are based on the assumption that the surface area of the blank is equal to the surface area of the finished shell.

In cases where the shell wall is to be ironed thinner than the shell bottom, the volume of metal in the blank must equal the volume of the metal in the finished shell. Where the wall-thickness reduction is considerable, as in brass shell cases, the final blank size is developed by trial. A tentative blank size for an ironed shell can be obtained from the equation

$$D = \sqrt{d^2 + 4dh\frac{t}{T}} \tag{5}$$

where t = wall thickness
T = bottom thickness

The blank diameters given in Table 10-2 are approximate and based on Eq. (1).

TABLE 10-2. BLANK DIAMETERS OF CYLINDRICAL SHELLS, INCHES

Shell diam., in.	Height of shell, in.																				
	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2	2 1/4	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	4
1/4	0.75	0.83	0.90	0.97	1.03	1.09	1.15	1.20	1.25	1.30	1.34	1.39	1.43	1.52	1.60	1.67	1.75	1.82	1.89	1.95	2.02
3/8	0.94	1.04	1.13	1.21	1.28	1.34	1.42	1.48	1.55	1.61	1.67	1.71	1.78	1.88	1.98	2.07	2.16	2.24	2.32	2.40	2.48
1/2	1.12	1.22	1.32	1.41	1.50	1.58	1.66	1.73	1.80	1.87	1.93	2.00	2.07	2.18	2.29	2.39	2.50	2.60	2.69	2.78	2.88
5/8	1.28	1.40	1.50	1.60	1.70	1.79	1.88	1.96	2.04	2.11	2.19	2.26	2.32	2.46	2.58	2.69	2.80	2.92	3.02	3.12	3.23
3/4	1.44	1.56	1.67	1.78	1.89	1.98	2.08	2.16	2.25	2.33	2.41	2.48	2.56	2.70	2.84	2.96	3.09	3.21	3.32	3.43	3.54
7/8	1.59	1.72	1.84	1.95	2.06	2.16	2.26	2.36	2.45	2.54	2.62	2.70	2.78	2.94	3.08	3.22	3.38	3.50	3.63	3.75	3.84
1	1.73	1.87	2.00	2.12	2.23	2.34	2.45	2.55	2.64	2.74	2.82	2.91	3.00	3.16	3.31	3.46	3.61	3.74	3.87	4.00	4.13
1 1/8	1.87	2.02	2.15	2.28	2.40	2.51	2.62	2.73	2.83	2.93	3.02	3.11	3.21	3.37	3.53	3.69	3.84	3.98	4.12	4.26	4.39
1 1/4	2.01	2.16	2.30	2.43	2.56	2.68	2.80	2.90	3.01	3.11	3.22	3.31	3.40	3.58	3.75	3.91	4.07	4.22	4.37	4.51	4.65
1 3/8	2.16	2.31	2.45	2.59	2.72	2.84	2.96	3.08	3.18	3.29	3.39	3.49	3.59	3.77	3.95	4.12	4.28	4.44	4.60	4.74	4.88
1 1/2	2.29	2.45	2.60	2.74	2.87	3.00	3.12	3.24	3.36	3.46	3.58	3.67	3.77	3.97	4.15	4.33	4.50	4.66	4.82	4.97	5.12
1 5/8	2.42	2.59	2.74	2.89	3.02	3.15	3.28	3.40	3.52	3.63	3.74	3.85	3.95	4.15	4.34	4.53	4.70	4.87	5.03	5.20	5.35
1 3/4	2.56	2.72	2.88	3.03	3.17	3.30	3.43	3.56	3.68	3.80	3.91	4.03	4.14	4.34	4.54	4.73	4.90	5.08	5.25	5.42	5.57
1 7/8	2.70	2.86	3.02	3.18	3.32	3.46	3.59	3.72	3.84	3.97	4.08	4.20	4.30	4.52	4.71	4.91	5.10	5.28	5.45	5.63	5.79
2	2.83	3.00	3.16	3.31	3.46	3.61	3.75	3.87	4.00	4.12	4.24	4.36	4.47	4.69	4.90	5.10	5.29	5.48	5.65	5.83	6.00
2 1/8	2.96	3.13	3.30	3.46	3.61	3.75	3.89	4.02	4.16	4.28	4.40	4.52	4.64	4.86	5.08	5.28	5.48	5.67	5.85	6.03	6.21
2 1/4	3.09	3.27	3.44	3.60	3.75	3.90	4.01	4.18	4.31	4.44	4.56	4.68	4.80	5.03	5.25	5.46	5.66	5.86	6.05	6.23	6.41
2 3/8	3.22	3.40	3.57	3.74	3.89	4.04	4.18	4.32	4.46	4.59	4.72	4.84	4.96	5.20	5.42	5.64	5.84	6.04	6.24	6.42	6.61
2 1/2	3.35	3.54	3.71	3.87	4.03	4.18	4.33	4.47	4.61	4.74	4.87	5.00	5.12	5.36	5.59	5.81	6.02	6.22	6.42	6.61	6.80
2 5/8	3.48	3.67	3.84	4.01	4.17	4.32	4.47	4.62	4.76	4.89	5.03	5.15	5.28	5.52	5.76	5.98	6.20	6.40	6.61	6.80	6.99
2 3/4	3.61	3.80	3.98	4.15	4.31	4.47	4.62	4.76	4.90	5.04	5.18	5.31	5.44	5.68	5.92	6.15	6.37	6.58	6.79	6.99	7.18
2 7/8	3.75	3.93	4.11	4.28	4.45	4.60	4.76	4.91	5.05	5.19	5.33	5.46	5.59	5.84	6.08	6.32	6.54	6.76	6.96	7.17	7.37
3	3.87	4.06	4.24	4.42	4.58	4.74	4.90	5.05	5.20	5.34	5.48	5.61	5.74	6.00	6.25	6.48	6.71	6.93	7.14	7.35	7.55
3 1/8	4.00	4.19	4.38	4.55	4.72	4.88	5.04	5.19	5.34	5.48	5.63	5.76	5.90	6.16	6.40	6.64	6.87	7.10	7.32	7.52	7.73
3 1/4	4.13	4.32	4.51	4.68	4.85	5.02	5.18	5.33	5.48	5.63	5.77	5.91	6.05	6.31	6.56	6.80	7.04	7.26	7.48	7.70	7.91
3 3/8	4.26	4.45	4.64	4.82	4.99	5.15	5.31	5.47	5.62	5.77	5.92	6.05	6.19	6.47	6.72	6.96	7.20	7.43	7.66	7.87	8.08
3 1/2	4.39	4.58	4.77	4.95	5.12	5.29	5.45	5.61	5.77	5.91	6.06	6.20	6.35	6.61	6.87	7.12	7.37	7.60	7.83	8.05	8.26
3 5/8	4.51	4.71	4.90	5.08	5.26	5.43	5.59	5.75	5.90	6.06	6.21	6.35	6.49	6.76	7.03	7.28	7.52	7.76	7.99	8.21	8.43
3 3/4	4.64	4.84	5.03	5.21	5.39	5.56	5.73	5.89	6.04	6.20	6.35	6.49	6.63	6.91	7.18	7.43	7.68	7.92	8.16	8.38	8.60
3 7/8	4.77	4.97	5.16	5.34	5.52	5.69	5.86	6.02	6.18	6.34	6.49	6.64	6.78	7.06	7.33	7.59	7.84	8.08	8.32	8.55	8.77
4	4.90	5.10	5.29	5.48	5.66	5.83	6.00	6.16	6.32	6.48	6.63	6.78	6.92	7.21	7.48	7.74	8.00	8.24	8.48	8.71	8.94
4 1/8	5.02	5.22	5.42	5.61	5.79	5.96	6.13	6.30	6.46	6.62	6.77	6.92	7.07	7.36	7.63	7.89	8.15	8.40	8.64	8.88	9.11
4 1/4	5.15	5.35	5.55	5.74	5.92	6.09	6.27	6.43	6.60	6.76	6.91	7.06	7.21	7.50	7.78	8.05	8.31	8.56	8.80	9.04	9.27
4 3/8	5.28	5.48	5.68	5.87	6.05	6.23	6.40	6.57	6.73	6.89	7.05	7.21	7.35	7.64	7.93	8.20	8.46	8.71	8.96	9.20	9.44
4 1/2	5.40	5.61	5.81	6.00	6.18	6.36	6.53	6.70	6.87	7.03	7.19	7.35	7.50	7.79	8.07	8.35	8.61	8.87	9.12	9.36	9.60

TABLE 10-2. BLANK DIAMETERS OF CYLINDRICAL SHELLS, INCHES *(Continued)*

Shell diam., in.	Height of shell, in.																				
	1/2	5/8	3/4	7/8	1	1 1/8	1 1/4	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	2	2 1/4	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	4
4 5/8	5.53	5.74	5.93	6.13	6.31	6.49	6.67	6.84	7.01	7.17	7.33	7.48	7.64	7.93	8.22	8.50	8.76	9.02	9.28	9.52	9.76
4 3/4	5.66	5.86	6.06	6.26	6.44	6.62	6.80	6.97	7.14	7.31	7.47	7.62	7.78	8.08	8.37	8.64	8.91	9.18	9.43	9.68	9.92
4 7/8	5.78	5.99	6.19	6.39	6.57	6.76	6.93	7.11	7.28	7.44	7.60	7.76	7.92	8.22	8.51	8.79	9.06	9.33	9.59	9.84	10.08
5	5.91	6.12	6.32	6.52	6.70	6.89	7.07	7.24	7.41	7.58	7.74	7.90	8.06	8.36	8.66	8.94	9.21	9.48	9.74	10.00	10.24
5 1/8	6.04	6.25	6.45	6.64	6.83	7.02	7.20	7.37	7.55	7.72	7.88	8.04	8.21	8.51	8.80	9.09	9.37	9.63	9.90	10.15	10.40
5 1/4	6.17	6.37	6.58	6.77	6.96	7.15	7.33	7.51	7.68	7.85	8.02	8.18	8.34	8.65	8.94	9.23	9.51	9.78	10.05	10.31	10.56
5 3/8	6.29	6.50	6.71	6.90	7.09	7.28	7.46	7.64	7.82	7.99	8.15	8.31	8.48	8.79	9.09	9.38	9.66	9.93	10.20	10.46	10.72
5 1/2	6.42	6.63	6.83	7.03	7.22	7.41	7.60	7.77	7.95	8.12	8.29	8.45	8.61	8.93	9.23	9.52	9.81	10.08	10.35	10.62	10.87
5 5/8	6.54	6.76	6.96	7.16	7.35	7.54	7.73	7.91	8.08	8.25	8.42	8.59	8.75	9.07	9.37	9.67	9.95	10.23	10.50	10.77	11.02
5 3/4	6.67	6.88	7.09	7.29	7.48	7.67	7.86	8.04	8.22	8.39	8.56	8.72	8.89	9.20	9.51	9.81	10.10	10.38	10.65	10.92	11.18
5 7/8	6.80	7.01	7.22	7.42	7.61	7.80	7.99	8.17	8.35	8.52	8.69	8.86	9.02	9.34	9.65	9.95	10.24	10.52	10.80	11.07	11.33
6	6.92	7.14	7.34	7.55	7.74	7.93	8.12	8.30	8.48	8.66	8.83	9.00	9.16	9.48	9.79	10.09	10.39	10.67	10.95	11.22	11.48
6 1/4	7.18	7.39	7.60	7.80	8.00	8.19	8.38	8.57	8.75	8.92	9.10	9.27	9.44	9.76	10.07	10.38	10.68	10.96	11.25	11.52	11.79
6 1/2	7.43	7.64	7.85	8.06	8.26	8.45	8.64	8.83	9.01	9.19	9.36	9.54	9.71	10.03	10.35	10.66	10.96	11.25	11.54	11.82	12.09
6 3/4	7.68	7.90	8.11	8.31	8.51	8.71	8.90	9.09	9.27	9.45	9.63	9.80	9.97	10.31	10.63	10.94	11.25	11.54	11.83	12.11	12.39
7	7.93	8.15	8.36	8.57	8.77	8.97	9.16	9.35	9.53	9.72	9.90	10.07	10.24	10.58	10.90	11.22	11.53	11.83	12.12	12.40	12.68
7 1/4	8.18	8.40	8.62	8.82	9.03	9.22	9.42	9.61	9.80	9.98	10.16	10.34	10.51	10.85	11.18	11.50	11.81	12.11	12.41	12.70	12.98
7 1/2	8.44	8.66	8.87	9.08	9.28	9.48	9.68	9.87	10.06	10.24	10.42	10.60	10.78	11.12	11.45	11.77	12.09	12.39	12.69	12.99	13.27
7 3/4	8.69	8.91	9.12	9.33	9.54	9.74	9.94	10.13	10.32	10.50	10.69	10.87	11.04	11.39	11.72	12.05	12.37	12.68	12.98	13.27	13.56
8	8.94	9.16	9.38	9.59	9.79	10.00	10.19	10.39	10.58	10.77	10.95	11.13	11.31	11.66	11.99	12.32	12.64	12.96	13.26	13.56	13.85
8 1/4	9.19	9.41	9.63	9.84	10.05	10.25	10.45	10.65	10.84	11.03	11.21	11.39	11.57	11.92	12.27	12.60	12.92	13.23	13.54	13.84	14.14
8 1/2	9.44	9.66	9.88	10.10	10.30	10.51	10.71	10.90	11.10	11.29	11.47	11.66	11.84	12.19	12.53	12.87	13.20	13.51	13.82	14.13	14.43
8 3/4	9.69	9.92	10.13	10.35	10.56	10.76	10.96	11.16	11.36	11.55	11.73	11.92	12.10	12.46	12.80	13.14	13.47	13.79	14.10	14.41	14.71
9	9.95	10.17	10.39	10.60	10.81	11.02	11.21	11.42	11.61	11.81	11.99	12.18	12.36	12.72	13.07	13.41	13.74	14.07	14.38	14.69	14.99
9 1/4	10.20	10.42	10.64	10.85	11.07	11.27	11.48	11.68	11.87	12.07	12.26	12.44	12.63	12.99	13.34	13.68	14.02	14.34	14.66	14.97	15.28
9 1/2	10.45	10.67	10.89	11.11	11.32	11.53	11.73	11.93	12.13	12.32	12.52	12.70	12.89	13.25	13.61	13.95	14.29	14.61	14.94	15.25	15.56
9 3/4	10.70	10.92	11.14	11.36	11.57	11.78	11.99	12.19	12.39	12.58	12.77	12.96	13.15	13.52	13.87	14.22	14.56	14.89	15.21	15.53	15.84
10	10.95	11.18	11.40	11.61	11.83	12.04	12.24	12.44	12.64	12.84	13.03	13.22	13.41	13.78	14.14	14.49	14.83	15.16	15.49	15.81	16.12
10 1/4	11.20	11.43	11.65	11.87	12.08	12.29	12.50	12.70	12.90	13.10	13.29	13.48	13.67	14.04	14.40	14.75	15.10	15.43	15.76	16.08	16.40
10 1/2	11.45	11.68	11.90	12.12	12.33	12.54	12.75	12.96	13.16	13.36	13.55	13.74	13.93	14.30	14.66	15.02	15.36	15.70	16.03	16.36	16.68
10 3/4	11.70	11.93	12.15	12.37	12.59	12.80	13.01	13.21	13.41	13.61	13.81	14.00	14.19	14.56	14.93	15.29	15.63	15.97	16.31	16.63	16.95
11	11.95	12.18	12.40	12.62	12.84	13.05	13.26	13.47	13.67	13.87	14.07	14.26	14.45	14.83	15.19	15.55	15.90	16.24	16.58	16.91	17.23
11 1/4	12.20	12.43	12.67	12.91	13.09	13.30	13.52	13.72	13.93	14.13	14.33	14.52	14.71	15.08	15.46	15.82	16.17	16.52	16.84	17.17	17.50
11 1/2	12.45	12.65	12.90	13.11	13.35	13.56	13.77	13.98	14.18	14.38	14.58	14.78	14.97	15.35	15.72	16.08	16.43	16.78	17.11	17.45	17.78
11 3/4	12.66	12.92	13.16	13.39	13.59	13.82	14.03	14.23	14.44	14.63	14.84	15.04	15.22	15.60	15.98	16.34	16.70	17.05	17.39	17.73	18.05
12	12.96	13.20	13.42	13.63	13.86	14.07	14.28	14.49	14.70	14.88	15.10	15.30	15.50	15.88	16.24	16.61	16.96	17.32	17.66	18.00	18.33

TABLE 10-2. BLANK DIAMETERS OF CYLINDRICAL SHELLS, INCHES (*Continued*)

Shell diam., in.	Height of shell, in. 4¼	4½	4¾	5	5¼	5½	5¾	6	6½	7
¼	2.08	2.13	2.20	2.25	2.31	2.36	2.41	2.46	2.56	2.66
⅜	2.55	2.63	2.70	2.76	2.83	2.90	2.96	3.03	3.15	3.27
½	2.96	3.04	3.12	3.20	3.28	3.35	3.42	3.50	3.64	3.77
⅝	3.32	3.42	3.50	3.59	3.68	3.76	3.84	3.92	4.08	4.23
¾	3.63	3.73	3.83	3.94	4.03	4.13	4.22	4.30	4.48	4.64
⅞	3.95	4.06	4.17	4.27	4.36	4.47	4.57	4.66	4.84	5.03
1	4.24	4.35	4.46	4.58	4.69	4.79	4.89	5.00	5.19	5.39
1⅛	4.51	4.63	4.75	4.87	4.98	5.10	5.21	5.31	5.52	5.72
1¼	4.78	4.90	5.03	5.15	5.27	5.39	5.50	5.61	5.84	6.04
1⅜	5.02	5.16	5.29	5.42	5.54	5.67	5.79	5.90	6.13	6.35
1½	5.26	5.40	5.54	5.68	5.81	5.93	6.07	6.19	6.42	6.65
1⅝	5.50	5.64	5.78	5.92	6.06	6.20	6.33	6.45	6.70	6.94
1¾	5.72	5.88	6.02	6.17	6.31	6.45	6.58	6.71	6.97	7.22
1⅞	5.95	6.10	6.25	6.41	6.55	6.69	6.83	6.96	7.23	7.49
2	6.16	6.32	6.48	6.63	6.78	6.93	7.07	7.21	7.49	7.75
2⅛	6.38	6.54	6.70	6.86	7.01	7.16	7.31	7.45	7.73	8.00
2¼	6.58	6.75	6.91	7.08	7.23	7.39	7.54	7.68	7.97	8.25
2⅜	6.78	6.96	7.13	7.29	7.45	7.61	7.76	7.91	8.21	8.49
2½	6.98	7.16	7.33	7.50	7.66	7.82	7.98	8.14	8.44	8.73
2⅝	7.18	7.36	7.53	7.71	7.88	8.04	8.20	8.36	8.67	8.97
2¾	7.37	7.55	7.73	7.91	8.08	8.25	8.41	8.58	8.89	9.20
2⅞	7.56	7.75	7.93	8.11	8.29	8.46	8.62	8.79	9.11	9.42
3	7.75	7.94	8.12	8.30	8.48	8.66	8.83	9.00	9.33	9.64
3⅛	7.93	8.12	8.31	8.50	8.68	8.86	9.03	9.20	9.54	9.86
3¼	8.11	8.31	8.50	8.69	8.88	9.06	9.23	9.41	9.75	10.08
3⅜	8.29	8.49	8.69	8.88	9.07	9.25	9.43	9.61	9.96	10.29
3½	8.47	8.68	8.87	9.06	9.26	9.45	9.63	9.81	10.16	10.50
3⅝	8.65	8.85	9.06	9.25	9.45	9.64	9.82	10.00	10.36	10.71
3¾	8.82	9.03	9.23	9.44	9.63	9.82	10.01	10.20	10.56	10.91
3⅞	8.99	9.20	9.41	9.61	9.82	10.01	10.20	10.39	10.76	11.11
4	9.16	9.38	9.59	9.79	10.00	10.20	10.39	10.58	10.95	11.31
4⅛	9.33	9.55	9.76	9.97	10.18	10.38	10.57	10.76	11.14	11.51
4¼	9.50	9.72	9.94	10.15	10.35	10.56	10.76	10.95	11.33	11.71
4⅜	9.67	9.89	10.11	10.32	10.53	10.74	10.94	11.14	11.52	11.90
4½	9.83	10.06	10.28	10.50	10.71	10.92	11.12	11.32	11.71	12.09

Shell diam., in.	Height of shell, in. 7½	8	8½	9	9½	10	10½	11	11½	12
¼	2.75	2.83	2.93	3.01	3.09	3.17	3.25	3.33	3.40	3.48
⅜	3.38	3.48	3.59	3.70	3.80	3.90	3.98	4.08	4.17	4.26
½	3.90	4.03	4.15	4.27	4.39	4.50	4.61	4.71	4.82	4.93
⅝	4.38	4.52	4.65	4.78	4.91	5.04	5.16	5.28	5.39	5.51
¾	4.80	4.96	5.10	5.25	5.39	5.53	5.66	5.79	5.92	6.05
⅞	5.19	5.36	5.52	5.68	5.83	5.98	6.12	6.26	6.40	6.53
1	5.57	5.74	5.92	6.08	6.24	6.40	6.56	6.71	6.86	7.00
1⅛	5.92	6.10	6.28	6.46	6.63	6.80	6.96	7.12	7.28	7.43
1¼	6.25	6.45	6.64	6.82	7.00	7.18	7.35	7.52	7.68	7.84
1⅜	6.57	6.78	6.97	7.16	7.35	7.54	7.73	7.90	8.07	8.24
1½	6.87	7.09	7.30	7.50	7.70	7.89	8.08	8.26	8.44	8.62
1⅝	7.17	7.39	7.61	7.82	8.02	8.22	8.42	8.61	8.80	8.98
1¾	7.46	7.69	7.91	8.13	8.34	8.55	8.75	8.95	9.14	9.33
1⅞	7.73	7.97	8.20	8.43	8.64	8.86	9.07	9.27	9.48	9.67
2	8.00	8.25	8.48	8.72	8.94	9.17	9.38	9.59	9.80	10.00
2⅛	8.26	8.52	8.76	9.00	9.23	9.46	9.68	9.90	10.11	10.32
2¼	8.52	8.78	9.03	9.28	9.52	9.75	9.98	10.21	10.42	10.63
2⅜	8.77	9.03	9.29	9.55	9.79	10.03	10.26	10.49	10.72	10.94
2½	9.01	9.29	9.55	9.81	10.06	10.31	10.55	10.78	11.01	11.24
2⅝	9.25	9.53	9.80	10.07	10.33	10.58	10.82	11.06	11.30	11.53
2¾	9.49	9.78	10.05	10.32	10.59	10.84	11.09	11.33	11.58	11.81
2⅞	9.72	10.01	10.29	10.57	10.84	11.11	11.35	11.61	11.85	12.09
3	9.95	10.25	10.53	10.82	11.09	11.36	11.62	11.87	12.12	12.37
3⅛	10.17	10.48	10.77	11.06	11.34	11.61	11.88	12.13	12.39	12.64
3¼	10.40	10.70	11.00	11.29	11.58	11.86	12.13	12.39	12.65	12.90
3⅜	10.61	10.93	11.23	11.53	11.82	12.10	12.37	12.64	12.91	13.17
3½	10.83	11.15	11.46	11.76	12.05	12.34	12.62	12.89	13.16	13.43
3⅝	11.04	11.36	11.68	11.98	12.28	12.57	12.86	13.14	13.41	13.68
3¾	11.25	11.58	11.90	12.21	12.51	12.80	13.09	13.37	13.65	13.93
3⅞	11.45	11.79	12.11	12.43	12.74	13.03	13.33	13.62	13.90	14.18
4	11.66	12.00	12.33	12.65	12.96	13.26	13.56	13.85	14.14	14.42
4⅛	11.86	12.20	12.54	12.86	13.18	13.49	13.79	14.09	14.38	14.66
4¼	12.06	12.41	12.75	13.07	13.40	13.72	14.02	14.32	14.61	14.90
4⅜	12.26	12.61	12.95	13.29	13.61	13.93	14.24	14.54	14.84	15.13
4½	12.45	12.81	13.16	13.50	13.82	14.15	14.45	14.77	15.07	15.37

TABLE 10-2. BLANK DIAMETERS OF CYLINDRICAL SHELLS, INCHES *(Continued)*

Shell diam., in.	Height of shell, in.																			
	4¼	4½	4¾	5	5¼	5½	5¾	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12
4⅝	10.00	10.22	10.45	10.67	10.88	11.09	11.30	11.50	11.90	12.28	12.65	13.01	13.36	13.70	14.04	14.36	14.68	14.99	15.30	15.00
4¾	10.16	10.39	10.62	10.84	11.05	11.27	11.47	11.68	12.08	12.47	12.84	13.21	13.56	13.91	14.25	14.57	14.90	15.22	15.52	15.83
4⅞	10.32	10.55	10.78	11.01	11.23	11.44	11.65	11.86	12.26	12.65	13.03	13.41	13.76	14.11	14.45	14.79	15.11	15.43	15.74	16.05
5	10.48	10.72	10.95	11.18	11.40	11.61	11.83	12.04	12.45	12.84	13.23	13.60	13.96	14.32	14.66	15.00	15.33	15.65	15.97	16.28
5⅛	10.65	10.88	11.12	11.34	11.57	11.79	12.00	12.21	12.63	13.03	13.41	13.79	14.16	14.52	14.86	15.21	15.54	15.87	16.19	16.50
5¼	10.80	11.04	11.28	11.51	11.74	11.96	12.17	12.39	12.81	13.21	13.60	13.98	14.35	14.71	15.07	15.41	15.75	16.08	16.40	16.72
5⅜	10.96	11.20	11.44	11.68	11.90	12.13	12.35	12.56	12.98	13.39	13.79	14.17	14.54	14.91	15.27	15.61	15.95	16.29	16.61	16.93
5½	11.12	11.36	11.60	11.84	12.07	12.29	12.52	12.73	13.16	13.57	13.97	14.36	14.73	15.11	15.47	15.82	16.16	16.50	16.83	17.15
5⅝	11.28	11.52	11.76	12.00	12.23	12.46	12.69	12.90	13.33	13.75	14.15	14.54	14.93	15.30	15.66	16.02	16.36	16.70	17.04	17.36
5¾	11.43	11.68	11.92	12.16	12.40	12.63	12.85	13.07	13.51	13.93	14.33	14.73	15.11	15.49	15.86	16.21	16.57	16.91	17.25	17.58
5⅞	11.59	11.84	12.08	12.32	12.56	12.79	13.02	13.24	13.68	14.10	14.51	14.91	15.30	15.68	16.05	16.42	16.77	17.11	17.45	17.79
6	11.74	12.00	12.24	12.48	12.72	12.96	13.19	13.41	13.85	14.28	14.69	15.10	15.49	15.87	16.24	16.61	16.97	17.32	17.66	18.00
6¼	12.05	12.31	12.56	12.80	13.05	13.28	13.52	13.74	14.19	14.63	15.05	15.46	15.86	16.25	16.63	17.00	17.36	17.72	18.07	18.41
6½	12.36	12.62	12.87	13.12	13.37	13.61	13.85	14.08	14.53	14.97	15.40	15.82	16.22	16.62	17.00	17.38	17.75	18.11	18.47	18.82
6¾	12.66	12.92	13.18	13.43	13.68	13.93	14.17	14.40	14.86	15.31	15.75	16.17	16.58	16.98	17.38	17.76	18.14	18.50	18.87	19.22
7	12.96	13.23	13.49	13.74	14.00	14.24	14.49	14.73	15.19	15.65	16.09	16.52	16.94	17.34	17.74	18.13	18.52	18.89	19.26	19.62
7¼	13.25	13.52	13.79	14.05	14.31	14.56	14.80	15.05	15.52	15.98	16.43	16.86	17.29	17.70	18.11	18.51	18.89	19.27	19.64	20.01
7½	13.55	13.82	14.09	14.36	14.62	14.87	15.12	15.37	15.85	16.31	16.77	17.21	17.64	18.06	18.47	18.87	19.26	19.65	20.03	20.40
7¾	13.84	14.12	14.39	14.66	14.92	15.18	15.43	15.68	16.17	16.64	17.10	17.55	17.98	18.41	18.82	19.23	19.63	20.02	20.40	20.78
8	14.14	14.42	14.69	14.96	15.23	15.49	15.74	15.99	16.49	16.97	17.43	17.88	18.33	18.76	19.18	19.59	19.99	20.39	20.78	21.16
8¼	14.43	14.71	14.99	15.26	15.53	15.79	16.05	16.31	16.80	17.29	17.76	18.22	18.66	19.10	19.53	19.95	20.36	20.76	21.15	21.54
8½	14.72	15.00	15.28	15.56	15.83	16.10	16.36	16.62	17.12	17.61	18.09	18.55	19.00	19.44	19.88	20.30	20.71	21.11	21.51	21.91
8¾	15.00	15.29	15.58	15.86	16.13	16.40	16.66	16.92	17.43	17.93	18.41	18.88	19.34	19.78	20.22	20.65	21.07	21.48	21.88	22.28
9	15.29	15.58	15.87	16.15	16.43	16.70	16.97	17.23	17.74	18.24	18.73	19.20	19.67	20.12	20.56	21.00	21.42	21.84	22.24	22.64
9¼	15.58	15.87	16.16	16.44	16.72	17.00	17.26	17.53	18.05	18.56	19.05	19.53	20.00	20.45	20.90	21.34	21.77	22.19	22.60	23.00
9½	15.86	16.16	16.45	16.74	17.02	17.29	17.57	17.83	18.36	18.87	19.37	19.85	20.32	20.79	21.24	21.68	22.11	22.54	22.96	23.37
9¾	16.14	16.44	16.74	17.03	17.31	17.59	17.86	18.14	18.66	19.18	19.68	20.17	20.65	21.12	21.57	22.02	22.46	22.89	23.31	23.72
10	16.43	16.73	17.02	17.31	17.60	17.88	18.15	18.43	18.97	19.49	20.00	20.49	20.97	21.44	21.90	22.36	22.80	23.24	23.66	24.08
10¼	16.71	17.01	17.31	17.60	17.89	18.18	18.46	18.73	19.27	19.80	20.31	20.81	21.29	21.77	22.23	22.69	23.14	23.58	24.01	24.43
10½	16.99	17.29	17.59	17.89	18.18	18.47	18.75	19.03	19.57	20.10	20.62	21.12	21.61	22.09	22.56	23.02	23.47	23.92	24.35	24.78
10¾	17.27	17.58	17.88	18.18	18.47	18.76	19.04	19.32	19.87	20.40	20.93	21.43	21.93	22.41	22.89	23.35	23.81	24.25	24.69	25.13
11	17.55	17.86	18.16	18.46	18.76	19.05	19.33	19.62	20.17	20.71	21.23	21.74	22.24	22.73	23.21	23.68	24.14	24.59	25.04	25.47
11¼	17.81	18.12	18.44	18.74	19.03	19.33	19.62	19.90	20.46	21.01	21.54	22.05	22.55	23.06	23.54	24.00	24.47	24.92	25.37	25.82
11½	18.09	18.41	18.71	19.02	19.32	19.63	19.92	20.20	20.76	21.30	21.84	22.36	22.87	23.36	23.85	24.33	24.80	25.25	25.70	26.15
11¾	18.38	18.70	19.01	19.32	19.61	19.90	20.21	20.50	21.05	21.61	22.14	22.67	23.18	23.68	24.17	24.66	25.13	25.58	26.04	26.49
12	18.64	18.97	19.28	19.59	19.89	20.20	20.49	20.77	21.35	21.90	22.45	22.97	23.50	23.99	24.48	24.97	25.45	25.93	26.37	26.84

Approximate Geometric Method. A simple graphical method (Fig. 10-9) for determining the diameter D of a circular blank, knowing the height h and the diameter d of a cylindrical shell to be drawn, is as follows:

1. From a level reference plane, raise a perpendicular of height h.
2. From top of the perpendicular, draw a hypotenuse of length $h + (d/2)$, to intersect the reference plane.
3. The horizontal component X, between the intersections on the reference plane, equals the radius of the necessary circular blank of diameter D.

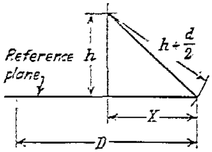


FIG. 10-9. A graphical method for determining the blank for a cylindrical shell.

Precise Method. The blank size for a symmetrical drawn cup as shown in Fig. 10-10 may be exactly determined by the rule of Goldinus, which states that the area is equal to the length of the profile, times the length of the path of its center of gravity. With the area known, it is a simple matter to calculate the diameter of the blank. The length of the lines C, L_1, L_3, and L_4 (taken along the neutral axis) is known, with the locations of their centers of gravity known in relation to axis A-B. Arc length

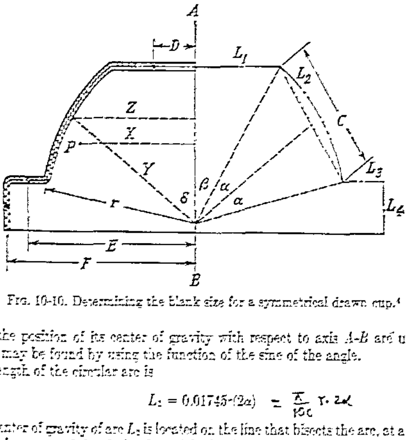


FIG. 10-10. Determining the blank size for a symmetrical drawn cup.[4]

L_2 and the position of its center of gravity with respect to axis A-B are unknown. Angle α may be found by using the function of the sine of the angle.

The length of the circular arc is

$$L_2 = 0.01745r(2\alpha) \quad = \frac{\pi}{180} r \cdot 2\alpha \tag{6}$$

The center of gravity of arc L_2 is located on the line that bisects the arc, at a distance Y from the center of the circle where C is the chord length:

$$Y = \frac{Cr}{L_2} \tag{7}$$

To find the horizontal distance Z, between the center of gravity of arc L_2 and the axis A-B, angle δ may be found by using the function of the sine of the angle. Then,

$$\delta = \beta + \alpha \qquad \beta = \frac{L_1}{Y} \tag{8}$$

and

$$Z = Y \sin \delta \tag{9}$$

To find the horizontal distance X between the combined center of gravity P and the axis A-B, divide the sum of the moments of each section by the combined lengths of the sections:

$$X = \frac{L_1D + L_2Z + L_3E + L_4F}{L_1 + L_2 + L_3 + L_4} \tag{10}$$

Applying the rule of Guldinus (also known as Pappus' second theorem),

$$A = (L_1 + L_2 + L_3 + L_4)2\pi X \tag{11}$$

Since the area is unimportant, the desired blank diameter D can be solved directly, instead, by using Eq. (12),

$$D = \sqrt{8X(L_1 + L_2 + L_3 + L_4)} \tag{12}$$

Area-of-element Method. The blank diameter for complex circular shells, as the one in Fig. 10-10, may be divided into simple elements of shape, such as the elements numbered 1, 2, 3, and 4 in Fig. 10-11. Element 1 is a cylinder, 2 is a flat ring, 3 is a

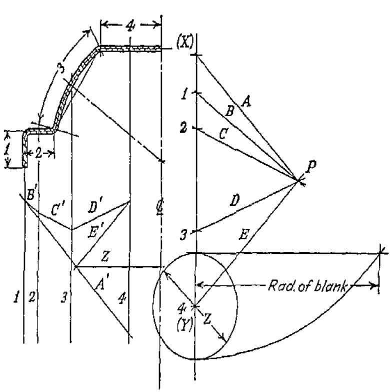


FIG. 10-11. Graphic method of determining the blank diameter of a symmetrical drawn cup.

radiused ring or a portion of a sphere, and 4 is a disk. The area of each element may be found by using the equations in Fig. 10-12. From the total of these areas, the diameter of the blank may be determined by

$$D = 1.128\sqrt{A} \tag{13}$$

Layout Method. A graphic method of determining the blank diameter of the same shell shown in Fig. 10-10 is illustrated in Fig. 10-11. The procedure to determine the blank is as follows:

1. Make an accurate layout of the part, including a line through the center of the stock.

2. Number each dissimilar section starting at the extreme edge of the part.

3. Draw vertical line X-Y and mark off the length of each section accurately starting with section 1 at the top of the line. Number each section to correspond with the same section of the shell.

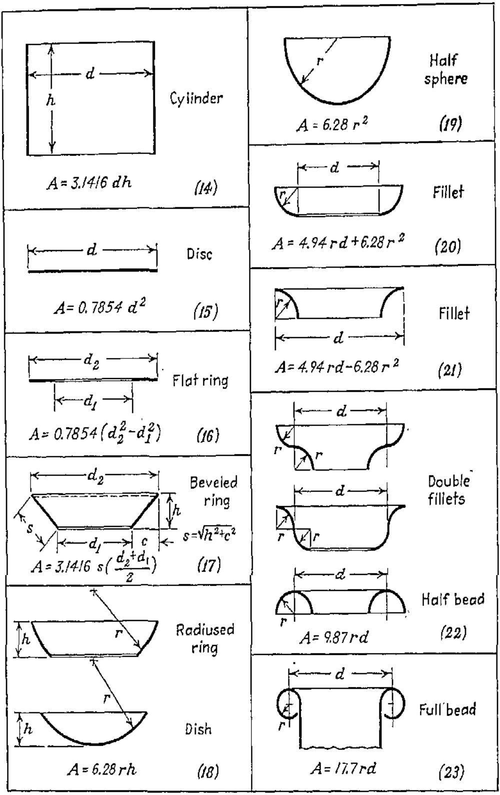


Fig. 10-12. Equations for areas of circular shell parts.

4. Through the center of gravity of each section, draw a line downward parallel to line X-Y. The center of gravity of an arc lies on a line which is perpendicular to and bisects the chord and is two-thirds of the distance from the chord to the arc.

5. From point X draw line A at 45° to point P, which is about midway between X and Y. Draw line A' parallel to line A intersecting the lines drawn in step 4.

6. Connect P to the ends of the sections on line X-Y obtaining lines B, C, D, and E. Draw parallel lines B', C', D', and E'. Note that B' starts where A' intersects the first center-of-gravity line and so on until where E' starts where D' intersects the fourth center-of-gravity line and continues to intersect A'.

7. Through the intersection of A' and E' draw a horizontal line Z to the center line of the shell. Construct a circle using Y as the center point and Z as the diameter. Using point X as the center point, scribe an arc tangent to the small circle.

8. Draw a horizontal line tangent to the top of the small circle until it intersects the large arc. The distance from this intersection to line X-Y is the radius of the required blank.

Figure 10-13 shows a group of equations for blank diameters of differently shaped symmetrical drawn shells.

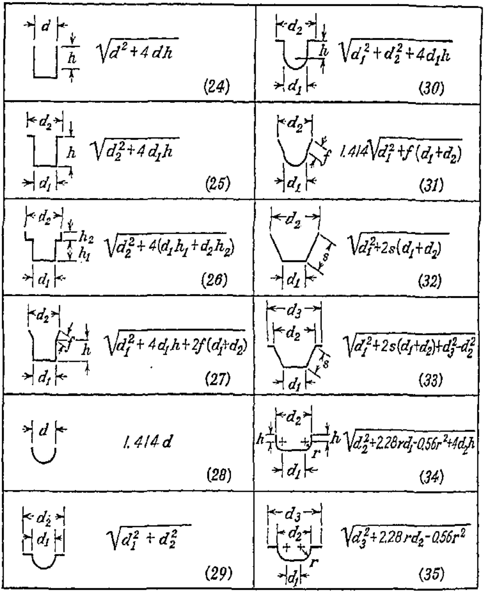


FIG. 10-13. Equations for blank diameters.

Reduction Factors. After the approximate blank size has been determined, the next step is to estimate the number of draws that will be required to produce the shell and the best reduction rate per draw. As regards diameter reduction, the area of metal held between the blankholding faces must be reasonably proportional to the area on which the punch is pressing, since there is a limit to the amount of metal which can be made to flow in one operation. The greater the difference between blank and shell diameters, the greater the area that must be made to flow, and therefore the higher the stress required to make it flow. General practice has established that, for the first draw, the area of the blank should not be more than three and one-half to four times the cross-sectional area of the punch.

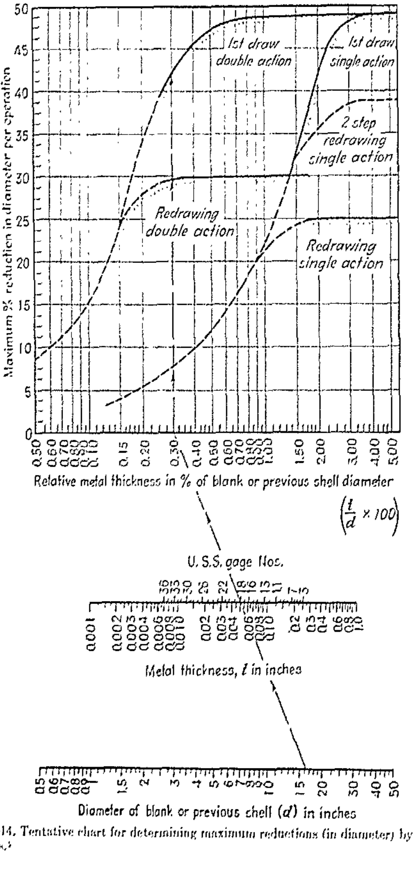


FIG. 10-14. Tentative chart for determining maximum reductions (in diameter) by various methods.[3]

One of the important factors in the success or failure of a drawing operation is the *thickness ratio*, or the relation of the metal thickness to the blank or previous shell diameter; this ratio is expressed as t/D. As this ratio decreases, the tendency to *wrinkling increases, requiring more blankholding pressure to control the flow* properly and prevent wrinkles from starting. The ratio t/D is used in Fig. 10-14 as a tentative means of determining maximum reductions permissible under single- and double-action draws. The top limit of about 48 per cent seems to be substantiated by practice and theory concerning the strains set up in the draw. The 30 per cent limit for double-action redraws is dictated by practice and is modified by corner radii, friction, and the angle of the blankholding faces with respect to the shell wall. Because of strain-hardening stresses set up in the metal, the third and subsequent draws would not exceed 20 per cent reduction without an annealing operation. The reduction percentages obtained from this chart should be considered tentative only, since they may be exceeded under certain conditions; under other circumstances they may have to be reduced.

The nomograph Fig. 10-14 is used as follows:

Given: A blank of approximate diameter of 16.6 in. and thickness of 0.050 in.

Solution: 1. Connect point 16.6 on d-chart and point 0.050 on t-chart with a line.

2. The projection of this line intersects the t/d-chart at 0.30 (0.3 of 1 per cent).

3. The vertical projection of this point on the "1st draw, double-action" curve at 42 establishes an approximate limit of 42 per cent reduction for the first draw, using a double-action die. Similarly, intersections as shown establish reduction limits of approximately 28 and 7½ per cent, respectively, for double-action and single-action redrawing.

When the maximum ratio of height divided by the diameter exceeds 5:8 or a possible 3:4, more than one reduction is required. Table 10-3 enumerates the probable number of reductions using this ratio.

TABLE 10-3. PROBABLE NUMBER OF REDUCTIONS POSSIBLE FOR A GIVEN RATIO OF HEIGHT TO DIAMETER

*Ratio, Height to Diameter**	*Probable Number of Reductions*
Up to 0.7	1
0.7–1.5	2
1.5–3	3
3–4.7	4

* To compute the height-diameter ratio, it is necessary to divide the inside shell height by the mean shell diameter.

Changes in Unit Stress. After each differential of draw depth, the material has a new group of physical properties resulting from cold working. Elastic limit, hardness, yield point, and to a lesser extent, ultimate strength are increased and plastic range is thereby decreased. The total depth of draw is not limited by the plastic range; only the depth in one operation is thus restricted. Annealing may be resorted to after a draw to restore, almost entirely, the original plasticity.

The use of strain-hardening curves to discover the extreme unit stress of a shell after an operation is illustrated in Fig. 10-15. The straight-line curve was drawn for a material having a modulus of strain hardening S_r* of 110,000 psi, an initial yield point S_y of 50,000 psi, and a maximum yield point S_x of 90,000 psi. A reduction of 40 per cent of the blank diameter was used for the first draw, and a reduction of 20 per cent of the shell diameter produced in the first draw was used for the second draw. This is a total reduction of 52 per cent for the two draws. After the strain-hardening line (O-S_r) is plotted, a line is drawn from the 40 per cent point on the X-X axis to point S_x. From point S_y extend a horizontal line until it intersects line (40 per cent-S_x). From this intersection, extend a vertical line up to the strain-hardening line (O-S_r). This intersection determines the approximate psi value of the yield point after the completion of the first draw. By using the same procedure and the new yield point, the unit stress after the second draw can be determined. Note that, when the vertical line of the second draw is extended downward, it intersects the horizontal

* Extrapolation of a yield point to a theoretical 100 per cent reduction.

line from S_y on the line between the 52 per cent point and the point S_x. Considering that the total reduction is above 50 per cent and that the unit stress after the second draw moved close to the maximum yield point, raising the possibility of high scrap loss because the shell fractures at local weak points, an annealing operation may be advisable between the first and second draws.

The properties of ferrous and nonferrous stamping materials may be found in Secs. 26 and 27.

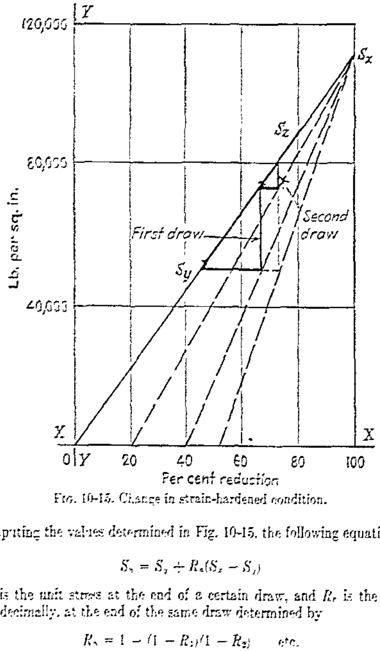


FIG. 10-15. Change in strain-hardened condition.

For computing the values determined in Fig. 10-15, the following equation may be used:

$$S_z = S_y + R_z(S_x - S_y) \tag{36}$$

where S_z is the unit stress at the end of a certain draw, and R_z is the reduction, expressed decimally, at the end of the same draw determined by

$$R_z = 1 - (1 - R_1)(1 - R_2) \qquad \text{etc.} \tag{37}$$

The amount of reduction R of each individual draw expressed decimally is found by the equation

$$R = \left(\frac{D - d}{D}\right) \tag{38}$$

where D is the blank or previous shell diameter and d is the resulting shell diameter.

Drawing Pressure. Figure 10-16, for computing the maximum drawing pressure in drawing operations, is based on a free draw with sufficient clearance so that there is no ironing, and upon a maximum reduction (about 50 per cent). The equation actually gives the load to fracture the shell or the tensile strength near the bottom of the shell. The use of this nomograph is as follows:

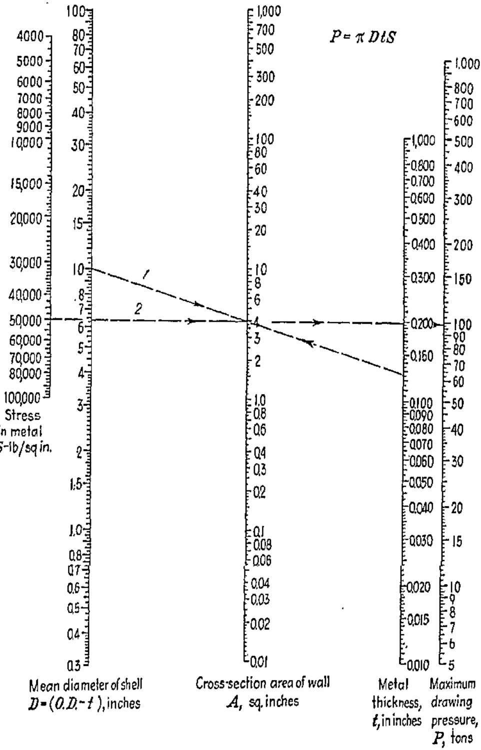


FIG. 10-16. Nomograph for computing drawing pressures. (*E. W. Bliss Co.*[5])

Given: Deep-drawing steel stock, ⅛ in. thick, tensile strength of 50,000 psi to be drawn into a shell of 10-in. diameter. Determine the drawing pressure.

Solution: 1. Connect point 10 on the *D*-scale with a line (line 1) to point 0.125 on the *t*-scale.

2. Its intersection with the *A*-scale is at 4.0, which is the approximate area.

3. Connect this point with a line (line 2) to point 50,000 on the *S*-scale.

4. Project the line to the right to intersect the *P*-scale at 98 tons, the drawing pressure required.

The pressure applied to the punch, necessary to draw a shell, is equal to the product of the cross-sectional area and the yield strength *S* of the metal. Taking into consideration the relation between the blank and shell diameters and a constant *C* of 0.6

to 0.7 to cover friction and bending, the pressure P for a cylindrical shell may be expressed by the empirical equation

$$P = \pi d t \left(\frac{D}{d} - C\right) \tag{39}$$

Draw Radii. The radius of the draw die should be kept as large as possible to aid in the flow, but if it is too large, the metal will be released by the blankholder too soon and wrinkling will result. When the radius is too small, the material will rupture as it goes over the radius, or against the face of the punch. Table 10-4 gives the practical drawing radii for certain stock thicknesses. The values in this table are based on a radius of approximately four times the stock thickness. In some cases the radius may vary from four to six times the stock thickness.

TABLE 10-4. PRACTICAL DRAWING RADII FOR CERTAIN THICKNESS OF STOCK[1]

Thickness of Stock, In.	Drawing Radius, In.
1/64	1/16
1/32	1/8
3/64	3/16
1/16	1/4
5/64	3/8
3/32	7/16
1/8	9/16

When cupping without a blankholder, it has been found that wrinkling will not occur if the flat contact area between the blank and the die does not exceed three times the thickness of stock. The width between the die opening and the point of contact should not exceed twenty times the stock thickness. The shape of the inlet to the die opening may be a true radius or an elliptic curve or taper, measured from the horizontal, of 45 to 60°. Figure 10-17 illustrates these points.

The drawing, without a blankholder, of cup-shaped parts of heavy-gage metals often requires draw radii of six to eight times the stock thickness. This reduces the width of the flat surface of the die upon which the blank lies. A taper or an elliptical curve may be used to increase the width of this surface and also aid the flow of metal into the die. The minor diameter of the ellipse may be approximately one-half the difference between the blank diameter and the shell diameter. The major diameter may be up to 1.5 times the minor diameter.

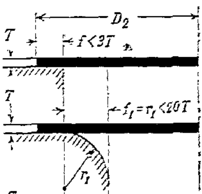


Fig. 10-17. Limitations of cupping without blankholder.[1]

Punch-nose Radii. There is no set rule as to how large the punch-nose radii should be for each successive die, except that each radius should be proportionally larger than that of the succeeding shell. To prevent excessive thinning at the bottom of the cup, the punch-nose radius should be from four to ten times the metal thickness. When sharp radii have been used in the first draws, thinning often appears on the side wall of later operations as a line or a depression and is increasingly higher on the wall as the diameter is reduced. The nose radius and sides of the punch should be polished with vertical strokes, especially when drawing soft metals, to eliminate any cross pockets into which the metal might flow and cause fracture when the metal is stripped from the punch.

Shells may be prepared with angular corners, as shown in Fig. 10-18. From the layout of the finished shell, the layout of each preceding shell is developed. The angle in the bottom of the last preliminary shell should start at a point equal to one-fourth of the bottom radius of the finished shell, measured inward from the inside of the shell. Angles for the other shells should start at a point equal to one-half the Y dimension. The angle Z measured from the horizontal should be 30° for stock up to 0.030 in. thick, 40° for 0.030- to 0.060-in. stock, and 45° for stock over 0.060 in. thickness. The

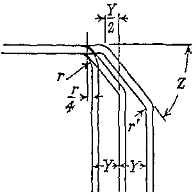


FIG. 10-18. Layout of bottom corners.

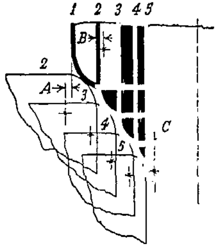


FIG. 10-19. Relation of punch-nose and die draw radii.

radius r' at the intersection of the slope and the bottom and sides should be approximately $0.6Y$.

The relation of the punch-nose and die draw radii to minimize thinning of stock is shown in Fig. 10-19. The center point of the draw radius should be approximately ⅛ in. outside the previous cup, as illustrated at A. The center point of the punch-nose radius should be slightly inside the following shell, as at B. The center points of the punch-nose radii on the last two operations are about on the same line, thereby maintaining the flat on the bottom of the cup, as at C.

Clearances. The die space usually allowed for drawing any metal should be proportional to the metal thickness plus an allowance to prevent wall friction. This allowance ranges from 7 to 20 per cent of the metal thickness, depending upon the type of operation and the metal. As the shearing strength of the stock decreases, the allowance must be increased. Table 10-5 gives factors for determining typical die-clearance dimensions. The sizing draw clearance is used for straight-sided shells where diameter or wall thickness is important, or where it is necessary to improve the surface finish in order to reduce finishing costs.

TABLE 10-5. DRAW CLEARANCE[1]

Blank thickness, in.	First draws	Redraws	Sizing draw*
Up to 0.015	1.07t to 1.09t	1.08t to 1.1t	1.04t to 1.05t
0.016 to 0.050	1.08t to 1.1t	1.09t to 1.12t	1.05t to 1.06t
0.051 to 0.125	1.1t to 1.12t	1.12t to 1.14t	1.07t to 1.09t
0.136 and up	1.12t to 1.14t	1.15t to 1.2t	1.08t to 1.1t

* Used for straight-sided shells where diameter or wall thickness is important, or where it is necessary to improve the surface finish in order to reduce finishing costs.

t = thickness of the original blank.

Air vents should be put in the punch and die to eliminate air pockets, which tend to collapse the cups when stripped from the die. When only one air vent is used in the tool, Table 11-4 shows the practical air-vent diameters for different punch diameters. In nonuniform shapes it might be advantageous to use two or more air vents. To prevent plugging of the air vents with drawing compound and dirt, they must be placed in such a position that they can be easily cleaned out.

TABLE 11-4. AIR-VENT DIAMETERS

Punch Diam., in.	Air-vent Diam., in.
Up to 2	3/16
2-4	1/4
4-8	5/16
Over 8	3/8

RECTANGULAR DRAWS

Blanks for Rectangular Shells. The combination of drawing, side flow, and bending of metal during the drawing of seamless rectangular shells creates the problem of finding a shell blank that will assure the proper amount of metal for forming the shell corners without ears, folds, tears, or excessive thickness and, if possible, without the necessity for a trimming operation.

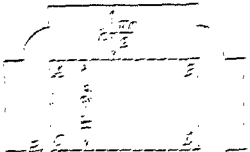


Fig. 11-21. Starting the layout of a blank for a rectangular shell.

To start the layout for the blank, a rectangle ABCD is drawn as shown in Fig. 11-21, having a width of $W-2r$ and a length of $L-2r$, where L, W, and r are the length, width, and bottom-corner radius respectively. By continuing the sides beyond the points A, B, C, D for a length equal to $h + 1.57r$, where h is the height of the flat portion of the sides of the finished shell, and connecting the points by lines parallel to the outline of the original rectangle, the outline of a shell blank is obtained where bending only is done during the drawing operation. To this outline add the quadrants with a radius equal to R. The value of R is obtained by the equation

$$R = \sqrt{[illegible]} \qquad (10)$$

where R = corner radius

h = height of the flat portion of sides

r = bottom radius

Theoretically this blank outline (solid line) contains enough metal to draw the shell, because the blank has sharp corners, folds and wrinkles will occur at the points where the quadrants meet the side walls when the shell is drawn. The sharp corners must be blended by drawing curves or by taking the metal from the side walls and adding it to the quadrants without any change in the amount of metal in the blank.

The method for blending the corners of rectangular blanks by drawing curves is illustrated in Fig. 11-22. To develop the corners, proceed thus:

1. Bisect arc ae. Through the dividing points e and f respectively draw ge and gf tangent to the quadrant arc.

Three cases may now occur as to the position of these tangents with respect to the quadrant arc: these tangents may coincide (Fig. 11-22a), they may cross each other outwardly (Fig. 11-22b), or they may cross each other inwardly (Fig. 11-22c).

2. Draw arcs with a radius R which will touch the outer edges of the side walls and the tangents ge and gf.

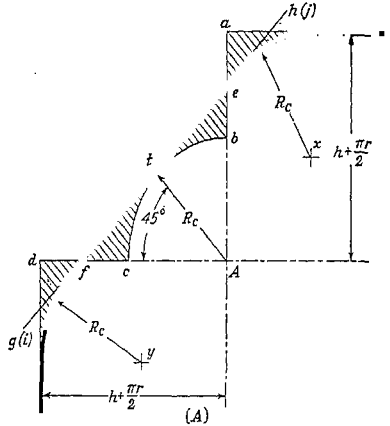


FIG. 10-21A. Corner development of blanks for rectangular draws: a straight line is produced if $R_c = 0.54(h + 1.57r)$.[6]

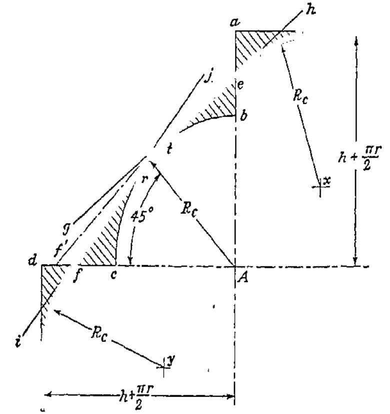


FIG. 10-21B. Corner development of blanks for rectangular draws: a convex sloping curve is obtained if $R_c > 0.54(h + 1.57r)$.

8. In case the tangents *gh* and *ij* cross each other before they touch the quadrant arc (Fig. 11-21C), an additional outside arc must be drawn for forming the sloping curve.

The development of the blank corners in this manner assures even distribution of the metal because the areas of the shaded curvilinear triangles outside the sloping curves in the side wall are equal to the areas of similar triangles added to the quadrant arcs inside the sloping curve.

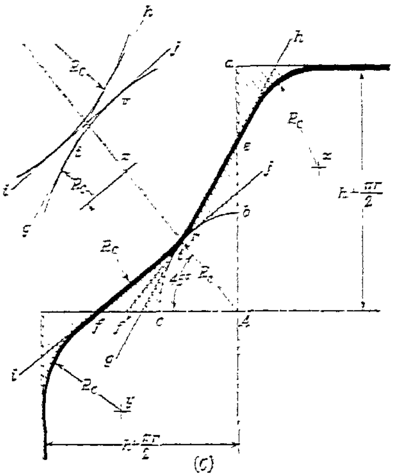


FIG. 11-21C. Corner development of blanks for rectangular draws: a concave sloping curve is produced if $R_c < 0.54h + 1.57r$.

Figure 11-22 shows a layout of a blank for an irregular kidney-shaped shell having one flat side with the corners of a radius *r* blending into the larger radius *R* and having a depth *h*. The diameter of the blanks containing the metal required to form shells having the radii *R* and *r* to a depth *h* may be calculated, using Eq. (1). Line *F* is drawn parallel to the straight side, a distance *h* below it. Arcs *R'* and *r'*, radii of the above calculated blanks, are constructed from the appropriate centers. Blend the radii *R'* and *r'* and line *F*; the resulting outline will be a fairly accurate development of the blank shape and size necessary to produce the shell.

Forming Limits for Rectangular Draws. One of the main things to consider is the number of operations required to complete the part to be drawn. The number of operations is governed by several factors, such as the quality of the material, its thickness, the corner radius, and the radius at the bottom edge of the part.

The limit of drawing a box can be expressed in various ways. Oval cups that are nearly cylindrical and square or nearly square cups can be drawn in one operation if the area of the blank does not exceed the cross-sectional area of the punch by more than four times. For boxes with a length-to-width ratio between 1 and 6, the ratio of the blank area to the punch area may be somewhat larger than for square boxes; the latter ratio increases to a maximum value of 4½ at a length-to-width ratio of 3.

and decreases as the length-to-width ratio increases. Draws may be made to a depth of *approximately 80 per cent of the width in case of a square box with a rather small* corner radius. Rectangular boxes can be drawn to a greater depth than can square boxes, and this maximum depth H increases with increasing ratio of length L to width W according to the following empirical equation:[10]

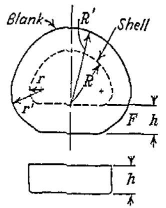


FIG. 10-22. Layout of a blank for an irregular shaped shell.[1]

$$\frac{H}{W} = C\sqrt{\frac{L}{W}} \text{ (in per cent)} \tag{41}$$

The constant C in this equation varies slightly with the metal; use 80 for steels and such ductile metals as copper and brass, 70 to 75 for ductile aluminum alloys. The relation applies to boxes not longer than three times their width. For longer boxes, the maximum *depth to which they can be drawn in a single operation* is approximately 135 per cent of their width.

It is also safe to assume that a part can be drawn in one draw to a depth of four to six times the corner *radius. If the corner radius is greater than ½ in., the depth for the draw should be* kept nearer the four times factor. Table 10-7 shows an idea of maximum depths that can be obtained from corners of a given radii.

TABLE 10-7. RELATION OF CORNER RADIUS TO HEIGHT OF DRAW:

Corner Radius, In.	*Length of Draw, In.*
3/32–3/16	1
3/16–3/8	1½
3/8–½	2
½–¾	3

Table 10-8 *is used for aluminum to determine the number of draws necessary to* produce noncircular shells and is based on the ratio of the depth of shell to the corner radius (h/r).

TABLE 10-8. NUMBER OF DRAWS BASED ON RATIO OF DEPTH TO CORNER RADIUS

Basic h/r value	Allowable range		No. of draws
	Min	Max	
6	. .	7	1
12	7	13	2
17	13	18	3
22	18	24	4

Data from J. W. Lengbridge.

The amount of reduction between draws for a rectangular part depends upon the corner radius and diminishes as the corner radius becomes smaller. Where two or more draws are required, the length and width of each die can be determined by multiplying the corner radius by 3 and adding the product to the length and width, thus finding the length and width of the preceding die. This method should apply only to a corner radius of less than ½ in. For all radii over ½ in., use a constant of 0.5 instead of the radius. The corner radius of the first die may be as much as four or five times the radius of the succeeding die or finished part. The radii of the two dies should not be laid out from the same center but, as shown in Fig. 10-23*A*, with enough surface X between the two corners to provide a drawing edge. The reason for using a large corner radius for the first die is that, when the larger corners are reduced to the *smaller radius in the second die, a large part of this compressed metal is forced out into* the sides of the box. If the first die were laid out as in Fig. 10-23*B*, there would be a comparatively large reduction at the corner and the metal would be more compressed. The drawing operation would therefore be made much more difficult since the drawing action is confined to the corners when drawing rectangular work.

Punch-and-die Radii. The size of the draw and bend radii on the draw ring is generally the same for rectangular draws as for circular draws. Some designers prefer to make the radius between the corners smaller than the radius at the corners in order to equalize the stresses in the metal at the corners. To perform some very deep draws successfully, the radius on the draw ring may be from four to ten times the metal thickness. The top surface of the draw die and the draw radii should be polished smooth, free of grind marks and well blended together, to prevent localized retardation flow with consequent uneven drawing of the metal.

There may be bulged areas in boxes of thin stainless steels and other high-strength alloys, where the length of the flat area extends over fifty times the metal thickness, which may be made to deflect by snap action referred to as "oil canning." To eliminate this, such parts are formed in two operations using slightly different tools, with an annealing between operations. The second draw should stretch the metal into shape to eliminate the canning. To facilitate stretching in the center of the long walls of the box-shaped part, the nose radius of the first draw punch may be enlarged at these locations. The use of a constant radius on the nose of the redraw punch then provides the stretching action.

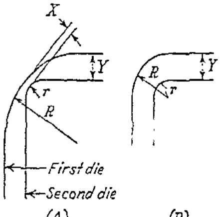


FIG. 10-23. Relation between the corners of first and second operation dies for square and rectangular work.[2]

If the corner radius of a box-shaped shell is smaller than the punch-nose radius, a corner relief should be provided at the intersection of the punch-nose and corner radii to avoid tearing at these locations. Beveling the punch nose at the corners permits the part to develop natural contours. The beveled portion should extend sufficiently far to permit the metal to curve at a radius at least equal to five times the metal thickness.

Draw Clearance. The clearance between the punch and die for a rectangular shell is about the same as for a cylindrical shell. There should be a little more clearance allowed at the corners than along the side walls. Some designers prefer to use the same corner radius on the die as on the punch to avoid ironing in these areas and to increase drawability.

Drawing Pressure for Rectangular Draws. Calculating the punch load for a rectangular shell should take into consideration the straight side-wall areas where only bending and friction are involved and stresses are low, and the corner areas where high compressive stresses are necessary to rearrange the metal. These areas are covered in the following equation:[3]

$$P = tS(2\pi r C_1 + LC_2) \qquad (42)$$

where P = drawing punch pressure, lb

t = metal thickness, in.

S = nominal ultimate tensile strength, psi

r = corner radius of the rectangular shell, in.

L = total length of straight sides of rectangular shell, in.

Constant C_1 = 0.5 for a very low shell, up to about 2 for a shell having a depth of five or six times the corner radius r

Constant C_2 = say 0.2 for easy draw radius, ample clearance, and no holding pressure; or about 0.3 for similar free flow and a normal blank-holding pressure of about $P/3$; or a maximum of 1 for a metal clamped too tightly to flow

These values for C_1 and C_2 are roughly empirical, and judgment must be used in their application.

REDRAWING

The term "redrawing" is used for a variety of operations in which a part is reduced in its lateral dimensions by means of single- or double-action tools without reducing the wall thickness. Regular redrawing is done by slipping the part over the punch which pushes the cup into the die, reducing the bottom dimensions and increasing the side-wall height. Reverse or inside-out redrawing is done by slipping the cup over a die ring, and the punch attacks the outside of the bottom, turning the part inside out into the die opening.

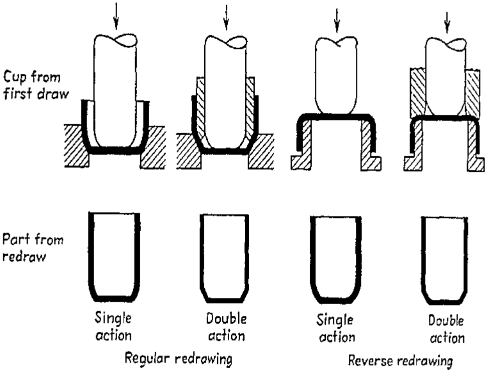


FIG. 10-24. Various types of redraw operations.

Figure 10-24 illustrates the various types of redraw operations. The regular redrawing shows the single-action tool with only a punch and die required, as the metal is heavy enough to withstand the reduction without wrinkling. The double-action tool has a blankholder, since the metal is thin and the flow must be controlled to prevent wrinkles. Most redraw operations use the regular double-action tools. The reverse drawing also shows single- and double-action tools.

References

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SECTION 11

DRAW DIES*

Draw dies are designed for use on many types of presses. They are used on single-action, double-action, and triple-action presses which are mechanical or hydraulically powered.

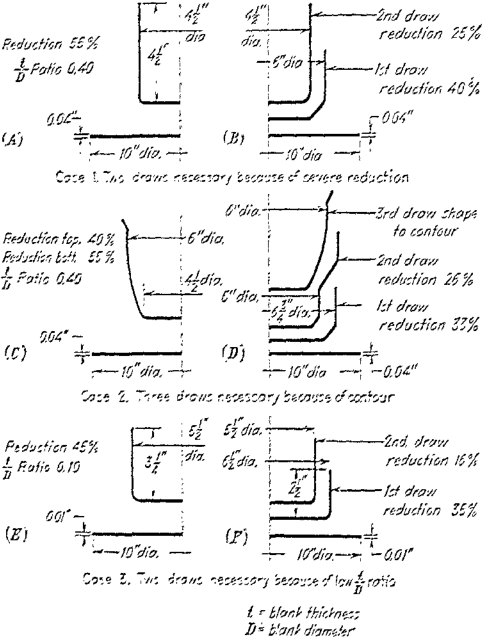

Fig. 11-1. Analysis of redrawing operations.**

* Reviewed by L. W. Langfelder, Chief Process Engineer, Aluminum Goods, Ltd.
** Superior numbers relate to References at the end of this section.

The simple single-action dies (Fig. 11-26) employ only a punch and die so arranged that they can be mounted in a press. As the shapes being drawn become more complex and difficult to fabricate, blankholders and pressure pads are added to the dies and the parts are developed in several operations rather than one. The blankholders may be permanently attached to the draw ring (Fig. 11-27) with spacers that allow insertion of the blank and its proper positioning over the die cavity. The movable blankholders and pressure pads are actuated by pressure arrangements built into or attached to the die or press.

The material, shape, and quantity of parts to be produced determine the number of operations and type of dies to be designed and built.

Analysis of Drawn Shapes. The finished shape of a shell must be carefully analyzed to determine the shape of each redraw. The shape to which a shell is redrawn determines to some extent the number of redraws required to produce the finished shape.

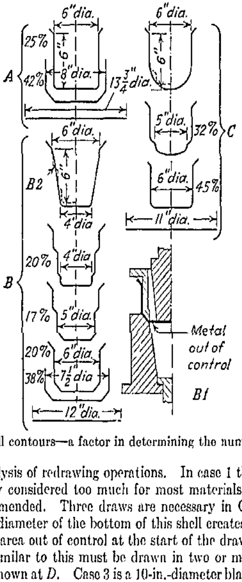

FIG. 11-2. Shell contours—a factor in determining the number of draws.[1]

Figure 11-1 is an analysis of redrawing operations. In case 1 the reduction is 55 per cent, which is usually considered too much for most materials; therefore, two draw operations are recommended. Three draws are necessary in Case 2 because of the contour. The small diameter of the bottom of this shell creates a condition in which there is a substantial area out of control at the start of the draw, if attempted in one operation. Shapes similar to this must be drawn in two or more operations, and a suggested method is shown at *D*. Case 3 is a 10-in.-diameter blank drawn to a 5½-in.-diameter shell. Although the reduction is only 45 per cent, the thickness-diameter ratio is only 0.10, requiring a smaller reduction in the first draw as suggested at *F*.

Shells of the same maximum overall dimensions are shown in Fig. 11-2 but, because of their contours, require different shape and number of redraws. *A* represents a straight-sided shell 6 in. in diameter and 6 in. deep, drawn in two draws from a 13¾-in.-diameter blank, a total reduction of about 56 per cent. *B* is a tapered shell of the same overall dimensions, drawn in five draws from a 12-in.-diameter blank. The illustration at *B*-1 shows the condition of the metal out of control if an attempt is made to redraw the tapered shell in the third operation. *C* illustrates a domed shell drawn in three operations because of the shape of the bottom. The blank for this shell is 11 in. in diameter.

A typical arrangement of redraws for a circular shell of 3SO aluminum is shown in Fig. 11-3. This shell was drawn in three operations without any intermediate anneals.

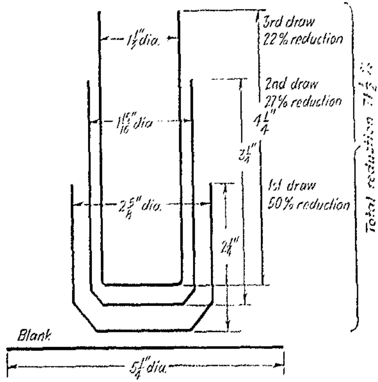

FIG. 11-3. An arrangement of draws for a circular shell of 3SO aluminum.[1]

A layout of drawing operations taken from an actual production job is shown in Fig. 11-4. The thickness-diameter ratio on this job was such that the 45 per cent reduction on the first draw gave some trouble and an arrangement containing an additional draw would have been more satisfactory.

In Fig. 11-5 a tubular part is shown formed from type 316 stainless steel. The first draw was a 40 per cent reduction, and the second 20 per cent. The third operation sized and flattened the flange. The die material was aluminum bronze with a ½-in. draw radius. The punch was high-carbon high-chromium steel, chromium-plated.

These die materials are used for drawing stainless steel, because they are less likely to scratch or gall the workpiece during the operation. For further information on die materials, refer to Secs. 24 and 25.

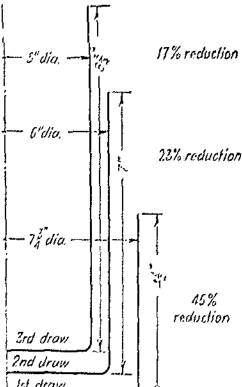

FIG. 11-4. Layout of drawing operations.

A large stainless-steel shell (Fig. 11-6) with a four-draw sequence used a two-step punch in the third draw and a shallow reverse contour at the bottom, using a mating die with a contour-bottom pad. The stock was type 302 stainless, annealed.

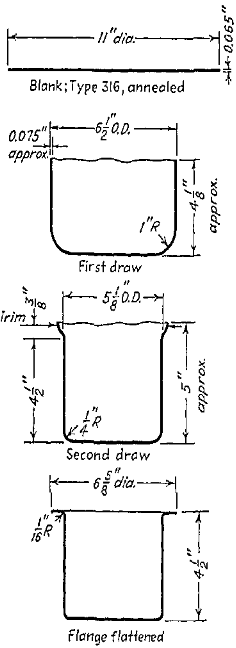

Fig. 11-5. Forming a tubular part of stainless steel.[2]

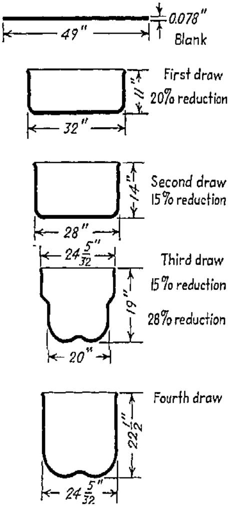

Fig. 11-6. Draw reductions for a large stainless-steel shell.[3]

A shell which required seven draw operations to reduce it to the final dimension is shown in Fig. 11-7. To facilitate the redraws, the shell was annealed after each operation. This part of type 347 stainless steel 0.091 in. thick was drawn in alloy cast-iron tools on a double-action hydraulic press. The tools were repolished every 100 to 300 parts.

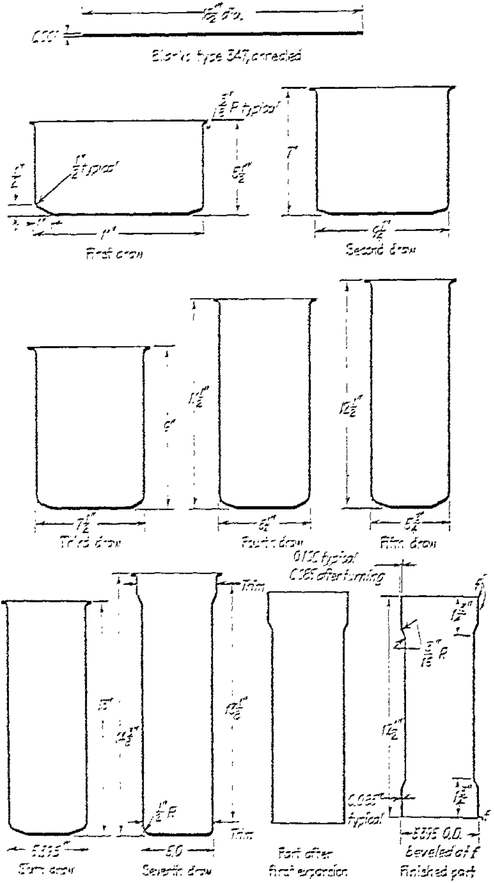

Fig. 11-7. Draw reductions for a deep stainless-steel shell.

A large stainless-steel shell (Fig. 11-6) with a four-draw sequence used a tw punch in the third draw and a shallow reverse contour at the bottom, using a m die with a contour-bottom pad. The stock was type 302 stainless, annealed.

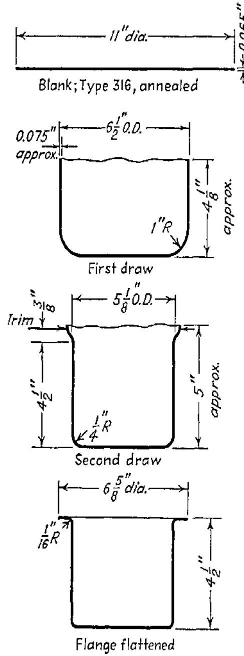

FIG. 11-5. Forming a tubular part of stainless steel.[2]

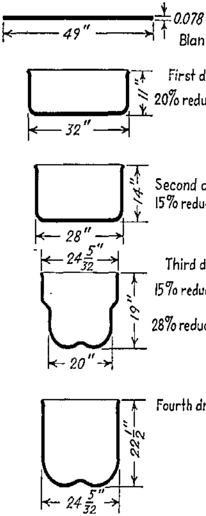

FIG. 11-6. Draw reductions for a stainless-steel shell.[3]

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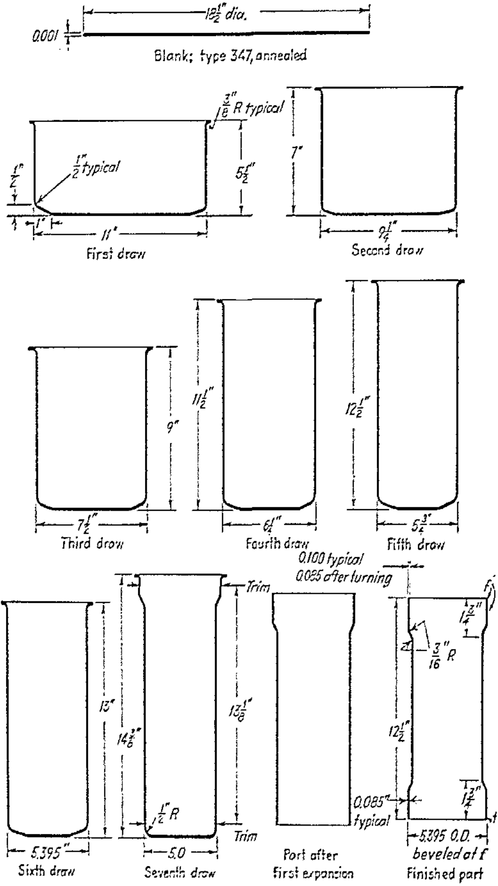


FIG. 11-7. Draw reductions for a deep stainless-steel shell.[3]

The development of a type 316 stainless-steel part, in which the bottom is pierced out and the remaining lower wall is straightened out, is shown in Fig. 11-8. High blankholding pressures were required on this operation, because of the large draw and punch-nose radii. This part was drawn with a hardened-tool-steel punch, die, and blankholder in a double-action press.

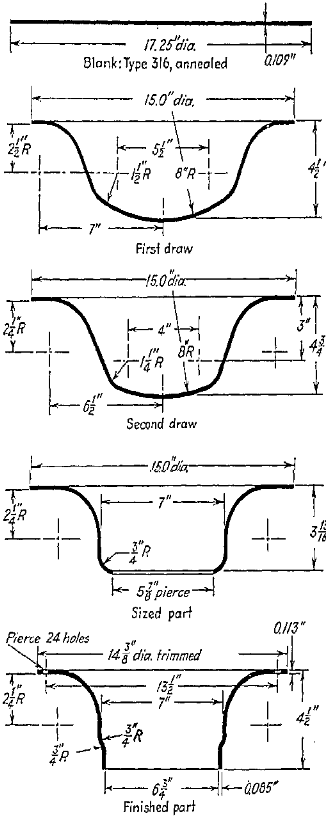


Fig. 11-8. An example of a draw using a high blankholding pressure.[2]

Cone Shapes. The drawing of cone-shaped shells requires additional draws to minimize the amount of material out of control. The tapered shell in Fig. 11-9 was completed in six draws, while the very severe cone in Fig. 11-10 required eight draws. These shells were made of annealed aluminum, but fewer steps are sometimes possible with higher-strength metals such as stainless steels because of their ability to withstand high blankholding pressures.

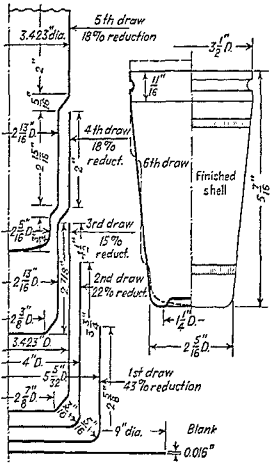


FIG. 11-9. Draw reductions for a tapered shell.[1]

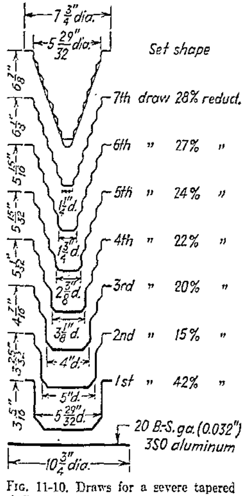


FIG. 11-10. Draws for a severe tapered shell.[1]

The development of a funnel-shaped part, drawn of type 302 stainless steel, is shown in Fig. 11-11. A single-action press with a die cushion was used with aluminum bronze die and blankholder and hardened-tool-steel punch for all the drawing operations.

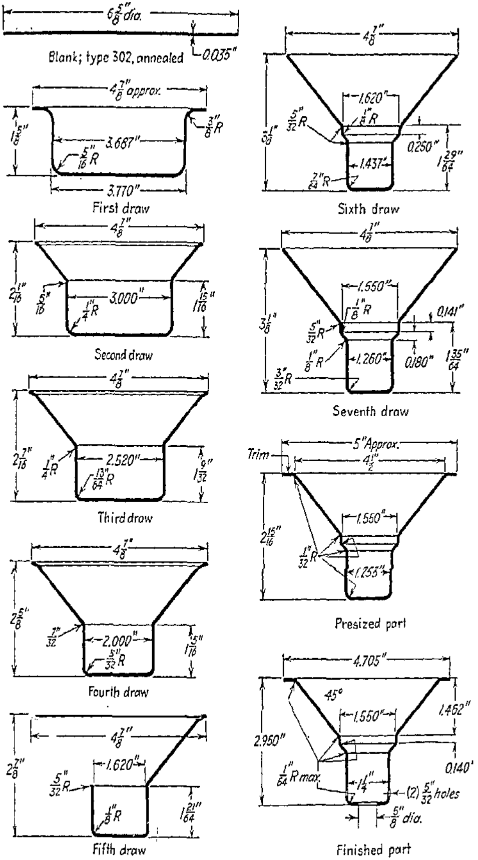


FIG. 11-11. Press-forming a funnel-shaped part.[3]

Tubular Part with Vertical Bead. The draw schedule for a tubular part formed from a 5¼-in.-diameter blank of 18-gage dead-soft sheet steel is shown in Fig. 11-12*A*. The plan view *B* shows the relative position through which these sections are taken.

The workpiece is first formed as a cup; then the beads in the side are formed. In three draws the stepped diameter is sunk into the bottom, and the cup is perforated and redrawn into the tubular shape. The redraw (third-draw) die (shown at *B*) to form the beads on the sides of the cup is an inverted-type die where the punch (*D*1)*, with inserts of the shape of the beads, is mounted on the die shoe, with the blank-

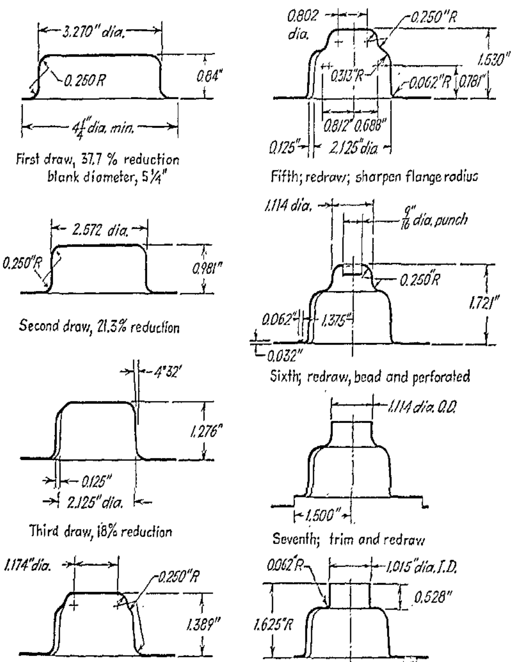


FIG. 11-12*A*. Blank development for drawing a tubular part. (*General Metal Products Co.*)

holder (*D*2) operated by the die cushion. The draw ring (*D*3) is mounted on the punch holder, and a spring-loaded stripper (*D*4) is recessed into the punch holder. In the die in view *C*, in which the previously perforated bottom is redrawn into a tubular shape, the shell is held between the draw ring (*D*1) and the blankholder (*D*2), then drawn over the punch (*D*3). Near the end of the stroke, the flange is trimmed to size. The positive knockout (*D*4) ejects the workpiece from the die.

* *D* indicates detail number on drawing.

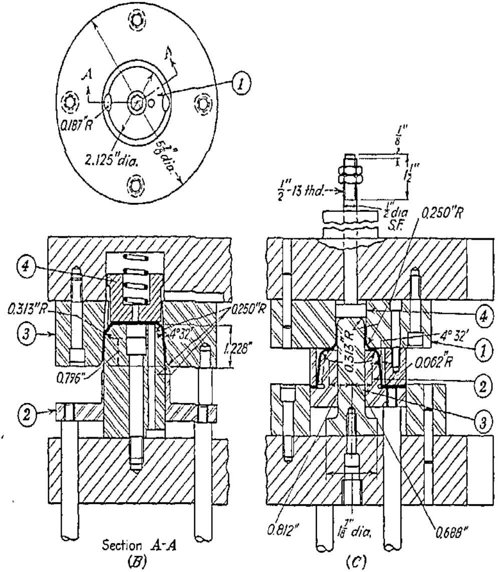


Fig. 11-12B and C. (B) Third-operation draw die, and (C) seventh-operation trim and redraw die for the part in Fig. 11-12A.

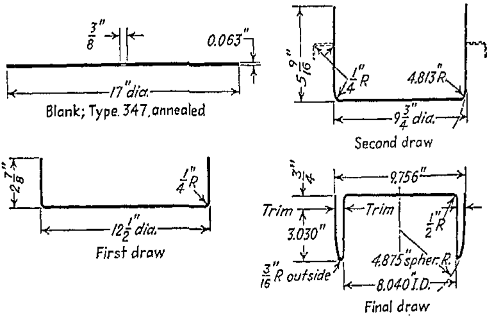


Fig. 11-13. Reverse-drawn shell.[2]

Reverse-drawn Shell. A part in which the final shape required a reverse draw is shown in Fig. 11-13. For this type 347 stainless-steel part, the die and blankholder were tool steel and the punch was cast iron, mounted in a double-action press. The second and final draw pieces were reverse-drawn to dimensions and shapes shown.

Reverse-contoured Cup. The steps taken in press-forming a reverse-contoured cup are illustrated in Fig. 11-14. This part was drawn on a single-action press with an aluminum bronze die ring and blankholder. The cast-iron punch used a hardened-steel nose. The second draw piece was made in a regular redraw die, and the third draw piece used a reverse draw to form the recess and outside contour. The part was sized, and a hole pierced and flanged in a three-station die on a single-action press. The bead was formed on rolls and crimped on a single-action press.

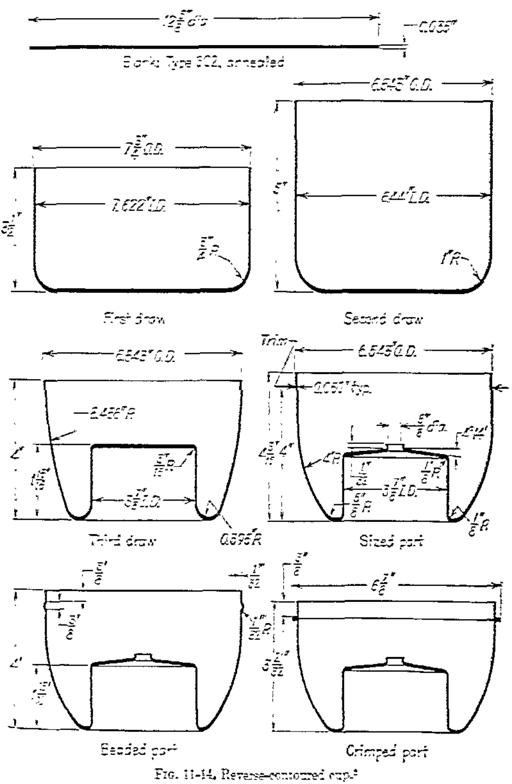


Fig. 11-14. Reverse-contoured cup.

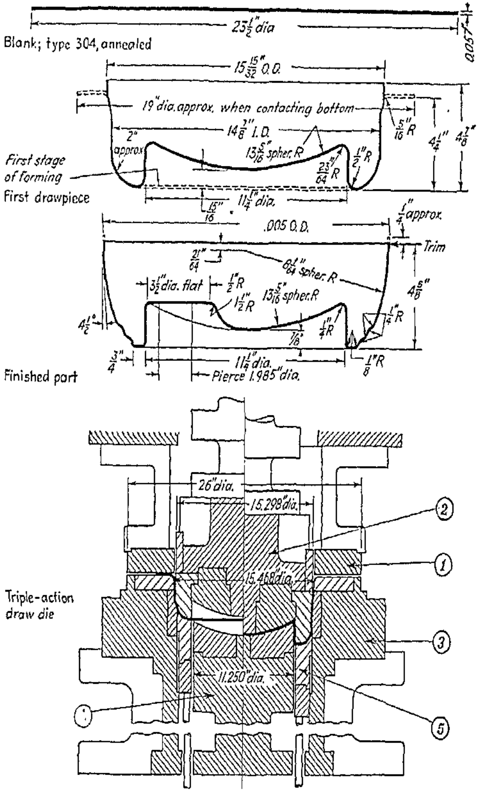


Fig. 11-15. Forming a reverse-bottom cup on a triple-action die.[2]

Reverse-bottom Cup. Figure 11-15 illustrates a type 304 stainless-steel part, 0.057 in. thick, drawn in a triple-action die on a double-action press. This operation is unique in that, since the limit of reduction was not reached in the cupping operation, the redraw starts while the cup possesses a considerable flange. During the first forming stage, the blank is held by the blankholder (*D*1) attached to the outer ram against the die (*D*3). The punch (*D*2) on the inner ram descends until it comes in contact with the recessing punch (*D*4). The second hold-down (*D*5), actuated by the die cushion has been holding the metal against the punch and, when the recessing punch starts working, the metal flows in a reverse draw between the main punch and the second hold-down, also continuing to draw the flange metal from under the first hold-down, producing the form of the first draw piece. A second die completes the part to the finished shape.

The main punch and recessing punch are cast iron with inoculated cast-iron inserts. The die is cast iron with aluminum bronze inserts. The first and second hold-down are aluminum bronze.

Three-die Four-draw Shell. Figure 11-19 shows a deep-drawn cup in which four reductions were done in three dies. The first operation is a regular draw with a blankholder. The second operation is a regular redraw using a blankholding sleeve. In the third draw die, the first draw ring reduces the part from 7.495 to 6.255 in. diameter, and the second ring reduces it to 5.973 in. diameter. All the dies are the push-through type, and the second and third have spring-operated stripping fingers (D1).

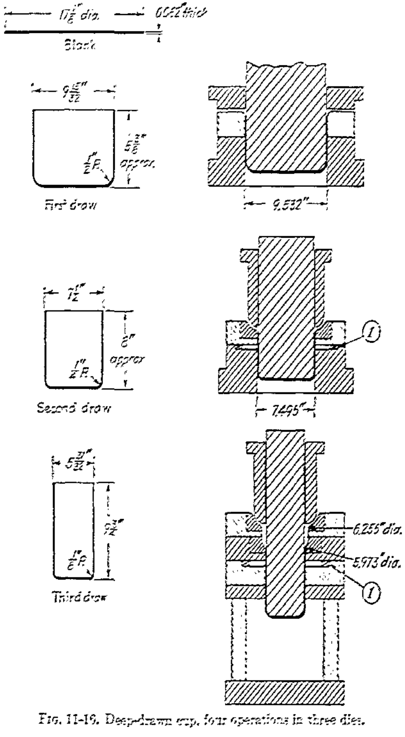


FIG. 11-19. Deep-drawn cup, four operations in three dies.

Large-flange Cup-shaped Part. The drawing of a stainless-steel part with a large flange is shown in Fig. 11-17. The first die draws a part with a beveled bottom corner. The second die has a blankholding sleeve that has the same shape as the shell drawn in the previous die. The redrawing of a shell with beveled corners is easier than drawing one with radius corners, since the metal does not have to flow around two 90° angle corners. The third operation flattens the flange and bottom surface.

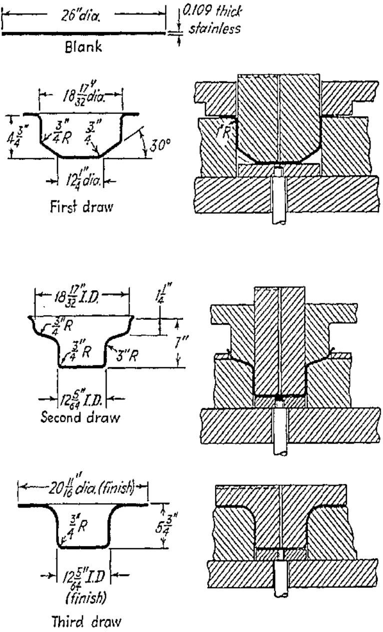


FIG. 11-17. Forming a part with a large flange.

Large-flange Tubular Part. The drawing operation for a tubular part with a large, shaped flange is shown in Fig. 11-18. The 10-in.-diameter cup was sunk to final diameter in three operations. A bevel was used on the bottom corner of the cup in the second and third draws as an aid to the drawing operation. The bevel in the flange, remaining after the third draw, was used as a start in forming the large radius around the 10-in.-diameter tubular portion. After the third draw, the bottom was blanked out of the cup, the tubular portion completed, and the radius around the tube was set. The outside contour was formed in the fourth draw.

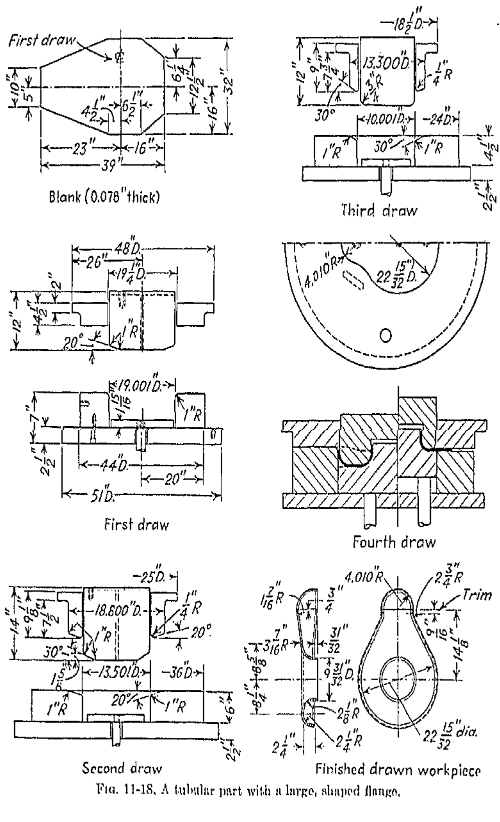


FIG. 11-18. A tubular part with a large, shaped flange.

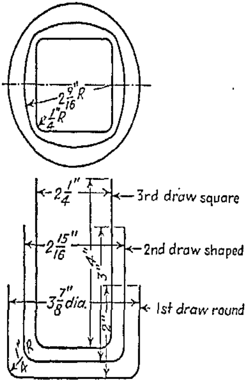


FIG. 11-19. Drawing a square shell from a circular blank.[1]

Square Shell from Circular Blank. On square shells, it is sometimes possible to use round blanks and even make the first draw circular. The square shape is approached gradually, as suggested by the 2¼-in.-square by 4-in.-deep radio shield (Fig. 11-19).

Square Flanged Shell from Square Sheared Blank. A box-shaped part drawn from a square sheared blank is shown in Fig. 11-20. Apparently the blank shape is unimportant as long as the total surface area of the formed part does not exceed three to four times the cross-sectional area of the punch. However, a part formed from a rectangular blank usually deviates considerably from the finished contour and necessitates a *large trimming allowance.* In this part, note the change in material thickness in the various parts of the shell.

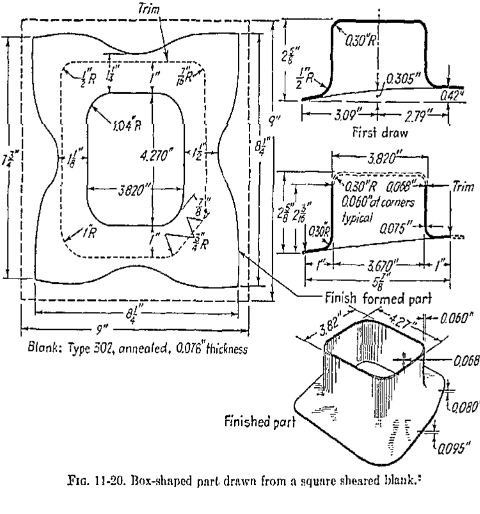


FIG. 11-20. Box-shaped part drawn from a square sheared blank.[2]

Drawing a Long Narrow Box. A long narrow box-shaped part is illustrated in Fig. 11-21. During the first draw, the preshaped blank was drawn to a flat elliptical shape and part of the flange was trimmed off before the second draw. In the second draw, the side of the shell was straightened, and to aid in eliminating canning, the punch-nose radius was increased from ¼ in. at the ends to ½ in. at the center. The third draw shaped the shell to the finish dimensions and stretched the long flat side wall to eliminate the canning effect. This type 304 stainless-steel part was annealed after the first and second draws. A cast-iron double-action die was used in a double-action press.

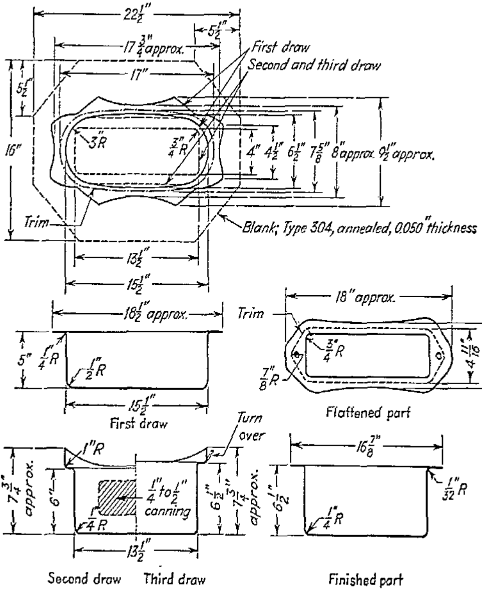


FIG. 11-21. Press-forming a box-shaped part.[2]

Square Box from Preshaped Blank. A preshaped blank and the box to which it was drawn are shown in Fig. 11-22. This part was drawn in a conventional tool-steel die on a double-action mechanical press. The material was 2SO clad aluminum 0.064 in. thick. The draw radius was $\frac{5}{16}$ in., punch corner radius was $\frac{3}{16}$ in., and the punch-nose radius was $\frac{1}{4}$ in., increased to $\frac{3}{8}$ in. at the corners. This draw was rather severe, since the part was drawn to a depth 23 times the corner radius, and the area of the blank was 4.5 times the area of the punch, but the depth was only 80 per cent of the width.

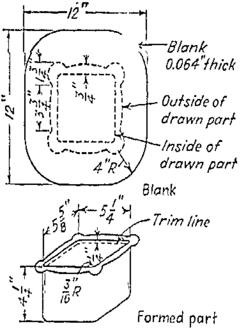


FIG. 11-22. Preshaped blank drawn into a box shape.[5]

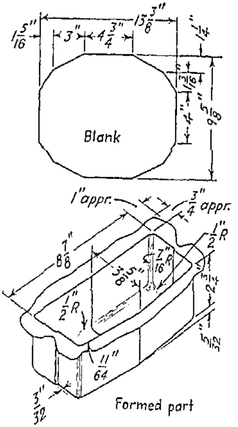


FIG. 11-23. Rectangular box-shaped part.[5]

Rectangular Box from Preshaped Blank. The rectangular box-shaped part shown in Fig. 11-23 was drawn of 0.064-in. 24SO clad aluminum from a preshaped blank. The draw radius was $\frac{11}{64}$ in., the punch-nose radius $\frac{1}{2}$ in., and the punch corner radius $\frac{7}{16}$ in. The part was drawn to a depth of about 6.6 times the corner radius. The blank area was 3.4 times the punch area, and the depth was 80 per cent of the width. This part has a $\frac{3}{32}$-in. offset in the vertical portion of the ends and a slope of $\frac{5}{32}$ in. at the bottom. A conventional-type die in a double-action press was used for the operation.

Eliminating Oil Canning in Rectangular Box Draw. A canning effect was experienced in the forming of the part shown in Fig. 11-24. The nose radius of the preform punch was gradually increased from $\frac{3}{4}$ to 1 in. at the center along the longest sides. The finish form punch had a $\frac{3}{4}$-in. radius the entire length, and the sharpening of the radius near the center of the long sides caused stretching of the center portions of the walls, eliminating the canning. Excess metal, or *ears*, was used at the corners to relieve the strain at those points, thus distributing it over the entire surface of the blank, avoiding corner breaks. The part was annealed between draws to aid in forming. A cast-iron double-action die was used in a double-action press. The shell material was type 302 stainless steel 0.050 in. thick.

Drawing an Irregular Contour. A contoured part of 0.040-in.-thick 52SO clad aluminum is shown in Fig. 11-25. The tool-steel draw ring had a $\frac{1}{2}$-in. draw radius with draw beads on the long sides. A 1-in. nose radius was used on the tool-steel punch. The blankholder was also made of steel.

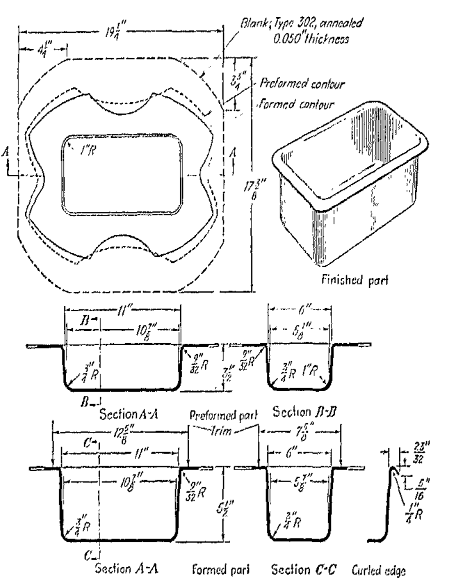


FIG. 11-24. Stainless-steel box-shaped part.[2]

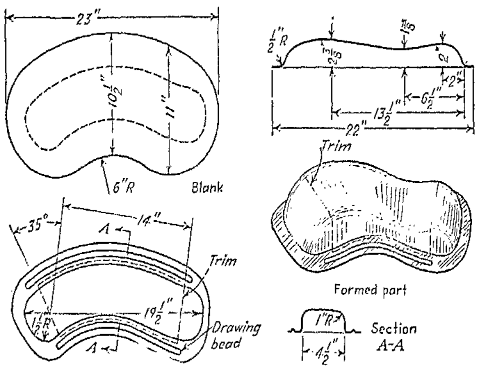


FIG. 11-25. An irregular contoured part.[4]

GENERAL DESIGN OF DRAW DIES, DIES FOR CYLINDRICAL SHAPES

Single-action Dies. The simplest type of draw die is one with only a punch and die. Each component may be designed in one piece without a shoe by incorporating features for attaching them to the ram and bolster plate of the press. This type of die forms shells from blanks with low D/d or D/t ratios. Figure 11-26 shows a simple type of draw die in which the precut blank is placed in the recess on top of the die, *and the punch descends, pushing the cup through the die. As the punch ascends, the* cup is stripped from the punch by the counterbore in the bottom of the die. The top edge of the shell expands slightly to make this possible. The punch has an air vent to eliminate suction which would hold the cup on the punch and damage the cup when it is stripped from the punch.

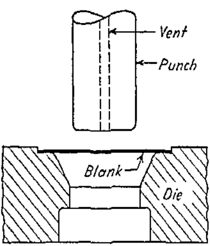


FIG. 11-26. Simple type of drawing die.

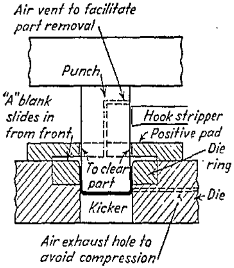


FIG. 11-27. Simple form of drawing die for use with heavy stock.

The method by which the blank is held in position is important, because successful *drawing is somewhat dependent upon the proper control of blankholder pressure.* A simple form of drawing die with a rigid flat blankholder for use with 13-gage and heavier stock is shown in Fig. 11-27. When the punch comes in contact with the stock, it will be drawn into the die without allowing wrinkles to form.

Another type of drawing die for use in a single-action press is shown in Fig. 11-28. This die is a plain single-action type where the punch pushes the metal blank into the die, using a spring-loaded pressure pad to control the metal flow. The cup either drops through the die or is stripped off the punch by the pressure pad. The sketch shows the pressure pad extending over the nest, which acts as a spacer and is ground to such a thickness that an even and proper pressure is exerted on the blank at all times. If the spring pressure pad is used without the spacer, the more the springs are depressed the greater the pressure exerted on the blank, thereby limiting the depth of draw. Because of limited pressures obtainable, this type of die should be used with light-gage stock and shallow depths.

A single-action die for drawing flanged parts, having a spring-loaded pressure pad and stripper, is shown in Fig. 11-29. The stripper may also be used to form slight indentations or reentrant curves in the bottom of a cup, with or without a flange. Draw tools in which the pressure pad is attached to the punch are suitable only for shallow draws. The pressure cannot be easily adjusted, and the short springs tend to build up pressure too quickly for deep draws. This type of die is often constructed in an inverted position with the punch fastened to the lower portion of the die.

Deep draws may be made on single-action dies, where the pressure on the blankholder is more evenly controlled by a die cushion or pad attached to the bed of the press. The typical construction of such a die is shown in Fig. 11-30. This is an inverted die with the punch on the lower portion of the die.

Double-action Dies. In dies designed for use in a double-acti . pr . : blank-holder is fastened to the outer ram which descends first and grips ' ' . hen the

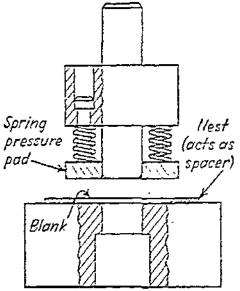


FIG. 11-28. Draw die with spring pressure pad.

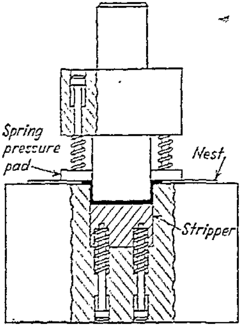


FIG. 1 . A draw die with spring pressure pad and stripper.

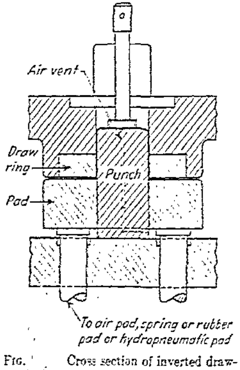


FIG. ' Cross section of inverted drawing die for single-action press; die is attached to ram; punch and pressure pad are on bed of press.[2]

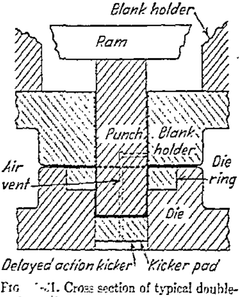


FIG. 11-31. Cross section of typical double-action cylindrical draw die.[2]

punch, which is fastened to the inner ram, descends, forming . . t. These dies may be a push-through type, or the parts may be ejected from the . ith a knockout attached to the die cushion or some delayed action. Figure 11-31 shows a cross section of a typical double-action draw die.

The inverted-type redraw die in Fig. 11-32 has the punch (*D1*) mounted on the lower shoe and the draw ring (*D2*) mounted on the upper shoe. The pressure exerted on the metal between the blankholder (*D3*) and the draw ring is controlled by the stop pin (*D4*). The large stop pin (*D5*) is used to control the depth of the redraw.

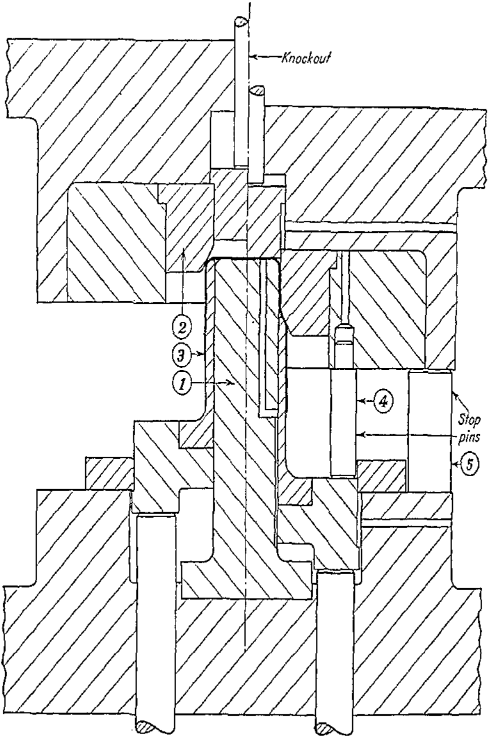


Fig. 11-32. Inverted-type redraw die.

The redrawing of cups can be made with less cold working of the metal by using a beveled bottom corner rather than a radius. If a radius is used, the metal is made to flow around two 90° angle bends. *Figure 11-33 shows a redraw die for a cup with a* beveled bottom corner. The blankholder sleeve and the mouth of the draw ring are shaped to fit the beveled bottom corner. In this die, the top of the cup has a tapered flange and may be flattened later. Cups may also be drawn into a die of this type, leaving no flange on the part.

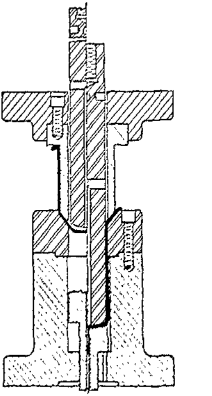


FIG. 11-33. Double-action redraw die for beveled bottom corner cups.[1]

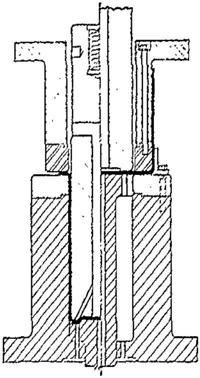


FIG. 11-34. Double-action redraw die for radius bottom corner cups.[1]

Figure 11-34 illustrates the typical construction of a double-action die for a cup with a radius at the bottom corner. The finished cup has a flange at the top; therefore, the bottom of the blankholding sleeve and top of the draw ring are flat. On this die, the ejector is shaped to indent the bottom of the cup at the end of the stroke. Note the air vents in the punch, die, and ejector, to eliminate air pockets.

Combination Draw-redraw Die. When the reduction of the first draw is limited because of a low diameter-thickness ratio, but the yield point of the material is still low, a shell may be drawn in a combination draw and redraw die as shown in Fig. 11-35. The blank is placed in the nest and held there by the blankholder (*D*1). The main punch (*D*2) draws the shell with the aid of the pressure pad (*D*3) into the draw ring (*D*4) and over the reverse draw punch (*D*5) into the cavity in the main punch. The top surface of the redraw punch should be below the top of the draw ring so that the first draw has been well started before the redraw starts. The left-hand part of the figure shows the cup partially drawn; the right-hand side shows the completed cup.

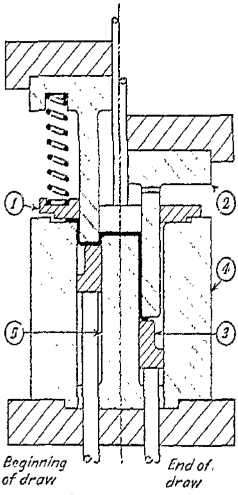


FIG. 11-35. Combination draw and reverse draw die.

Combined Cylindrical and Elliptical Draw. A combination cylindrical- and elliptical-shaped draw is shown in Fig. 11-36, with details of the die design. The shape of the developed blank is shown with the position of the first draw. The stock is 0.120-in. deep-draw steel.

Operation 1 includes a combination blank and draw. *D*1 is a combination blanking punch with hardened steel inserts and draw ring; the blankholder (*D*2) is actuated by a die cushion. The blanking die (*D*3) is scalloped to provide shear. The draw punch is 9 in. in diameter, and the spherical crown is finished to size. This draw die is mounted on a heavy die set with guide pins and long guide bushings.

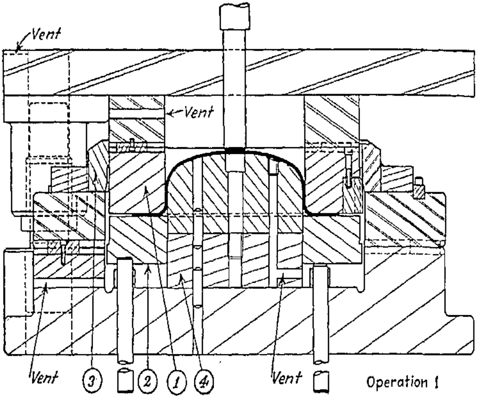


Fig. 11-36*A*. Combination cylindrical and elliptical draw die, operation 1. (*Right Tool & Die Co.*)

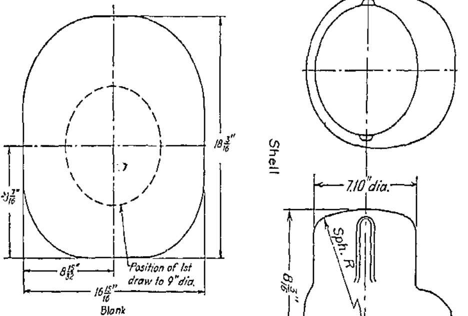


Fig. 11-36*D*. Developed blank and finished part, for the dies of Figs. 11-36*A*, 11-36*B*, and 11-36*C*.

Operation 2 is a regular redraw with the blankholder operated by the die cushion. The punch and draw ring are vented to allow the air to escape and prevent suction. The part can be ejected from the draw ring by a knockout operated by the press knockout bar.

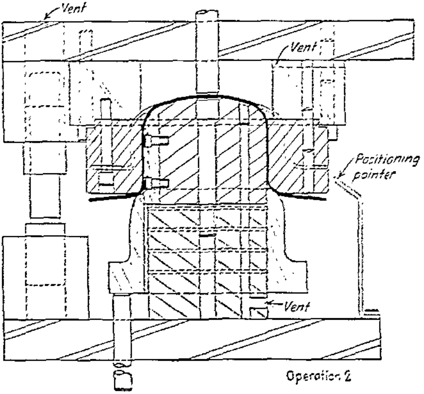


FIG. 11-36*B*. Combination cylindrical and elliptical draw die, operation 2.

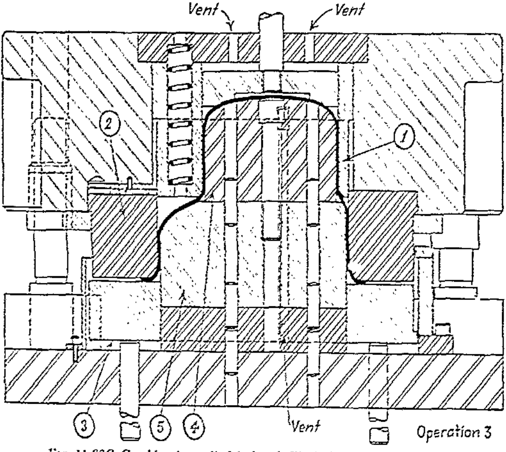


FIG. 11-36*C*. Combination cylindrical and elliptical draw die, operation 3.

In *Operation* 3, the elliptical portion is drawn, with a spring-operated sleeve (*D*1) sliding over the cylindrical portion to prevent its being pulled out of shape in this operation. In this inverted-type die, the holding sleeve is recessed into the die shoe and slides inside the draw ring (*D*2). The blankholder (*D*3) is operated by a die cushion. For ease of manufacture, the punch is made in two parts, one cylindrical (*D*4) and the other elliptical (*D*5).

DIES FOR BOX-SHAPED DRAWS

Combination Blank, Draw, Pinch-trim. The die shown in Fig. 11-37 is a combination die to blank, draw, and pinch-trim to height a rectangular box of 0.050-in. cold-rolled deep-drawing steel. The box is 3⅞₁₆ in. long, 1½ in. wide, and 1 in. deep, with a corner radius of ⁵⁄₃₂ in. and bottom corner radius of ⅓₂ in. The strip stock is fed into the die against the stop (*D*1) and is held in position by the spring-loaded pressure pad (*D*2), while the combination blanking punch and draw ring (*D*3) punches the blank in the die (*D*4). The box is formed over the draw punch (*D*5) with the aid of the blankholder (*D*6) and is pinched to height with the pinch punch (*D*7). The die is used in a single-action press with a die cushion and uses a positive knockout to eject the box from the draw ring.

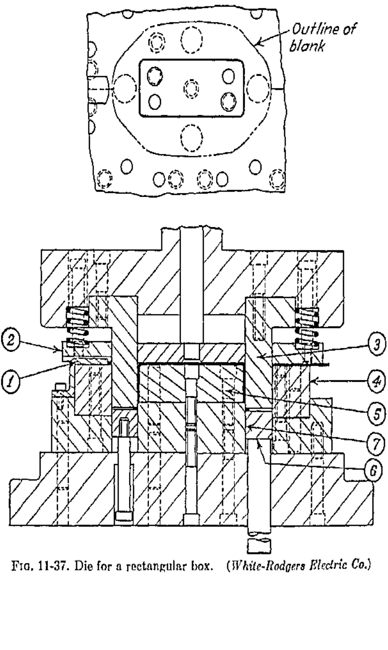
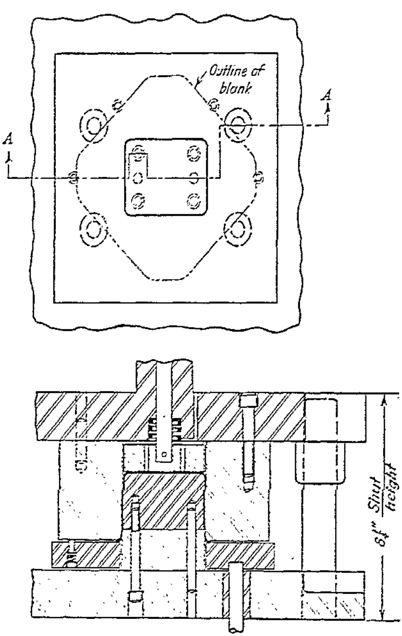


FIG. 11-37. Die for a rectangular box. (*White-Rodgers Electric Co.*)

Inverted Deep Draw. An inverted-type draw die for a single-action press with a die cushion is shown in Fig. 11-38. This die is for a box of 0.031-in. cold-rolled steel, 3⅝ in. long, 2¾ in. wide, and 2¹⁄₁₆ in. deep. The corner and bottom radii are ¼ in. The preshaped blank is located on the blankholder by disappearing pins. Near the end of the stroke, the box is trimmed between the draw ring and pinch-trim block.



Section A-A

Fig. 11-38. Draw die for a deep box. (*White-Rodgers Electric Co.*)

Draw Die for a Transmission Support. Figure 11-39 is a draw die for a transmission support made of 0.187-in.-thick SAE 1008 stock. A preshaped preflanged blank is placed on the locating pins (*D*1). As the die closes, the center portion of the punch (*D*2) and the pressure pad (*D*3) grip the metal, and the two end punches (*D*4) start drawing the metal into the die. Because of the thickness of the material, no blankholder is required in this die. The closing of the die sets the radii and flanges to dimensions.

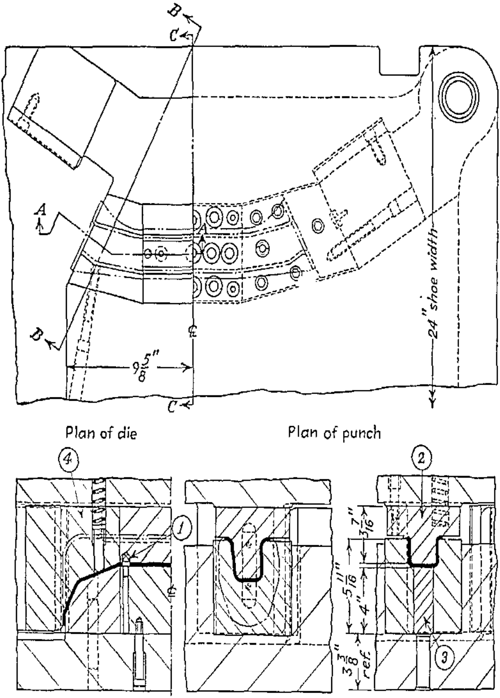
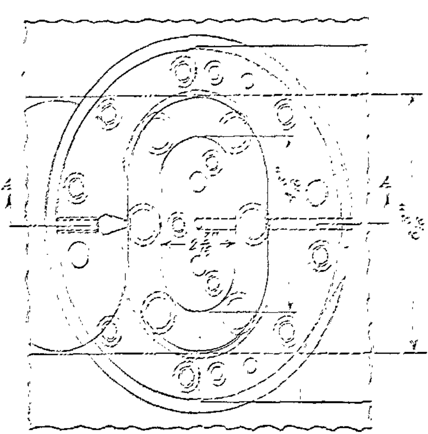
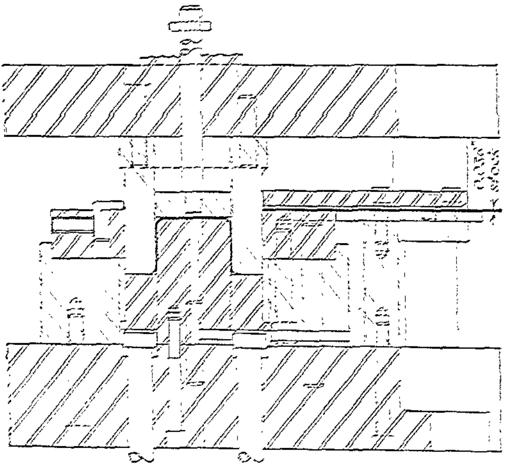


FIG. 11-39. Draw die for a transmission support. (*Buick Motor Division.*)

Drawing an Oval Can. A die to blank and draw an oval-shaped can is shown in Fig. 11-40*A*. This is an inverted-type die for use in a single-action press with a die cushion. Figure 11-40*B* shows the redraw and pinch-trim die for the same can. This die is also designed for use on a single-action press with a die cushion using a positive knockout for ejecting the part from the die.

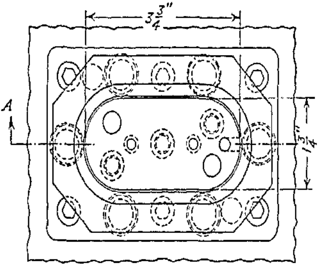


Plan of die

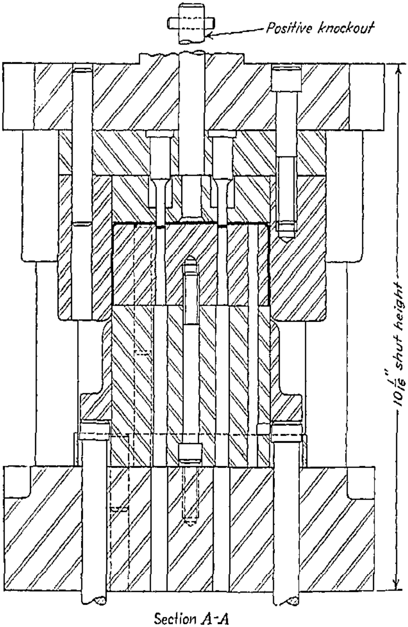


Section A-A

Fig. 11-49A. Blank and draw die for an oval-shaped can. (White-Rodgers Electric Co.)



Plan of die



Section A-A

FIG. 11-40B. Die for redrawing and pinch-trimming the oval can of Fig. 11-40A.

DRAWING MAGNESIUM

Magnesium can be deep-drawn, under proper conditions, with a greater percentage of reduction than most other metals. Circular draws up to a depth of twice the diameter of the drawn shell are common in magnesium alloys. In rectangular draws, depths of one and one-half to two times the width are possible.

The forming of magnesium alloys at room temperature is recommended only for simple bends and very shallow draws. The drawing of the metal at a temperature of between 300 and 650°F overcomes the rapid work hardening which occurs at room temperature. The heating of annealed sheets does not affect its room-temperature properties, but heating the full-hard sheet to 650°F results in properties similar to those in the annealed state.

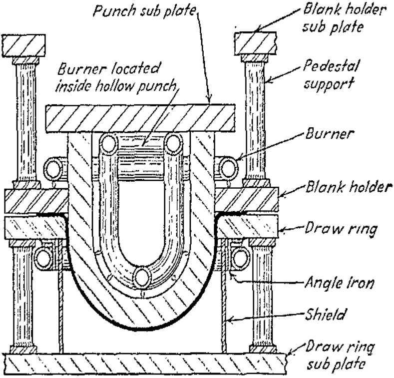


FIG. 11-41. Heated die with hollow punch and draw ring (size of gas pipe is exaggerated).[6]

The heating of the magnesium alloy sheets can be done by placing them in a portable heater with necessary racks. These heaters can be placed convenient to the press to provide and maintain the required temperature. Relatively thin sheets can be placed in the nest of the draw die for approximately 30 sec preceding the draw, which allows sufficient time for the sheet to reach the required temperature.

The drawing of magnesium differs from the drawing of other metals in that the dies must be heated to an elevated temperature to keep the workpiece at an even temperature during the forming. There are several methods of heating the tools, but gas and electricity are most commonly used. It is important that the correct temperature be maintained throughout the production run. Controlling pyrometers, with thermocouple leads to the tools, are desirable to maintain a constant tool temperature. When drawing small diameters in thin-gage metal, it is sometimes desirable to use an unheated punch. This provides maximum strength in the area under the punch but still permits maximum ductility in the shell where the drawing actually takes place. The use of an unheated punch with a large cross-section area is not advisable, since the low heat capacity and the high heat conductivity of magnesium alloys may result in the chilling of the metal under the blankholder as well as the punch. It is important that the area being worked remain at the correct temperature prior to and during the drawing operation.

Gas burners may be made of pipe with ports made with a No. 40 drill. These pipes should be bent as near to the shape of the parts of the die which they are heating as possible. A space of ⅝ to ⅞ in. should be maintained between the burner and die part. When using the open-die construction, as shown in Fig. 11-41, a shield should be provided to prevent the magnesium alloy from becoming overheated. This die also has a hollow punch which has a burner located inside.

An inverted die for use on a single-action press is shown in Fig. 11-42. The blankholder and draw ring are heated by gas burners. An insulating material is used between the subplates and die set to reduce the amount of die metal to be heated.

Die Materials. The material used in heated dies should be hot-work tool steel for the smaller dies and Meehanite or a good grade of cast metal for larger dies. These materials are less likely to distort at the elevated temperatures. When determining the dimensions for the punch and draw ring, the difference in the coefficient of expansion of the die metal and the magnesium alloy in the workpiece should be considered.

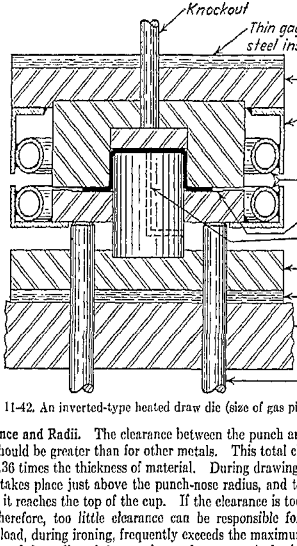


FIG. 11-42. An inverted-type heated draw die (size of gas pipe is exaggerated).[6]

Clearance and Radii. The clearance between the punch and die for drawing magnesium should be greater than for other metals. This total clearance should be from 2.24 to 2.36 times the thickness of material. During drawing operations, thinning of the wall takes place just above the punch-nose radius, and thickens gradually in its rise until it reaches the top of the cup. If the clearance is too small, ironing is introduced; therefore, too little clearance can be responsible for ruptures because the ultimate load, during ironing, frequently exceeds the maximum load a cup can resist.

The size of the radius of the punch nose has no particular influence on the depth of the draw; however, too small a radius increases the possibility of bend cracks. The draw radius is not so effective relative to bend cracks, but decreasing the draw radius decreases the drawability of the material. A good radius to use for the punch nose is about eight times the metal thickness, for the draw radius about six times the thickness.

Lubrication. A colloidal graphite suspended in lactol spirits is satisfactory, provided that the tools are cleaned regularly. The sheet stock should be in an oiled condition for use with colloidal graphite as a lubricant. When using a chrome-pickled surface, an oil-type forming lubricant should be used.

CARBIDE DRAW DIES

The use of sintered carbide for the draw ring and punch in a draw die greatly increases the life of these parts. The die set, punch plate, and die block should be made heavier and of higher-quality materials than are used in all-steel dies. The rules and practices used in designing steel dies apply in the design of carbide dies, but it should be remembered that carbide is not so easily machined as steel and must be designed to permit the use of grinding wheels to finish the contours. To facilitate

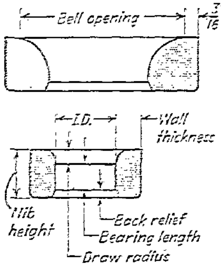


FIG. 11-42. Nomenclature for carbide nibs.

finishing, inserts are often made in sections instead of in a solid piece. The draw radii are the same as for steel, but the bearing length may be shorter, because of longer life of carbides. Liberal back relief on the exit side of the nib is recommended as a precaution against the possibility of flaking. Table 11-1 may be used to determine the various nib dimensions in reference to the inside diameter. See Fig. 11-43 for nomenclature.

TABLE 11-1. CARBIDE NIB DIMENSIONS

ID, in. From	ID, in. To	Length of bearing, in.	Back relief
	1/2	1/8	1/16
1/2	1	3/16	1/8
1	1 1/2	1/4	
1 1/2	2	5/16	3/16
2	Up	3/8	

For nibs with a bellmouth such as are used for single-action draws without a blankholder, the OD of the nib may be taken as bell opening plus 5/8 in., on diameter.

The steel case for carbide nibs should be large enough to give ample support. For average draws, the diameter of the casing should be 1 1/2 to 1 3/4 times the nib diameter. Heavy draw work and ironing require a heavier case of 2 times the nib diameter. The steel recommended for the casing is SAE 4340 or equivalent, hardened to Rockwell C 38 to 42. The nibs of a draw die should have a shrink fit in the casing. Table 11-2 is a guide for the shrink fit to be allowed.

TABLE 11-2. SHRINK ALLOWANCES FOR STEEL DIE CASES OF HARDNESS NOT MORE THAN ROCKWELL C 45*

OD of nib, in.	Shrink, in.	OD of nib, in.	Shrink, in.
0.4375-0.5624	0.0013-0.0018	3.0000-3.4990	0.0055-0.0060
0.5625-0.6874	0.0016-0.0021	3.5000-3.9990	0.0065-0.0070
0.6875-0.8124	0.0021-0.0026	4.0000-4.9990	0.0070-0.0080
0.8125-0.9374	0.0025-0.0030	5.0000-5.9990	0.0080-0.0090
0.9375-1.1240	0.0028-0.0033	6.0000-6.9990	0.0090-0.0100
1.1250-1.3740	0.0035-0.0045	7.0000-7.9990	0.0100-0.0110
1.3750-1.7490	0.0038-0.0048	8.0000-8.9990	0.0110-0.0120
1.7500-1.9990	0.0043-0.0053	9.0000-9.9990	0.0120-0.0130
2.0000-2.9990	0.0045-0.0055		

Carbide Draw Punches. The same general design used for steel punches should be followed for carbide punches. The carbide section of the punch should be long enough to cover the wear points. The carbide may be secured to the steel shank in various ways depending upon the diameter. If the punch is large enough and holes in the face are not objectionable, the carbide may be fastened as shown in Fig. 11-44,*A*. With the

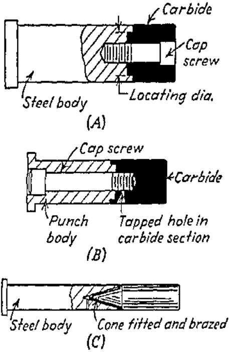


FIG. 11-44. Carbide-punch construction.

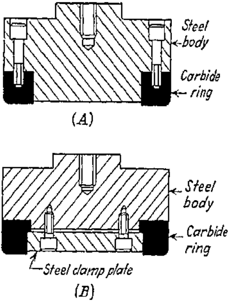


FIG. 11-45. Method of attaching carbide wear rings to large punches.

development of electric-arc machining, holes may be tapped in the sintered carbide and the cap screws, running through the steel body, as shown in Fig. 11-44,*B*, hold the tip to the body. Unless the pilot on the carbide is longer than the depth of the tapped hole, a counterbore should be made a little deeper than the length of the pilot to direct the stresses away from the thin section around the tapped hole. Punches which are too small in diameter for a tapped hole should be made solid carbide or can be brazed as shown in Fig. 11-44,*C*.

Mechanical retaining of carbide wear rings to large punch bodies is illustrated in Fig. 11-45. View *A* shows holes tapped in the carbide for cap screws; the construction in view *B* utilizes a shoulder on the ring and a steel clamping plate.

A die with a carbide draw ring is shown in Fig. 11-46. This die produces a cup of ¼-in. stock without the use of a blankholder. The part is ejected from the die with a delayed-action ejector and is stripped from the punch with a riding stripper. The employment of a riding stripper makes it possible to use a shorter punch for a long stroke. The stripper is supported by springs above the die and guided by headed guide pins in the lower shoe at a sufficient height to permit loading and unloading the die. The punch descends pushing the stripper down, to enable the short punch

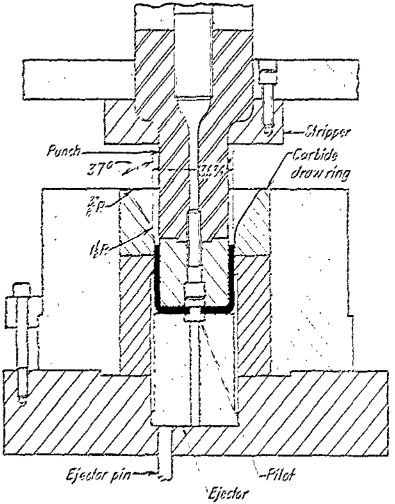


FIG. 11-48. Cupping die with a carbide draw ring. *(Worcester Pressed Steel Co.)*

to form the cup. On the upstroke of the press, the stripper is raised by the springs until it engages the heads of the guide pins, then strips the cup from the punch.

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SECTION 12

DIES FOR LARGE AND IRREGULAR SHAPES*

The dies described in this section present special problems because of their sizes and shapes. Many of the dies perform more than one of the fundamental sheet-metal-working operations and, as they are located in adjacent areas, do not conflict with one another or require delicate and complicated punches and dies.

The drawing and forming of large and irregular shapes require dies that are carefully designed, especially as concerns the shape of the blankholder rings and the position of the part in the die to obtain a reasonably uniform depth of draw or to form the part with a minimum number of dies. The sizes and irregular outlines in the plan and cross-sectional views of these parts present many problems in the control of metal flow. The placement of draw beads or the application of a lubricant in local areas to restrict or divert the metal flow in order to produce a satisfactory part are results of reasoning after reviewing past experience on similar parts or at the trial run of the die in the pressroom.

Establishing Draw Lines for Large Irregular Shapes. A model of the irregular-shaped workpiece to be drawn is rotated and tilted so that it may be observed in various positions. This is to determine a position which will produce an acceptable stamping. The following are conditions which should be considered during the period of observation:

1. The securing of a uniform depth of draw
2. Avoidance of localized contact of punch to blank
3. Elimination of a restrike operation to form an undercut or back-draft area
4. The facilitating of the embossment of character or mold lines
5. Ease of performing trimming, flanging, reforming, and other subsequent die operations

When the draw position is established, a line is scribed on the model parallel to the established base of the die and is used to reset or check the position of the model. This line is also used as the work or reference line on the die drawing.

The contour of the model of the workpiece precisely determines the punch contour excepting its surface corresponding to allowances for blankholding surfaces and flanging or other areas in subsequent operations. To simulate these areas, the model is added to or built up peripherally around and outward from the draw line. In the working position, the lower surface on the built-up areas outward from the draw line is an approximate replica of the lower surface of the blankholder ring.

A soft female plaster cast is generally made of the altered die model. This cast is made to establish the die-cavity size and extends outward from the cavity a sufficient distance to allow for development of the draw-ring surface. Soft plaster is added to or removed from the cast until the shape of the draw ring is such as to provide the best conditions for drawing the part.

Vertical lines right to left and front to back, and a horizontal line parallel to the established base line, are scribed on the plaster cast and are used as reference lines by the die designer and patternmaker.

* Reviewed by A. Manoli, Assistant Superintendent, Tool, Die and Fixture Department, Auto Body Division, Chrysler Corp.

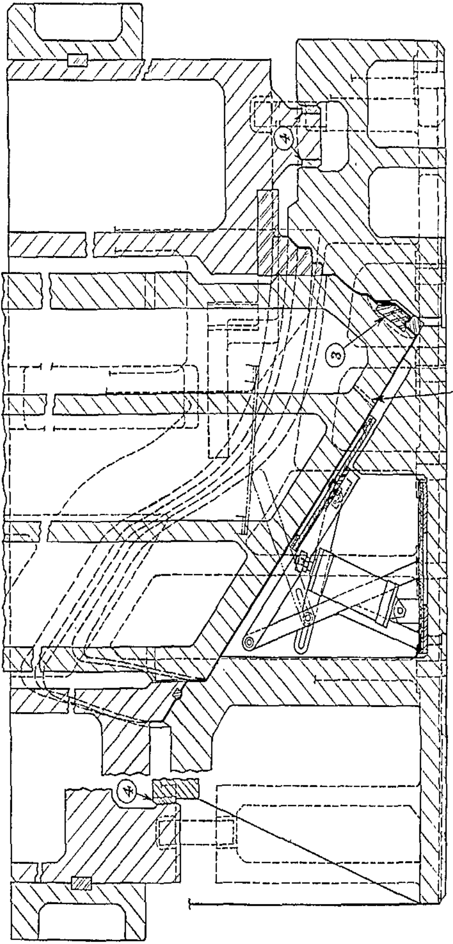


FIG. 12-1A. View A, longitudinal section of a draw die for an automobile fender, showing angle of tip. (Ford Motor Co.)

The die designer can make the die layout from dimensions and templets taken from this plaster cast. The patternmaker also uses similar information for constructing patterns for castings and master contour blocks required to machine the castings.

Angle of Tip Shown by Fender Draw Die. The section through the lowest point of an automotive-fender draw die (Fig. 12-1, view *A*) illustrates the tipping at an extreme angle to draw the nose end. The blank for this fender is trimmed, formed, and welded into a cone shape to place the stock in a position similar to the finished drawn shape.

The preshaping of the blank reduces the amount of metal drawn into the die, reduces the actual depth of draw, and facilitates control of the metal in the die during the operation. The shape of the blankholder ring was determined by the periphery of the finished part, and to permit use of a minimum-sized blank.

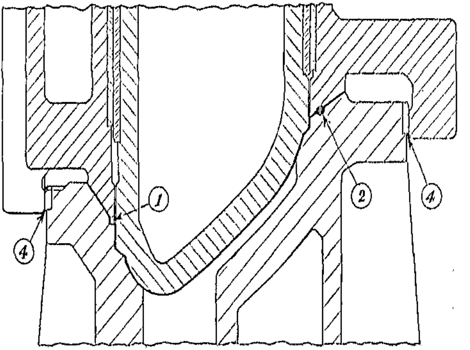


FIG. 12-1*B*. View *B*, cross section of fender die showing draw bead construction. (*Ford Motor Co.*)

The acute slope of the blankholder surface at the nose end of the fender has been eliminated by using steps. These steps act as locking beads and add strength to the steel insert. View *B* shows the use of a locking bead (*D*1)* on the low side and a conventional draw bead (*D*2) on the high side of the die. In addition to offering greater resistance to the metal movement, the steps provide horizontal surfaces for spotting surfaces and increasing the actual pressure on the blank since the resultant force is at right angles to the metal blank.

The excess material in the nose end of the fender is pulled into the head-lamp area, which is blanked out in a succeeding operation, by a small hooked-shaped extension (*D*3) on the punch.

Alignment of the blankholder and lower die member is assured by the guide surfaces (*D*4). An air-operated lifter is incorporated in this die to facilitate gripping and removal of the drawn part by a mechanical ejector. On the production line, this die was scheduled to operate in a 120-in. double-action press. In the die shop, the largest die tryout press available was a 108-in. press; for this reason the blankholder was designed with two detachable channel-shaped extensions, as shown in the illustration, to be used during the production run.

Forming Parts by Stretching and Drawing. Shallow parts with contours in either one or both directions, *i.e.*, longitudinally and laterally, often require that the dies

* *D* indicates detail number on drawing.

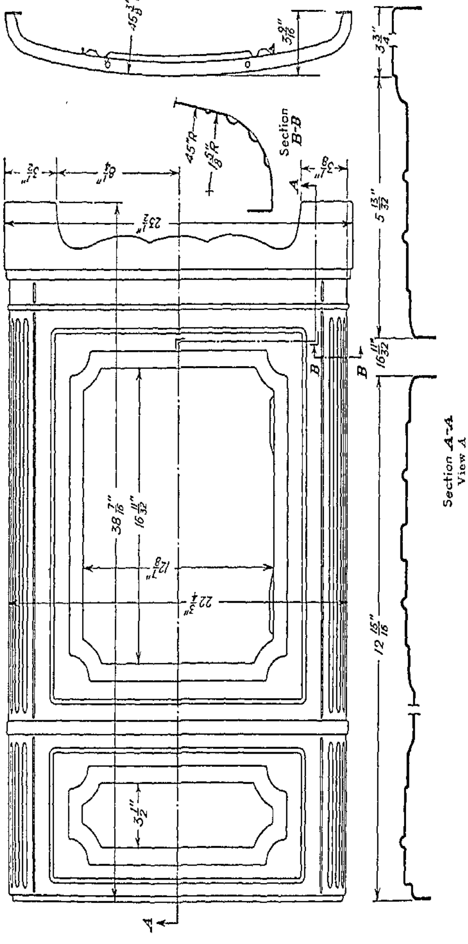
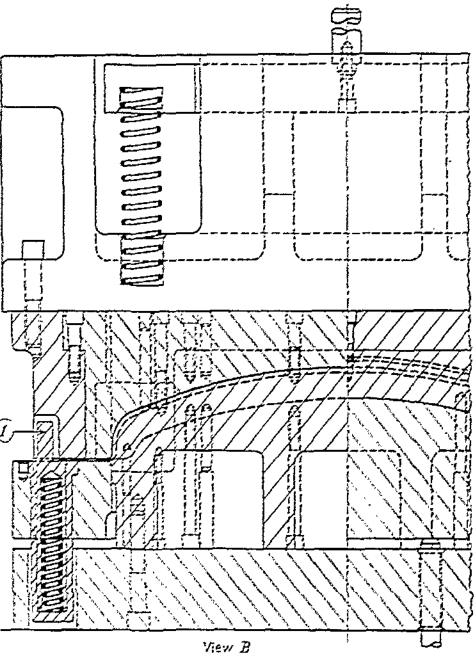
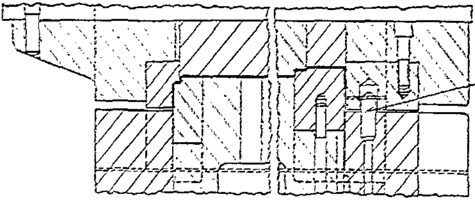


FIG. 12-2A. View A, front panel of a space heater. (*Motor Wheel Corp.*)



View B



View C

FIG. 12-2B. Draw die for the front panel of a space heater: view B, lateral cross section, and view C, longitudinal cross section. (Motor Wheel Corp.)

grip the metal rather tightly so that it can be stretched to a certain extent rather than being drawn to shape.

The front panel for a space heater (Fig. 12-2, view *A*) is an example of this type of part. The blankholder at the ends, view *B*, has a curvature similar to the finished outline to preform the sheet before the actual forming takes place. Along the sides, the blankholder is straight and contains beads to help control metal flow. The lower edge of the blank has a developed contour which is trimmed to shape in a preceding operation. Positioning of the blank in the die is accomplished by two spring-loaded locating pins (*D1*) on each side and a fixed pin (*D2*) at the lower end. The blankholder is actuated by the die cushion and grips the blank while a flange at each end and the contour are formed. This die closes tightly on the workpiece to emboss or coin the sharp corners of the offsets as shown in view *C*. Additional operations on this front panel will be discussed later in this section.

Roof-panel Draw Die. The roof-panel die shown in Fig. 12-3 produces a shape which requires careful positioning to enable the low point of the punch to contact the blank near the middle so that a uniform stretch is obtained in the blank as the operation proceeds. The shape and relatively shallow depth of the roof panel require the blank to be stretched to retain the finished shape. An elongation in the blank of 5 to 10 per cent will, under most conditions, produce an acceptable part with a minimum loss due to scrap. The amount of elongation in the blank should be sufficient to eliminate the oil-can effect, without producing surface defects such as orange peel or stretch lines. In large relatively flat areas a certain amount of crown to the contour is also desirable to overcome the oil canning.

The blankholder faces are shaped in such a manner that, when they grip the blank, sufficient stock is under the punch to enable the desired amount of stretch to take place without drawing additional material into the die. Thus, the overall dimensions of the blank within the draw ring, plus stretch allowance, are equal to the corresponding girth dimensions of the finished part, including trim allowance. Beads in the blankholder surfaces control the metal flow and facilitate the stretching of the metal to the desired contours.

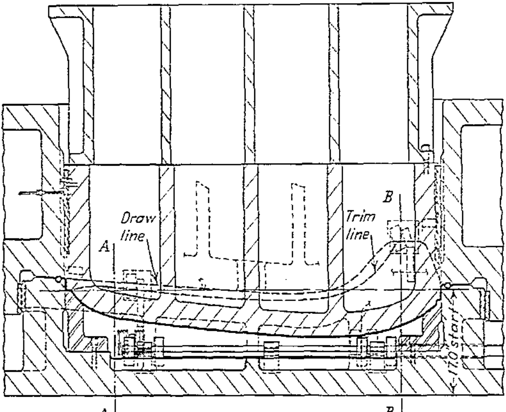
Draw Beads. One of the functions of a draw bead in a blankholder is to provide additional resistance to metal flow, thus helping to control the movement of the metal into the die cavity. This often reduces the amount of blankholding pressure required for an operation. Another function is to work the metal in a manner similar to that of leveling rolls, which momentarily heats the metal to stress-relieve and anneal it to improve the drawing characteristics. Beads are also used to deflect metal into or away from local areas.

In double-action presses it is possible to adjust the blankholder to grip the blank more tightly in certain areas to control the metal flow. Sometimes this procedure is satisfactory but often it is not, since gripping of these areas sufficiently to control the metal often results in fracture caused by the punch pushing through the blank.

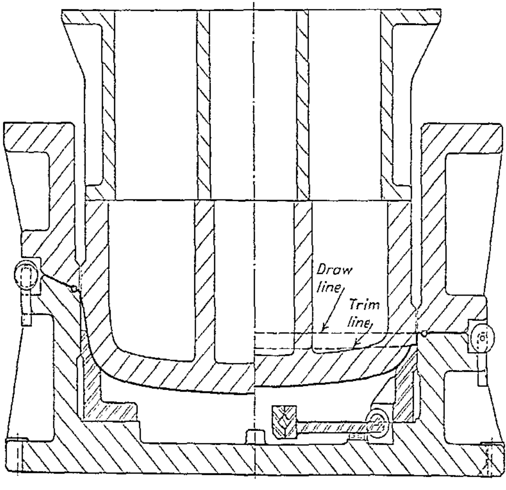
As an alternative to using excessive blankholder pressure, beads are placed in the blankholder surfaces to retard the movement of the metal into the die cavity. Two or more beads may be placed in areas requiring greater control of the metal. The location of the beads is usually determined in the die tryout, although dies for producing similar parts may be used as a guide when they are available. When beads are used, a single bead is placed around the die cavity and additional beads are placed in local areas only as required. Conditions may even dictate that the single bead be reduced in size or eliminated in some areas. Short beads or beads placed at an angle are used to deflect the metal into or away from local areas.

The placing of the bead in the upper or lower blankholding surface is often determined by the construction of the die. Where possible, the bead should be placed in the lower member and the groove in the upper member where it will not catch dirt. However, the groove should be placed in the member that is to be altered during the spotting or mating of the blankholding surfaces.

The size, spacing, and position of draw beads, in relation to the draw radius, will vary in accordance with company practices. The commercial rolled-steel sections

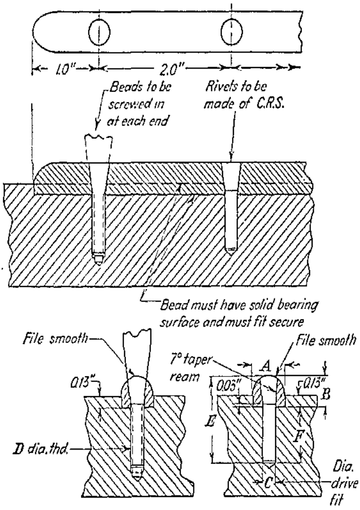


View A



Section B-B View B Section A-A

FIG. 12-3. Cross sections through a roof-panel draw die: view A, section at center line; view B, half sections at front and rear of roof panel. (*Ford Motor Co.*)



A	B	C	D	E	F
0.50	0.38	0.18	10-24	1.12	0.75
0.62	0.44	0.24	¼-20	1.38	1.0

FIG. 12-4. A method of installing draw beads made from commercial rolled sections.

used by many companies, and a method of installing this type of bead, are shown in Fig. 12-4. A groove is milled in one of the die members and the press-fit bead and the die member are drilled together for a cold-rolled pin which is driven into the hole and peened over to hold the bead in place. The excess portion of the pin is filed smooth with the surface of the bead. A mating groove is milled and spotted into the opposite die member. As a safety measure a screw with a tapered head is used at each end of the bead. The recess for the bead must be machined to a uniform depth and width to fit the section so that little or no shear is placed on the retaining rivets.

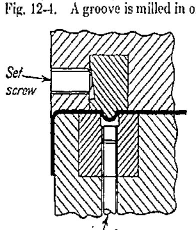


FIG. 12-5. Draw bead and mating groove machined from bar stock and recessed into die members.

A bead and its mating groove as shown in Fig. 12-5 can be machined from bar stock and inserted into the die members. The insert containing the bead is recessed into the blankholder and secured by setscrews from the side. The insert in the draw ring is secured by cap screws from the underneath side. This type of construction is used when small beads are required but cannot be fastened to the die members, or where build-up by welding is not feasible.

Another method of providing draw beads is to cast the beads into the face of the blankholder. The size and location are determined from past experience on similar parts and, where additional beads are required, they are built up with welding rods and ground or machined to shape and smoothness.

Short beads used to restrict the flow of metal in local areas have small radii on the corners to provide greater resistance to the metal flow (Fig. 12-6). The lower type of bead is adaptable to dies using air or springs to exert the pressure on the blankholder. The height of these beads permits them to deform the metal to such a degree that the

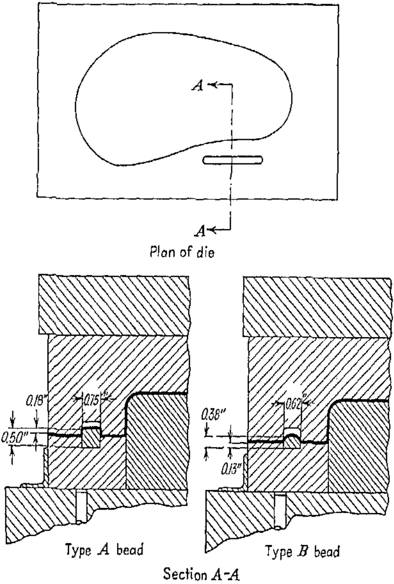


FIG. 12-6. Draw beads to restrict the flow of metal in local areas.

metal between the bead and draw radius is confined by the surface of the blankholder and draw ring. The optimum height and corner radius of these beads must be determined by the results obtained at the tryout of the die. The material, blank size, nature of stretch, and shape of panel are factors in determining the size, shape, and location of draw beads.

The lock-type draw bead in Fig. 12-7 is installed in dies to provide maximum restriction to metal flow. The beads are rectangular in shape with minimum corner radius. The locking bead offers more resistance to the metal when it is a part of the draw ring, but in many cases it is a part of the upper or blankholder ring. The figure shows the locking beads machined into a piece of bar stock, hardened, and inserted into the draw ring. They may also be cast and machined directly into the draw ring.

Positioning the Blank in Draw Dies. The amount of metal lying on the blankholder surface outside the draw radius is important. An excess amount of metal will retard the flow; an insufficient amount will not provide enough metal for proper gripping. The positioning of the blank in the die is the function of the gage pins or blocks. Positioning of the blank can be achieved by nesting it between pins or blocks or by using full or partial holes in the blank. A means of adjusting the location of the gages should be provided. This is particularly important to the die-tryout man, who must be able to reposition them if necessary.

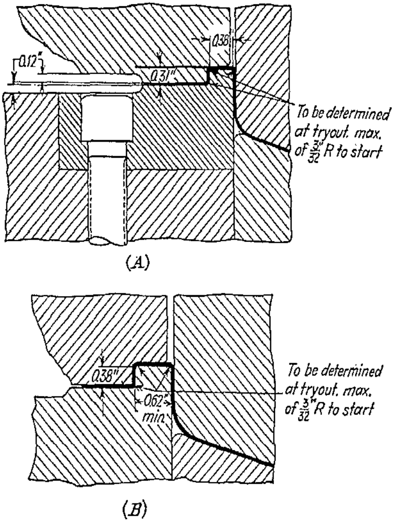


Fig. 12-7. Locking beads: (*A*) insert type; (*B*) cast integral type.

The cycling time of an automatic line may be so closely set that a blank, loaded into a die by automatic devices, does not have time to come to rest between the gages before being gripped by the blankholder. Parts removed from the die by automatic means may require that the gages be retracted during the time of part removal and then return to position in time to catch and position the incoming blank. Air cylinders with controls interlocked with the slide movement are used to actuate gage pins of this design.

REPRESENTATIVE DIE DESIGNS

The materials used in dies for irregular shapes depend upon the severity of the operation. Under normal conditions cast iron is commonly used. Figure 12-8 shows typical die construction with a third-action punch for large and irregular-shaped parts. Areas subject to wear are often flame-hardened, or inserts made of hardened tool steel are placed in punch and draw ring.

In addition to the regular leader pins and guide bushings, hardened-steel or bronze wear plates are fastened to the punch and blankholder rings to keep them in alignment

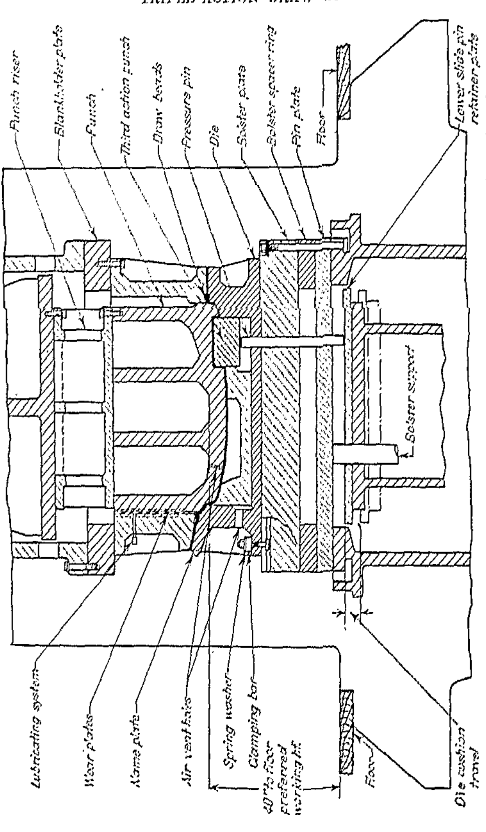


FIG. 12-8. Typical die construction with a third-action punch for a large and irregularly shaped part.

and to avoid excessive wear. Lubrication grooves are machined in these wear plates, copper tubing is installed between them, and grease fittings are placed in an accessible location. The planning of the route of the grease lines while the die is still in the drafting stage can eliminate the later drilling or chipping of holes in inaccessible places. Also, such planning can assure a more direct route, resulting in shorter and straighter tubes for the grease to pass through from the fitting to the wear plate.

Air-vent holes drilled in the punch and die can prevent sticking of the parts to the die members because of vacuum. These holes must be cleaned out occasionally to remove the accumulation of dirt and drawing compound. These holes may be shown on the drawing for the diemaker's drilling instruction, or their position can be determined at die tryout.

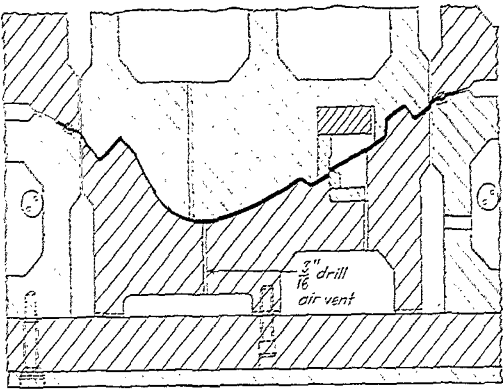
The final fitting or mating of the blankholder faces to each other, with a space between them, is called "spotting." A stamping is made in the die, and one side of the part lying in the area of the blankholder faces is covered with a blue dye. The stamping is then returned to the die and the die is closed.

The blue dye is transferred from the part to the high spots on the die member. These areas are then ground off, and the process is repeated until the evenness and parallelism of the two surfaces transfer a large percentage of the blue dye from the part to the die. The corners and part of the bottom of the draw bead groove should also be mated as well as the faces of the die members.

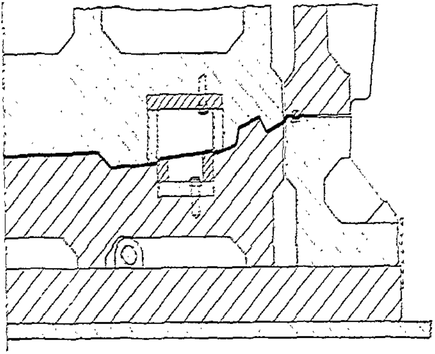
The degree of surface finish on the blankholder surfaces, draw radius, and punch face can govern the amount of scoring, tearing, fracturing, and breaking encountered in parts being drawn. Some of these spots will wear in from use and early in the production run may require the use of extreme-pressure lubricants until this takes place.

There are times when only a certain amount of stretching or drawing of the metal can take place in local areas, and the required shapes are not complete. This can be accomplished by blanking and restrike operations or can be combined into the first operation by lancing the metal in the scrap area. Figure 12-9 illustrates the construction of the lancing elements. The part being formed is the inner panel of a luggage-compartment lid for an automobile. The cutters are placed in several of the lightening holes which are blanked out later. This device is used wherever the metal is stretched completely over the face of the punch and into the draw-ring face, and more stretch or metal movement is required locally. The cutting operation is timed to lance and release the metal at the opportune time. The stock is cut on only three sides, so that a hard-to-eject blank is not left in the die but necessary metal movement is still allowed. The utilization of a third action of the press to lance and form local areas is shown in Fig. 12-10. This die forms the outer panel for an automobile door and the third press action lances and draws the recess at the window opening. The male portion of the lancing punch (*D*1) is mounted in the draw punch, and the female portion (*D*2) is mounted in the third-action forming punch (*D*3). A locking bead is installed in the blankholder to grip the metal for stretching around the draw punch. The die cavity has an open center since it is not necessary to squeeze the metal between the two surfaces to set it to shape. The die is designed in such a manner that the blankholder is guided by the draw ring to maintain their relative position during the operation.

Combination Forward and Reverse Draw. The drawing of an inner-panel, upper lift gate on a station wagon is an example of combination forward and reverse drawing in the same operation. The blank, with a rectangular hole in the center, is positioned in the die (Fig. 12-11) and gripped by the blankholder (*D*1) against the surface of the draw ring (*D*2). The punch (*D*3) draws the stock into the cavity from the outside over the regular draw ring and from the inside over the punch (*D*4). The pressure pad, which is in the die cavity, holds the blank against the draw punch, thus controlling the amount of metal flowing into the die cavity. Since the metal being drawn into the die from the inside of the blank is under tension, no blankholder is required on the inner portion of the blank. The pressure pad also lifts the finished part out of the die.



View A



View B

FIG. 12-9. Lancing of a blank after it is partially formed. (Ford Motor Co.)

Air-cushion Drawing. Single-action presses with an air cushion can produce a relatively uniform draw faster than a double-action press. The die for drawing a pair of automobile-front-seat side shields on a single-action press equipped with an air cushion is shown in Fig. 12-12. Drawing with a cushion is more satisfactory if the shape and depth of the draw are fairly uniform. The area of actual draw of this part is uniform even though beads and flanges are formed into the part as it is drawn and stretched over the punch.

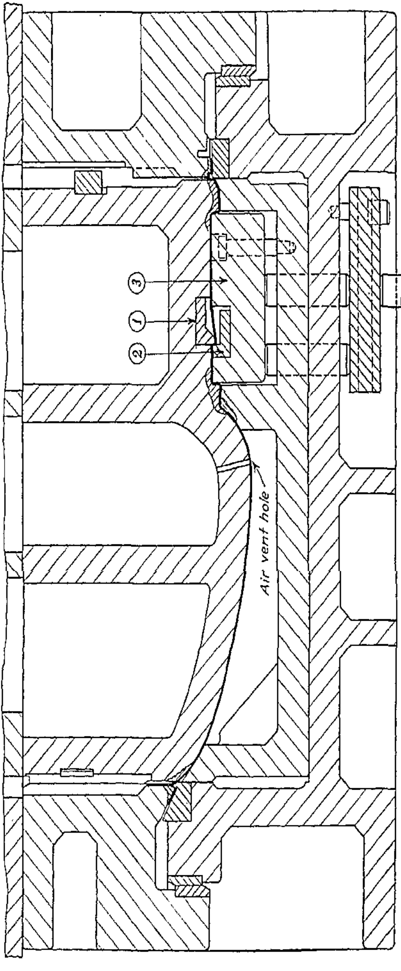


FIG. 12-10. Third action of the press used to lance blank and final form. (*Ford Motor Co.*)

The blank is positioned in the die by the piloting pins (*D1*), and the closing of the upper portion of the die to the blankholder preforms the blank to a *U* shape over the center portion of the blankholder. This is accomplished by the arch-shaped part of the blankholder as shown in view *A*, which fits into a recess in the punch as shown in view *B*. Continued descent of the press slide results in the forming of the part over the punch. The punch and die close tightly to emboss the sharp corners of the contour. The air cylinder (*D2*) lifts the ejector pad (*D3*) and the part to such a height that the jaws of the mechanical ejector (view *B*) are able to grip the part and remove it from the die.

Lateral movement of the blankholder is restricted by a wear plate on an overhanging flange of the upper die. As a safety measure, a flange is cast onto the base plate surrounding the blankholder.

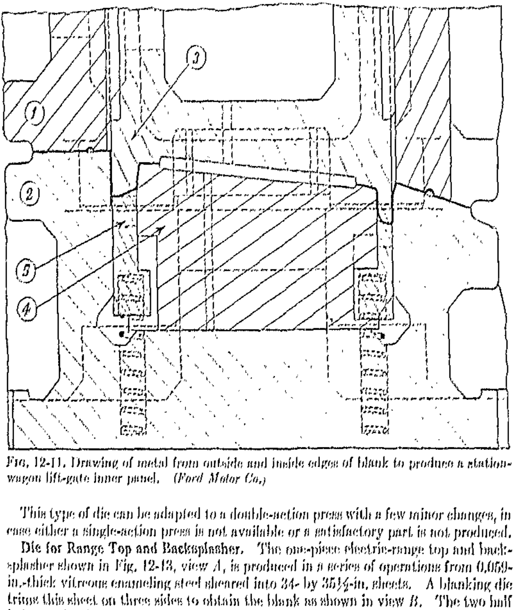
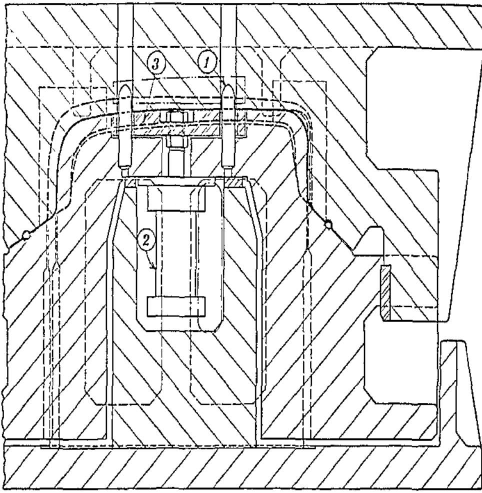


FIG. 12-11. Drawing of metal from outside and inside edges of blank to produce a station-wagon lift-gate inner panel. (*Ford Motor Co.*)

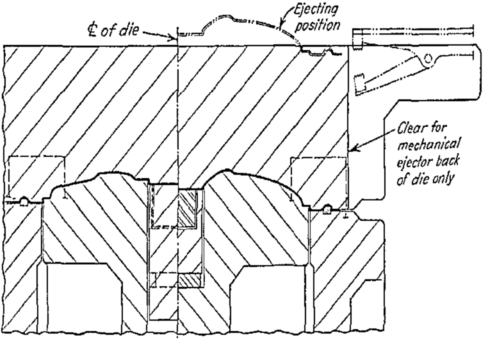
This type of die can be adapted to a double-action press with a few minor changes, in case either a single-action press is not available or a satisfactory part is not produced.

Die for Range Top and Backsplasher. The one-piece electric-range top and backsplasher shown in Fig. 12-13, view *A*, is produced in a series of operations from 0.059-in.-thick vitreous enameling steel sheared into 34- by 35½-in. sheets. A blanking die trims this sheet on three sides to obtain the blank as shown in view *B*. The two half holes on the sides are used to position the blank in the first two forming dies. View *C* shows the part after the first forming operation.

The die to preform the corner flanges, face, and top of the backsplasher and the front edge is shown in Fig. 12-14. The forming punch on the upper shoe is comprised of four sections. The portion *D1* forms the front edge and the two punches (*D2*) are for preforming the corner flange. The blankholder functions between these three punches, since the forming operations are performed on the outer edges of the blank. Pressure is applied to the blankholder by four rubber pads. The blankholder is also used to bend the sheet to form the backsplasher and to emboss certain areas.



View *A*



View *B*

Fig. 12-12. Double-action die with a die-cushion-actuated blankholder for forming a front-seat side shield. (*Ford Motor Co.*)

The two foolproof locating pins (*D4*) position the blank on the lower die. The part of the die (*D5*) containing the locating pins is elevated by an air cushion to a sufficient height to permit the flat blank to be placed in position. When the die is open, the upper blankholder drops below the lower edges of the fixed members and the air cushion raises the lower blankholder to grip the stock. The foolproof locating pins recede with the upstroke of the press, permitting quick removal of the stamping.

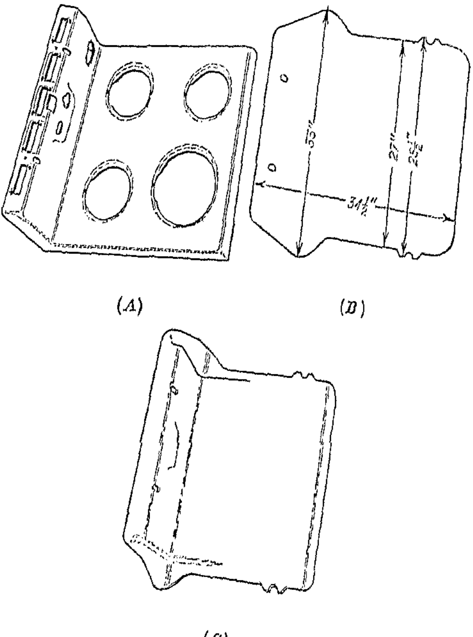


FIG. 12-13. One-piece electric-range top and backsplasher: (*A*) finished part; (*B*) blank; (*C*) part after first forming operation. (*General Electric Co.*)

The die for drawing the side flanges, finish-forming the front edge and top rear flanges, and embossing three switch-bracket openings of the part shown in Fig. 12-13 is shown in Fig. 12-15. A spring-loaded pressure pad (*D1*) on the upper die holds the preformed blank on the punch (*D2*) and the locating pins (*D3*) during the drawing operation. This die is made of Meehanite iron castings with hardened-steel inserts at the points of wear and areas where the embossing is performed. A ¼-in. draw radius was used on this draw die.

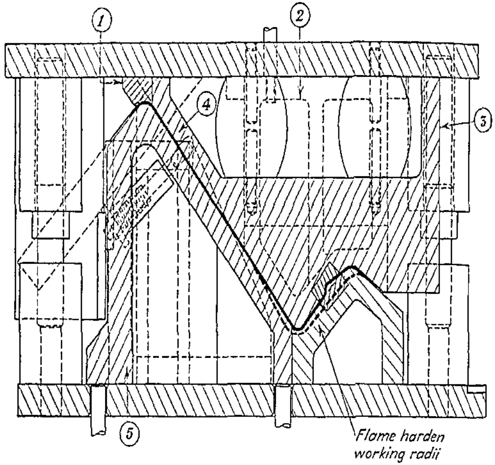


FIG. 12-14. Section through die to produce part shown in Fig. 12-13.

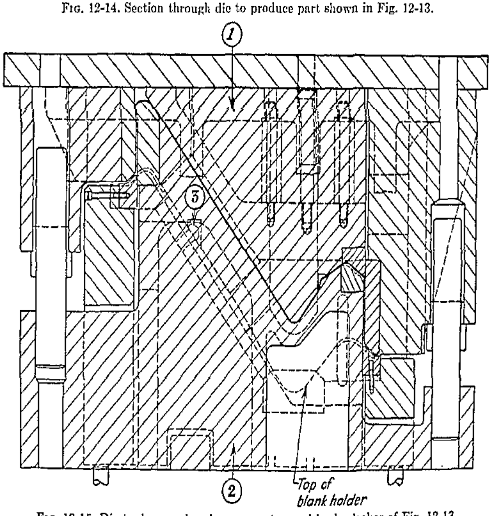


FIG. 12-15. Die to draw and emboss range top and backsplasher of Fig. 12-13.

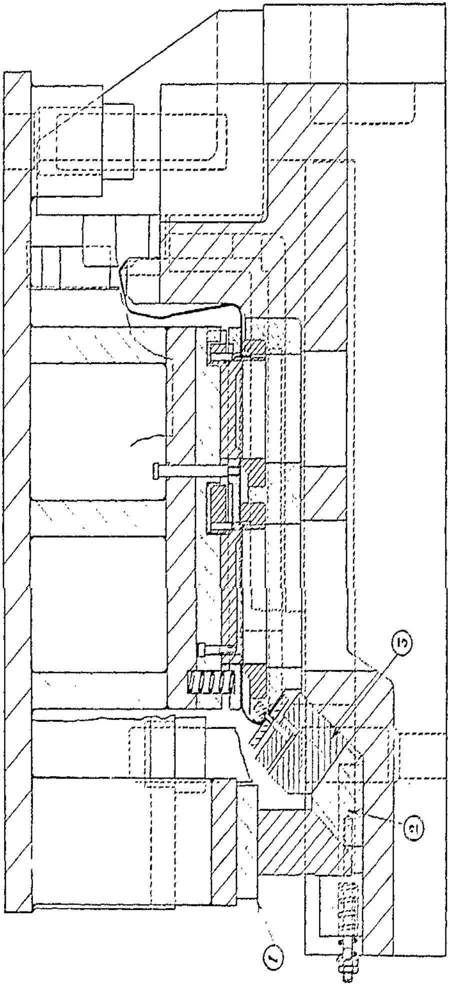


Fig. 12-16. Cam-actuated and conventional type piercing die (workpiece shown in Fig. 12-13).

The die in Fig. 12-16 is for piercing the four holes for the heating unit, four 0.110-in. diameter holes for securing the units, and holes along the front-edge flange. This die and other dies for subsequent operations employ complex cam arrangements which combine several operations into one die so that several operations are performed with each stroke of the press. Unless cam-actuated dies of this type are correctly designed

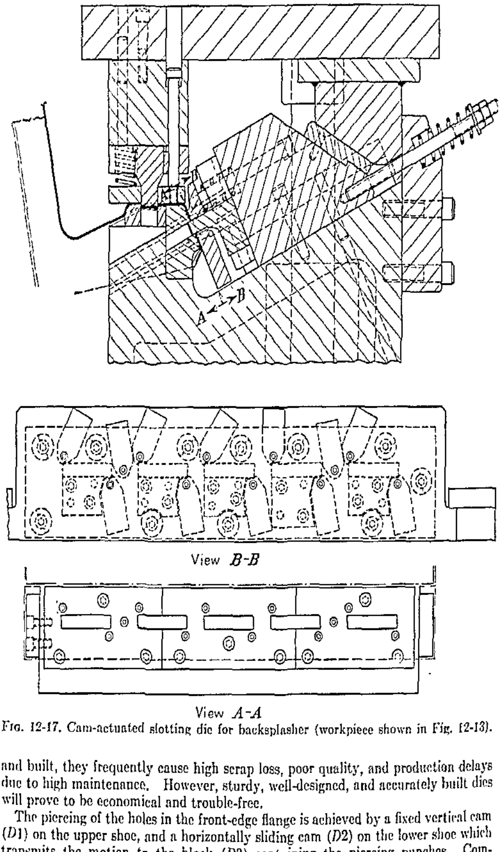


FIG. 12-17. Cam-actuated slotting die for backsplasher (workpiece shown in Fig. 12-13).

and built, they frequently cause high scrap loss, poor quality, and production delays due to high maintenance. However, sturdy, well-designed, and accurately built dies will prove to be economical and trouble-free.

The piercing of the holes in the front-edge flange is achieved by a fixed vertical cam (*D*1) on the upper shoe, and a horizontally sliding cam (*D*2) on the lower shoe which transmits the motion to the block (*D*3) containing the piercing punches. Commercially standard punches, punch retainers, and die buttons are used with hardened-steel backup plate behind the punches. The die rings for the larger holes are made from air-hardening tool-steel tubing and are recessed into a machine-steel subplate.

The upper die shoe has been fabricated from steel plates as a weldment; the lower shoe is a casting.

The next operation performed on this part is piercing five rectangular slots and twelve holes in the top of the backsplasher and, at the same time, two irregular-shaped holes for instruments in the face of the backsplasher.

The part is positioned in the die (Fig. 12-17) so that the two holes in the face of the part are pierced in the conventional manner, while the remainder of the holes are pierced by a cam-actuated slide. Spring-loaded pads precede the punches and clamp the workpiece to the die, also serving as punch strippers on the upstroke of the die. Springs are utilized to return the slide for loading and unloading the die.

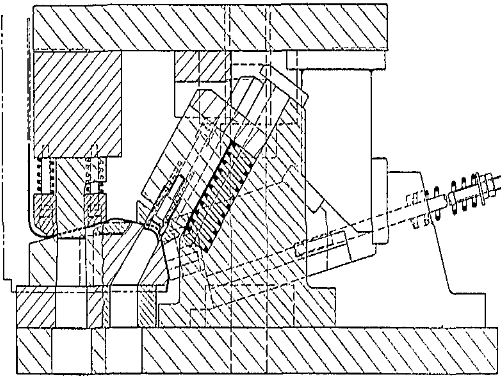


FIG. 12-18. Piercing and embossing backsplasher by cam-actuated punches (workpiece shown in Fig. 12-13).

Additional piercing and embossing operations are performed on the part by the die shown in Fig. 12-18. The conventional vertical punch cuts a hole in the face of the backsplasher; the cam-actuated punch sitting at about a 45° angle pierces a rectangular hole at the radius, and the other cam-actuated sliding block embosses a circular indentation around four of the instrument-mounting holes.

A commonly used type of cam flanging die is shown in Fig. 12-19, but incorporated in the die are additional cams for other die functions.

The cam-actuated flanging punch (*D*1) is mounted on the plate (*D*2) which is supported by pins extending to the die cushion. Also on this plate is a sliding form block (*D*3) around which the flange is formed. The raising of this plate by the air cushion engages a set of cams (*D*4) to withdraw the form block to facilitate removal of the part, since the flanges are being formed on three sides by the die. Before the plate can be raised by the air cushion, the upper shoe must ascend carrying with it the cam (*D*5) and releasing the latch plate (*D*6).

Not shown but included in this die are cam-operated punches for forming a vertical flange on each side of the backsplasher, and a conventional punch and form block to flange downward the rear edge of the top of the backsplasher.

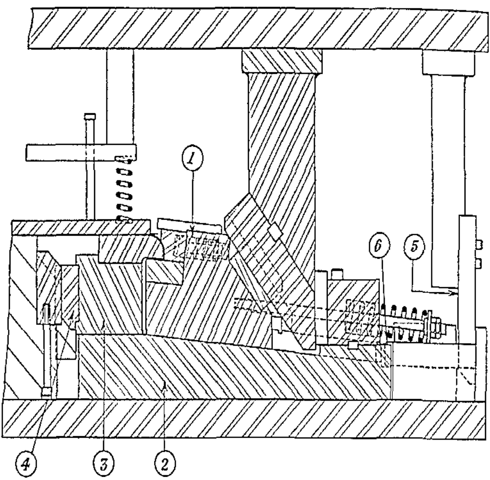


Fig. 12-19. Cam-operated flanging die for workpiece shown in Fig. 12-13.

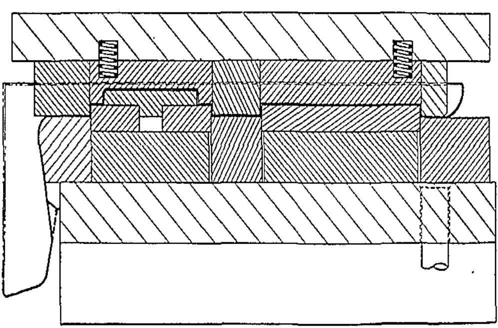


Fig. 12-20. Draw die for recesses in range top of Fig. 12-13.

A section through the die for drawing the recesses in the top for the heating units is shown in Fig. 12-20. The die is an inverted type with the draw punches and air-cushion-actuated blankholder on the lower shoe, and the draw rings attached to the upper shoe. Spring-loaded pressure pads are installed in the die cavities to help control the moving metal. The limited amount of pressure exerted on the small area of metal in this type of draw is often beneficial in that it directs the flow of metal over the draw radius instead of allowing it to move unrestricted. These pads also bottom at the low point of the press stroke to flatten the flanges and sharpen the corners.

This die is of sturdy construction and uses two 2½-in.-diameter guide pins to align the upper and lower shoes.

Floating-draw-ring Die. This type of die construction enables the draw ring to be elevated to a predetermined height above or nearly above the high point of a reverse contour in the part. This permits the blank to be gripped with a natural deflection that would not be possible with the blankholder line in the low position. With a fixed draw line at the higher position, a deeper draw would be required. But a part with a high center and high sides may be rather difficult to draw satisfactorily, because of the possibility of being unable to flow the metal in the reverse direction around the

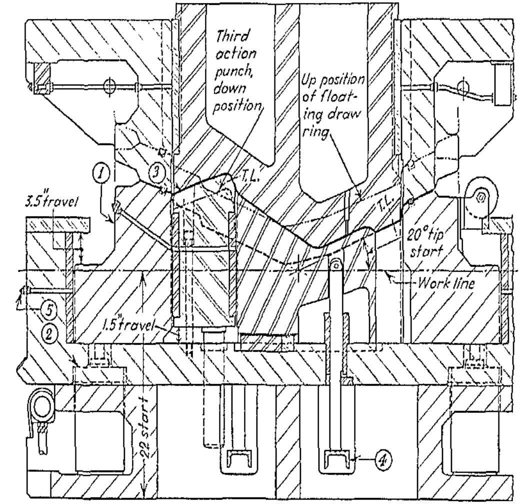


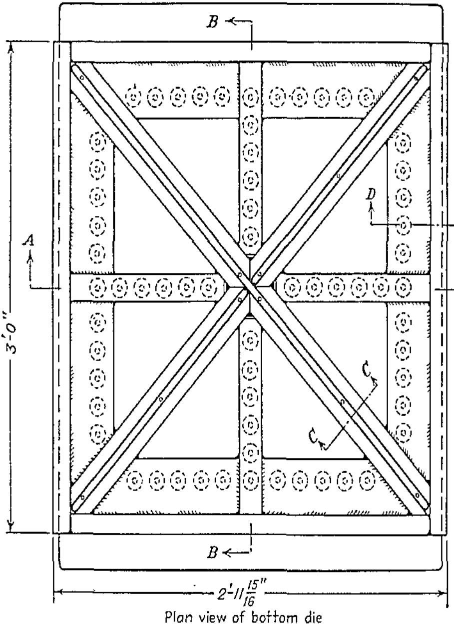
FIG. 12-21. Draw die with a floating draw ring to form a dash panel. *(Ford Motor Co.)*

punch nose. The shape of some parts does not require the higher drawn sides; therefore, a smaller blank is used in these cases. This type of die is used on a regular double-action press, with the floating draw ring actuated by a die cushion in the press bed or a cushion built integral with the die.

The floating draw ring grips the metal against the surface of the blankholder, and the simultaneous descent of these two die members draws and stretches the blank over the die. With the blankholder in dwell position, the punch continues downward, forming the part to the contours of the punch and die.

This type of die construction has a higher first cost and more maintenance than a regular double-action die because of the movement of the lower blankholder and the fact that the blankholding faces require a higher degree of spotting.

An example of the floating draw ring is shown in Fig. 10-21. This die forms an *automobile dash panel, which is the panel between the passenger and engine compartments* and the sloping portion of the floor board. It has a hump in the center to clear the transmission and the engine.



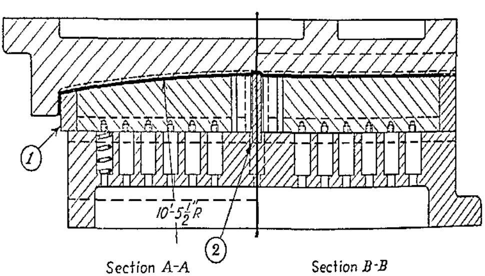
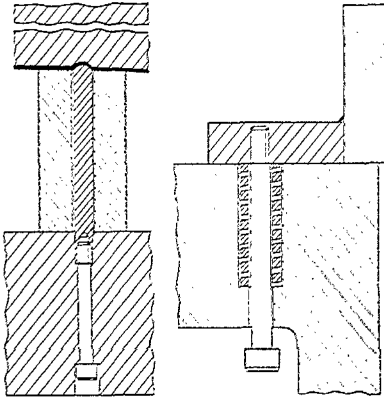


FIG. 12-22. Die to form stiffening beads, large radius contour and flanges on an air duct panel. (*Pullman Standard Car Mfg. Co.*)

The floating draw ring (*D1*) is elevated by a group of air cylinders (*D2*) and has a travel of 3.5 in. The reentrant contour of the part necessitated the use of a third-action punch (*D3*). The "up" position of the draw ring and the "down" position of the third-action punch are shown by the phantom lines and indicate the interferences given to the blank by the reverse contour in the die.

Incorporated in this die is a lifter mechanism (*D4*) to raise the drawn part out of the die so that the jaws of the mechanical ejector can grip and remove the part from the die. Also shown are grease fittings (*D5*) at holes and tubing leading to the wear plates for lubrication purposes.

Die to Form Stiffening Beads. A die to form crossed stiffening beads, a large-radius contour, and flanges along two sides is shown in Fig. 12-22. The floating punch (*D1*) is of open construction, contacting the sheet only at the beads, through the center, and



Section C-C Section D-D

Fig. 12-22 (*Continued*).

around the outer edges. The floating punch is supported by springs to form the contour and flanges before the beads are formed by the stationary punch (*D2*).

Die to Form Shallow Recesses. The liner top and bottom panels of a refrigerator are formed together in one piece by the die shown in Fig. 12-23, view *A*. Springs lift the blankholder above the top surfaces of the forming punches and provide the pressure for gripping the blank while forming. In addition to guide pins, the upper die is aligned with the punches by heel blocks on each end of the die. View *B* is a section through the die to separate the two panels, trim the periphery, and perforate holes in the bottom panel. The pressure pad (*D2*) in the upper die holds the part against the punch (*D3*), to be cut by the die (*D4*). The scrap is stripped from the punch by the stripper pad (*D5*). The parting punch (*D6*) and the die steels (*D7*) separate the two panels. The punch and die units (*D8*) pierce 15 holes in the liner bottom.

Die to Form Refrigerator Bottom Pan. The die in Fig. 12-24 forms the spherically curved surface, two beads, a rectangular-shaped indentation, and flanges on the four sides in one operation.

The punch (*D1*) for the spherical segment is fastened solidly to the lower shoe (*D2*). The form block (*D3*) for the remaining operations is spring-loaded so that it can be

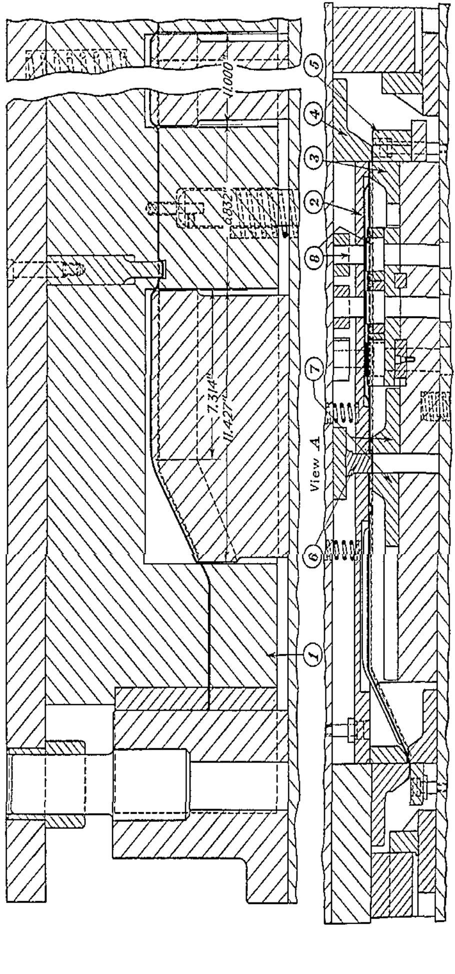


FIG. 12-23. Sections through dies for refrigerator liner top and bottom panels: view A, die for forming panels; view B, die for trimming and parting panels. (*Ready Machine Tool & Die Co.*)

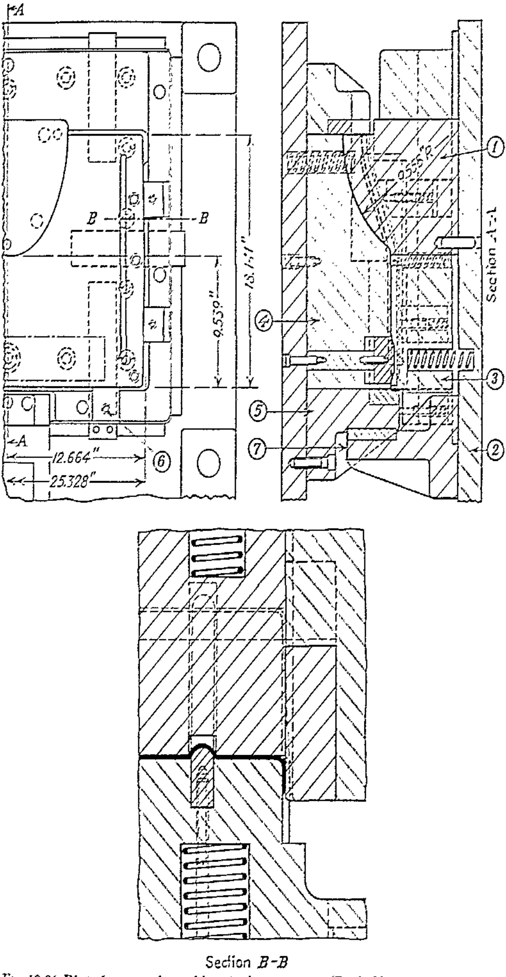


FIG. 12-24. Die to form complete refrigerator bottom pan. (*Ready Machine Tool & Die Co.*)

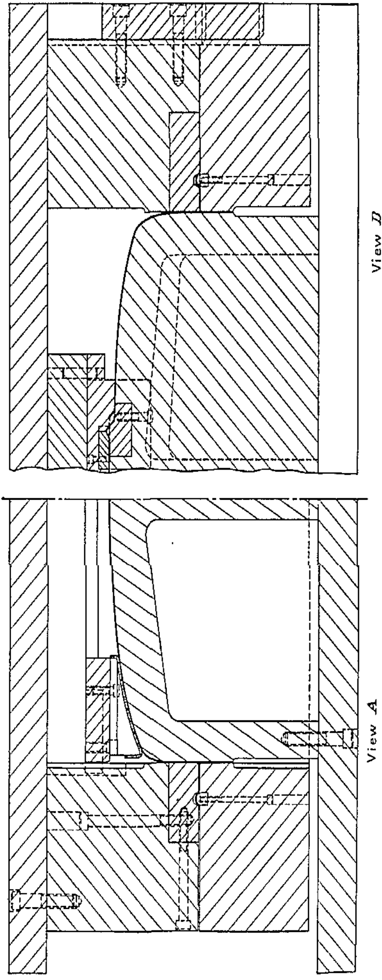


FIG. 12-25. Sections of dies for producing refrigerator doors. View A, horizontal section through the draw die. View B, vertical section through the draw die near top of door.

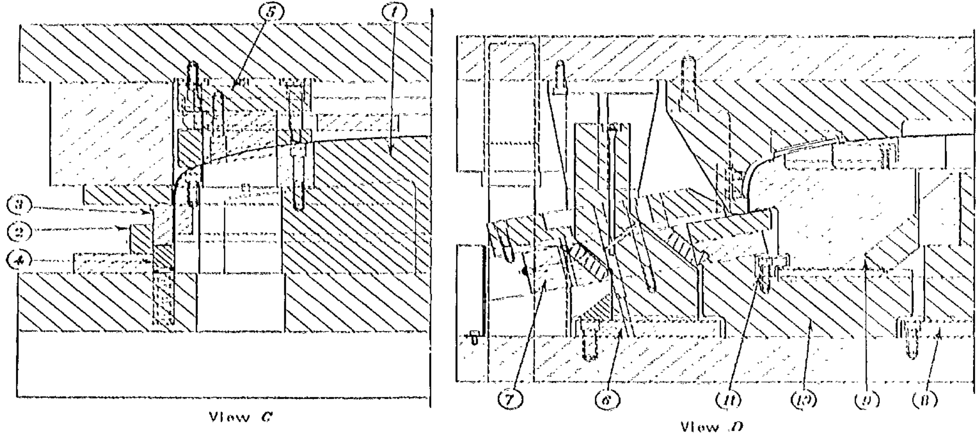


Fig. 12-25 (*Continued*). View *C*, section of die for trimming and straightening the sides. View *D*, section of the cam-actuated flanging die. (*Ready Machine Tool & Die Co.*)

raised to a height equal to the high point on the punch. The pressure pad (*D4*) on the upper shoe is spring-loaded and is constructed to drop flush with the surface of the draw ring (*D5*).

Closing of the die grips the blank, which has been positioned by six spring-loaded disappearing gage pins (*D6*) between the surfaces of the forming block and pressure pad. Continued descent draws the metal around the spherically curved surface of the punch. As the form block reaches the end of its travel, the draw ring forms the four flanges. Bottoming of the pressure pad against the upper shoe embosses the beads and rectangular-shaped indentation. This die is mounted on a large four-post die set but, to prevent shifting of the upper die by the inclined surface, a heavy heel block

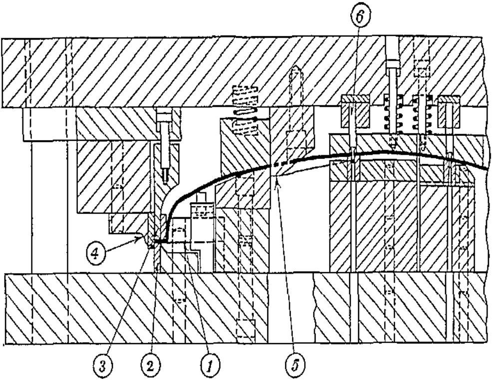


FIG. 12-26. Dies for a space-heater front panel. View *A*, section through trimming and blanking die.

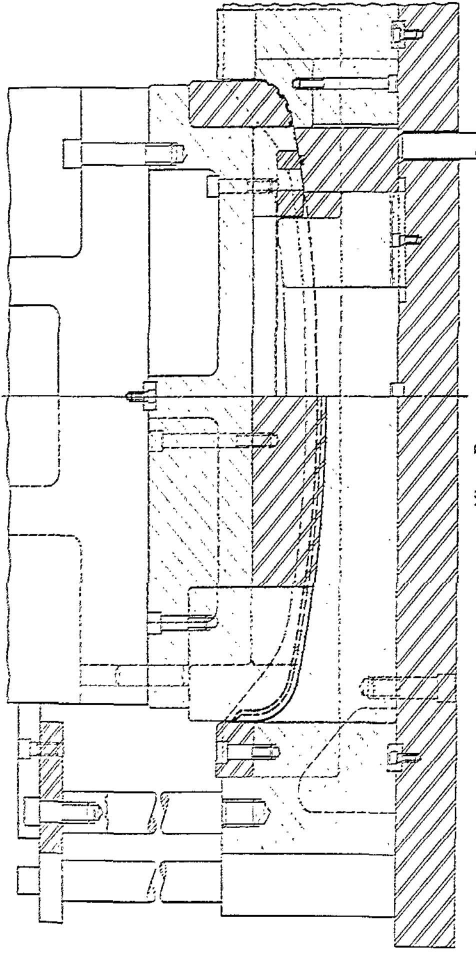
(*D7*) with wear plates has been attached to the lower shoe. Sheet-metal shields surrounding the form block and fastened to the lower shoe prevent unwanted objects from getting underneath the form block.

Dies to Produce Refrigerator Doors. Refrigerator doors have contours and corner radii which require the combined operations of stretching and forming to produce the required shapes. Since these panels are enameled, care must be taken not to scratch the outer surfaces.

The illustration in Fig. 12-25, view *A*, is a horizontal section through the draw die, showing the draw punch, draw ring, air-actuated blankholder with draw heads, and a leather-faced pressure pad within the draw ring. View *B* is a vertical section through the die, showing the forming of an offset near the top of the door.

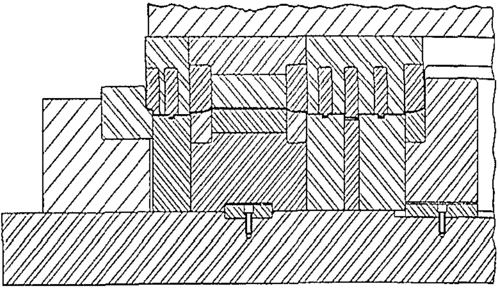
A section through the trimming and piercing die is shown in view *C*. The part is placed over the block (*D1*), with the flange resting on the trimming die (*D2*). The periphery is trimmed by the punch (*D3*). Continued downward travel of the punch straightens the flange into the side wall of the stamping. The spring-loaded pressure pad (*D4*) controls the flow of the metal over the draw radius on the inner edge of the punch.

The punch and die assembly (*D5*) blanks out a hole for the door handle. This assembly is interchangeable with the block on the opposite side of the die to facilitate



View *B*

FIG. 12-28 (Continued). View B, cross section of the flanging and embossing die.



View *C*

FIG. 12-26 (*Continued*). View *C*, partial vertical section showing inserts for embossing.

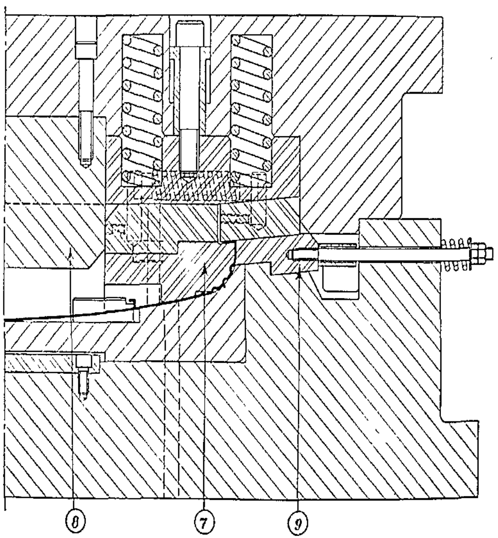


FIG. 12-26 (*Continued*). View *D*, cam-action flanging die.

the blanking of right- and left-hand doors. Small holes are pierced near the top and bottom of the door in this die with commercial punches and dies.

Flanging of the door panel is accomplished in the die shown in view *D*. The actuating cam (*D6*) for the flanging slides (*D7*) is secured to the lower die shoe. Likewise is the cam (*D8*) for actuating the sliding form block (*D9*). The unique feature of this flanging die is that the sliding form blocks and flanging slides are mounted on a vertically moving plate (*D10*) actuated by the die cushion. The upper die serves as a blankholder and the closing of the die lowers the floating plate, forcing the form blocks outward to a dwell position. Continued descent of the upper die and

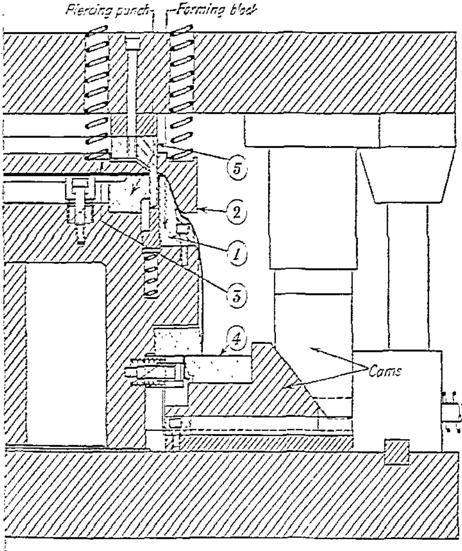


FIG. 12-27. Combination die performing pierce, draw-neck, and edge-trim operations on a large drawn shell. (*Maytag Co.*)

the floating plate permits the flanging slide to be forced inward by its actuating cam. Cams incorporated in the die assure positive return of the sliding members upon the raising of the floating plate by the die cushion. To prevent the form block from being tipped upward by the flanging operation, a slot has been machined in the side of the block to accommodate the overhanging block (*D11*).

Dies for Space-heater Front Panel. Dies for performing additional operations on the space-heater front panel (Fig. 12-2) are shown in Fig. 12-26. The die section shown in view *A* is taken through the various cutting operations of the die. The flanges along the sides are held against the locating block (*D1*) and the segmental punch (*D2*) by the pressure pad (*D3*), while the die (*D4*) trims the excess stock. The punch (*D5*) blanks out the door opening, leaving stock for flanges formed in a later die. The small piercing punch ($D6$) pierces holes for mounting trim to the upper portion of the panel.

The straightening of the flange trimmed in the previous die, forming of the flanges around the door opening, and forming of the numerous embossments are performed in the die of which a cross section is shown in view B. The punch-and-die elements of this tool are made with several inserts because of the beads and indentations embossed

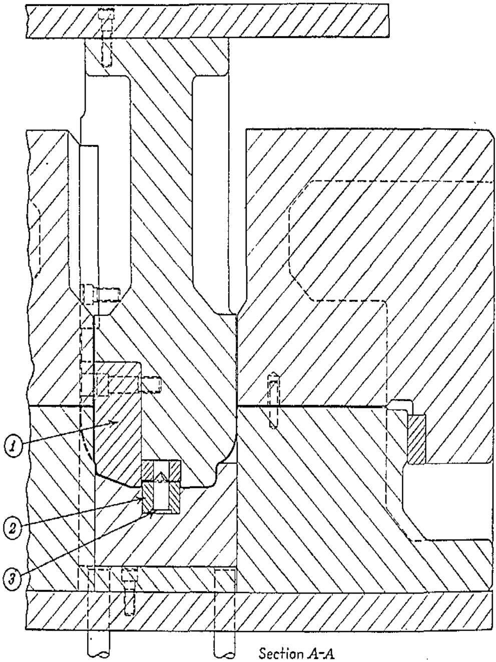


FIG. 12-28. Die to draw a cylinder-head cover. (*Chrysler Corp.*)

on the panel. View C is a section taken along the vertical center line of the panel showing the various inserts used in the die construction. The panel is lifted from the die by pads actuated by the die cushion.

A section through a cam-action die for flanging the vertical sides of the panel is shown in view D. The panel is placed face down in a nest in the lower die. The form block ($D7$) is forced into position by the cam ($D8$) and the flanging punch is pushed inward by the beveled surface on the upper shoe. The form block and flanging punch are carried on a spring-loaded pad attached to the upper die shoe. To assist in setting the bend radius, the sliding block ($D9$) on the lower shoe is pushed against the panel by the same beveled surface that actuates the flanging punch. The sliding members are all returned to their neutral positions by springs.

All these dies are solidly constructed to withstand the continuous usage in production runs.

Pierce, Form, and Trim Die for a Large Shell. Trimming of the top edge and piercing and forming the bottom of a washing-machine tube of No. 18 Armco sheet steel are shown in Fig. 12-27. The drawn tub is placed on the locator *(D1)* and held in place by two spring-loaded hold-downs *(D2* and *D3)*. The trimming of the top edge is performed by four cam-actuated trimming punches *(D4)*. The combination piercing and forming punch *(D5)* blanks out the bottom and forms a flange around the

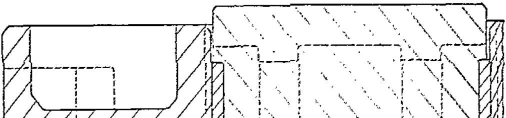


FIG. 12-29. Double-action die for drawing a body oil pan. *(Cadillac Motor Car Division, General Motors Corp.)*

bottom. The part is raised for removal by a spring-actuated lifter. Another spring lifter in the die elevates one side of the scrap blank so that it can be gripped for removal.

Die to Draw Cylinder-head Cover. The cylinder-head cover produced in the die shown in Fig. 12-28 is basically rectangular in shape but has some irregular curves in the top. On each side are three semicircular recesses to provide clearance for mounting bolts. Steel inserts *(D1)* are placed in the punch in these areas. Four circular indentations are formed in the cover by the inserts *(D2)*. Material is provided for these recesses by piercing with the nail punch *(D3)*, thus avoiding fracture by overstressing the material at the nose of the punch. A die-cushion-operated pressure pad holds the material against the nose of the punch during the drawing operation. The die is designed of cast parts for use in a regular double-action press.

Draw Die for Automobile Oil Pan. Sections of the draw die for forming a body oil pan having an uneven depth of draw are shown in Fig. 12-29. The material for this part is 16-gage SAE 1008 steel. View *A* is taken along the longitudinal center line of the die, showing the die construction and the shape of the part. The partial sections

A-A and *B-B* show the relative difference in the depth of draw at each end of the oil pan. Hardened-tool-steel wear plates with oil grooves guide the punch within the blankholder and the blankholder over the lower die. The die is designed for use in a regular double-action press with a die-cushion-actuated pressure pad to assist in the control of the metal within the die cavity.

Draw Die for Bumper Part. A front-bumper impact bar made from 0.1196-in. SAE 950 steel is produced in the die shown in Fig. 12-30. The irregular shape of the draw line is shown by the plan view of the die. Sections *A-A* and *B-B* illustrate the

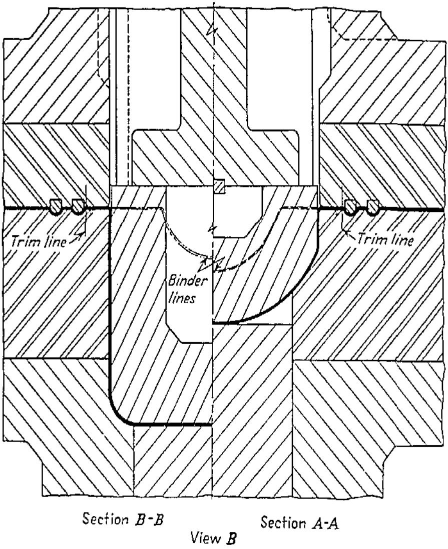


FIG. 12-29 (*Continued*). Section *A-A* and section *B-B* through die.

shape to which the part is drawn. A spring-loaded lifter mechanism, shown in section *B-B*, is incorporated in this die to raise the part so that it can be removed from the die by a mechanical hand. The thick, high-strength material from which the part is made requires heavy construction in the draw die.

Dies for Soft-drink-vending-machine Cabinet. The front door of the cabinet shown in Fig. 12-31 is made from 0.042-in. cold-rolled steel, deep-drawing quality, sheared into blanks 35½ by 57⅝ in. and oiled before being sent to the pressroom. The first drawing operation forms the vertical recess through the center, the offset across the face of the panel near the top, and the flanges on the sides and bottom to the depth of the offset. Sections through the die showing its simple construction are in Fig. 12-32. The section *A-A* is taken along the vertical center line of the die, the partial section *B-B* shows the construction above the vertical recess, and section *C-C* is through the vertical recess.

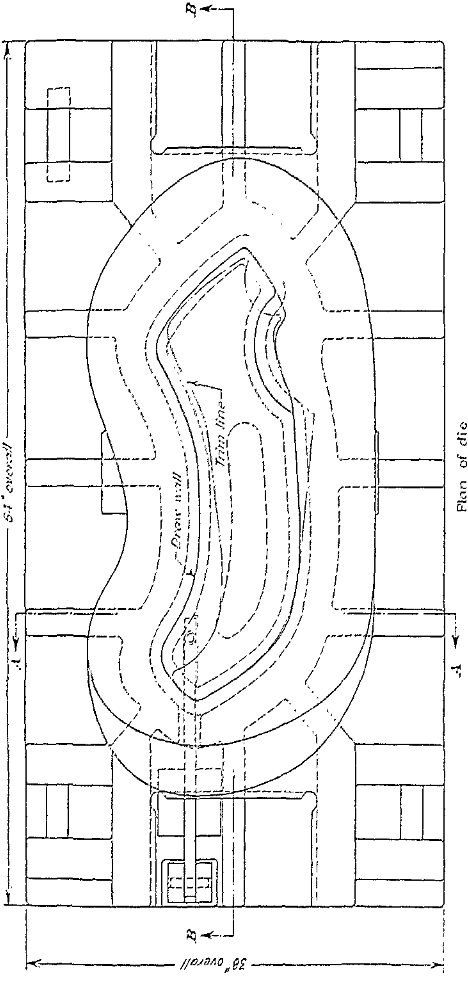


FIG. 12-30. Draw die for forming a bumper part of 0.1196-in.-thick high-strength steel.

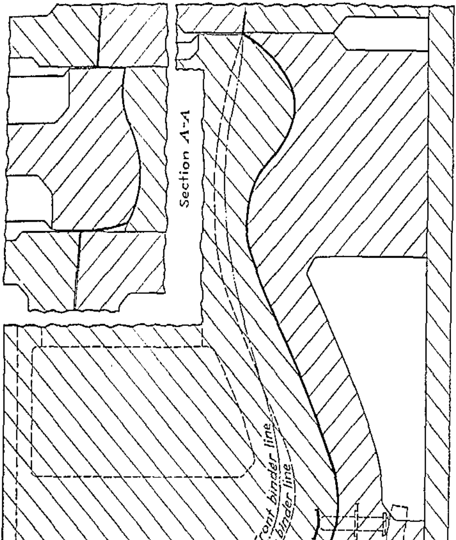


FIG. 12-30 (*Continued*). Sections A-A and B-B through die. (*Cadillac Motor Car Division, General Motors Corp.*)

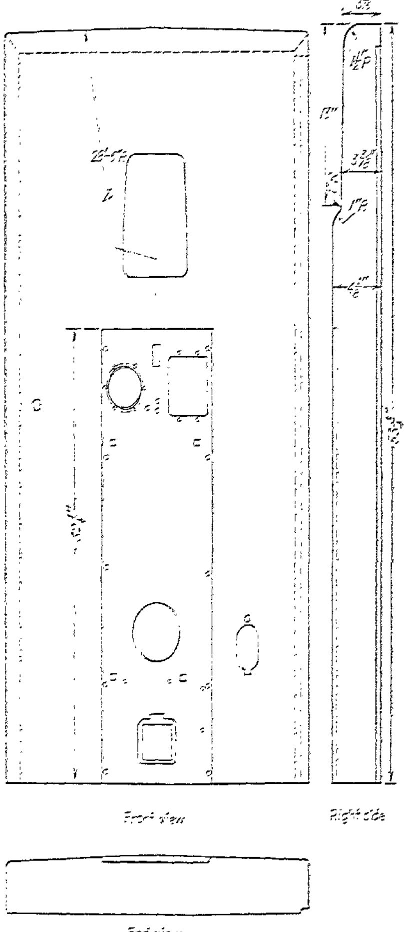


FIG. 12-31. Front-door panel for a soft-drink-vending-machine cabinet. (MCA Industries, Inc.)

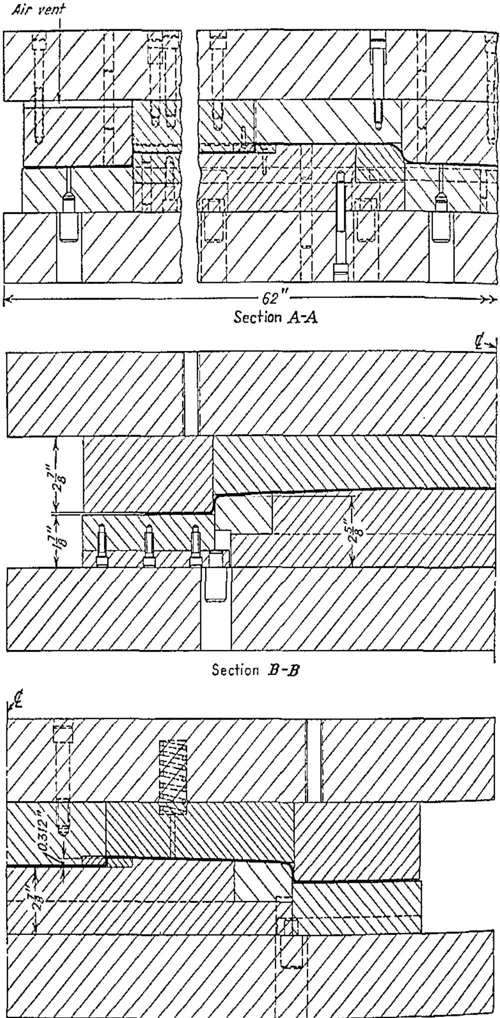


FIG. 12-32. Sections through the first draw die for the part shown in Fig. 12-31. (*Mills Industries, Inc.*)

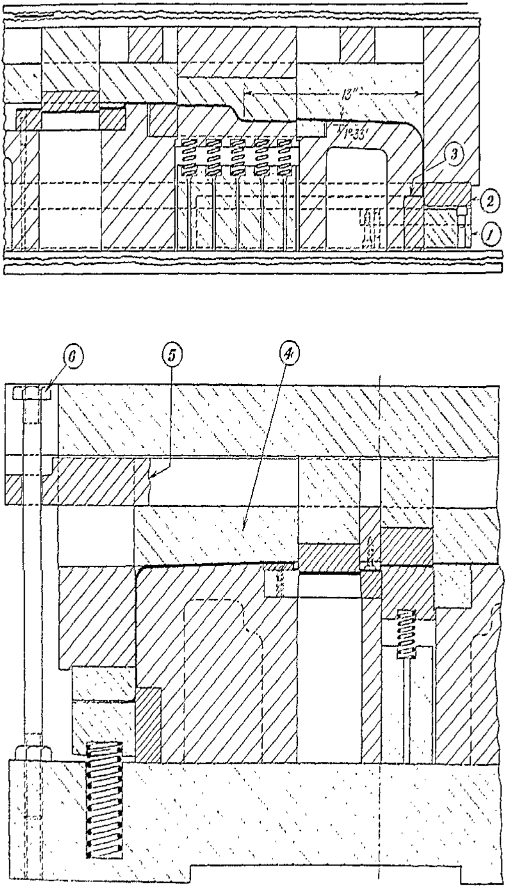


FIG. 12-33. Final draw, pinch-trim, and blanking die for vending-machine door. (*Mills Industries, Inc.*)

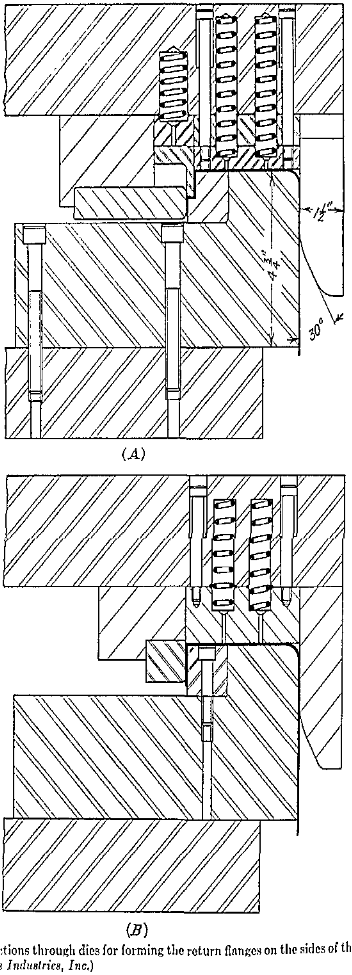
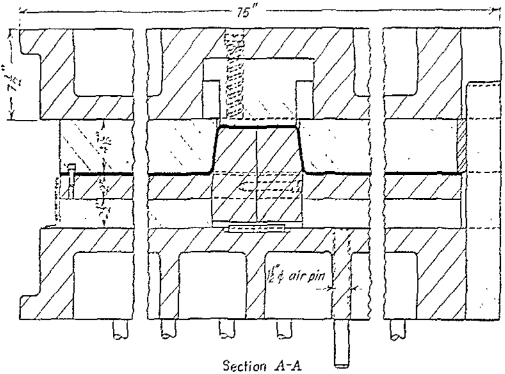
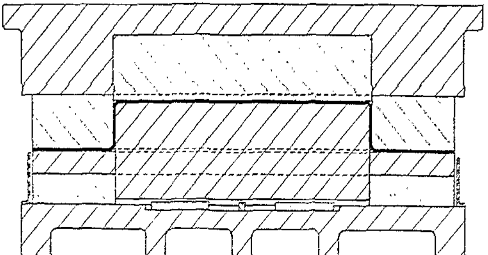


FIG. 12-34. Sections through dies for forming the return flanges on the sides of the front-door panel. (*Mills Industries, Inc.*)

A second draw operation forms flanges around the door to a maximum height of 3¼ in. To facilitate the final draw, the flanges are trimmed to width across the top and along the sides for a distance of about half the height of the door. The top corner areas are blanked to a developed shape so that an even flange height is produced in the final draw die.



Section A-A



Section B-B

FIG. 12-35. Draw die for automatic washer top. *(General Electric Co.)*

The door panel was finish-drawn and the side walls pinch-trimmed to height in the die from which the sections in Fig. 12-33 were taken. Punch-and-die steels are *incorporated in this die to blank out the openings in the face of the panel.*

The spring-actuated blankholder (*D*1) surrounds the punch and grips the flange of the part against the face of the draw ring (*D*2). The pinch-trim steel (*D*3) is inserted into the cast-iron punch. The draw ring of the die is also cast iron with hardened-steel inserts.

After completion of the operations, the door panel is removed from the draw ring by the positive stripping arrangement. The stripper consists of a pad (D4) fitting

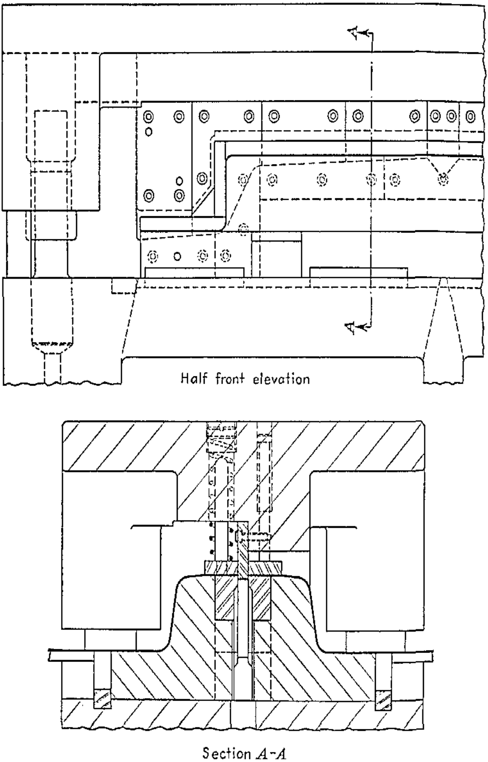


FIG. 12-36. Parting die for part drawn in the die shown in Fig. 12-35. (*General Electric Co.*)

the inside of the draw ring, the extension bars (*D*5), and the headed studs (*D*6) attached to the lower shoe.

The smaller scrap blanks are permitted to drop through the die. The larger blanks requiring support during the blanking operation are lifted to the surface of the die by their individual pressure pads.

The forming of the return flange along the top edge is achieved by a cam-action die of conventional design. The flanges along the sides are formed in the dies shown in Fig. 12-34. Shoes and spring-loaded pads hold the door panel firmly against the form block while the flanging operations are performed.

Additional dies are used to pierce, pierce and dimple, and pierce and extrude the small-diameter holes as required by the engineering drawing of the part.

These dies were designed for use in single-action mechanical presses having a maximum stroke of about 8 in. and die cushions where required.

Dies for Automatic Washer Top. The top and backsplasher for the machine cabinet are made in one piece from 0.041-in.-thick deep-draw-quality steel. A rectangular draw to form the backsplasher is made from a developed blank which is later cut into two pieces to make two parts. The section of the draw die shown in Fig. 12-35 illustrates a split draw ring which permits the insertion of a 0.093- by 6-in.-wide

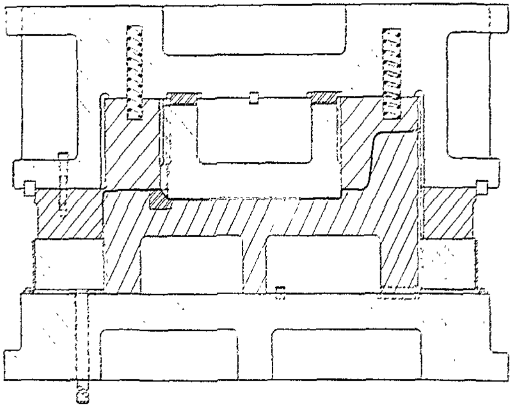


FIG. 12-37. *Die to draw flanges and restrike recess in washer top.* *(General Electric Co.)*

shim to be located between the split draw ring adjacent to and surrounding the draw punch. This construction facilitates localizing the draw pressure and thereby preventing an oil-can effect in the large flat surface surrounding the drawn portion. The spotting time is also reduced by the use of the split-draw-ring design.

The parting die (Fig. 12-36) for the part uses a sectional punch and incorporates shear on the punch to reduce the punch load. A chisel-shaped part of the punch in the center cuts the scrap into two pieces for easier disposal. A spring-loaded pressure pad surrounding the punch holds the part securely against the die members. Guide pins and heel blocks are utilized to maintain die alignment. The hardened-tool-steel die sections are inserted into heavy cast-iron blocks shaped to position the drawn blank in the die.

Subsequent operations rough-pierce and draw a recess in the center of the top, then trim three sides of the blank to a developed shape prior to drawing the flanges and restriking the center recess. The later operations are performed in the die shown in Fig. 12-37. A spring-loaded pressure pad holds the blank against the draw punch while a die-cushion-actuated blankholder grips the metal in the flange area.

The return flanging of the three horizontal and two vertical sides is accomplished in the cam-action die shown in Fig. 12-38. The cam *(D1)* attached to the upper shoe

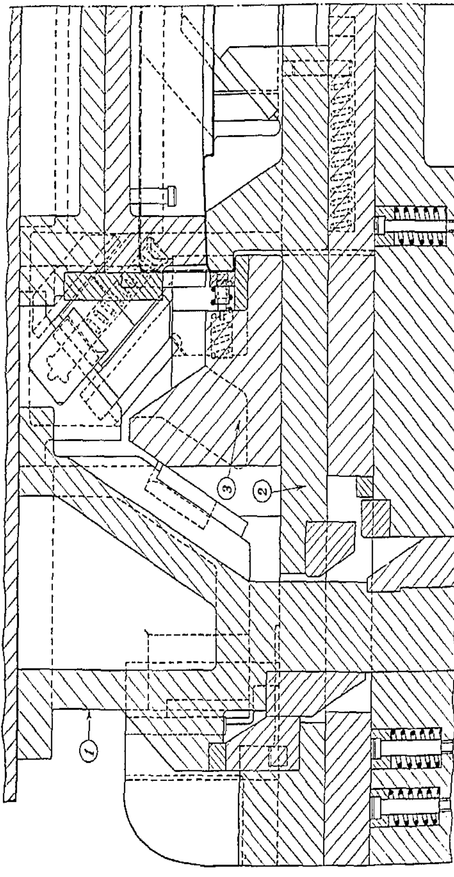


Fig. 12-38. Cam-action flanging die for washer top. (*General Electric Co.*)

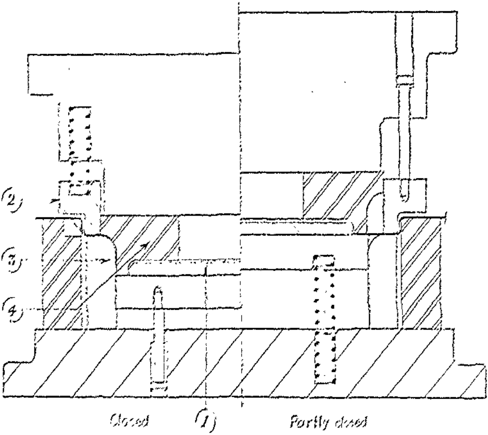


FIG. 12-39. Die for drawing flange around center opening. (General Electric Co.)

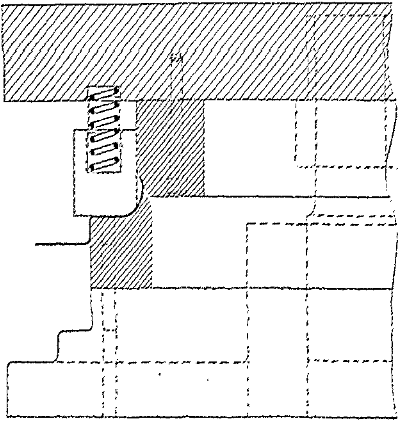


FIG. 12-40. Curling die for flange around center opening of washer top. (General Electric Co.)

pulls the slide (*D*2) (to which is attached the form block) outward to a dwell position. This action also raises the form block for the backsplasher to position. During the dwell period of the form-block slide, another surface on the cam engages the flanging slide (*D*3), forcing it inward to form the flanges. This arrangement is typical for the three horizontal flanges on the top and two additional cams actuate slides to form the vertical flanges on the backsplasher.

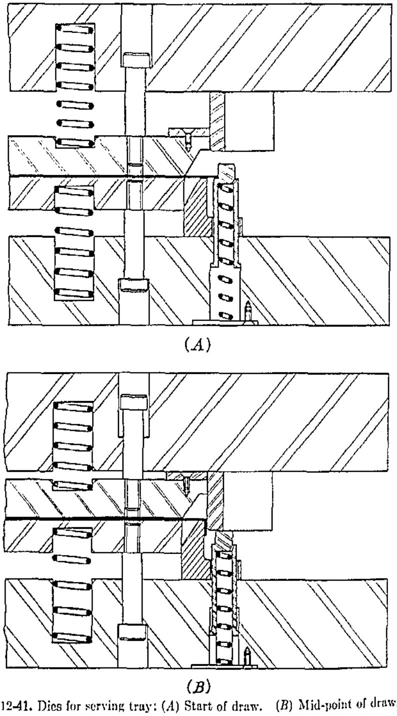
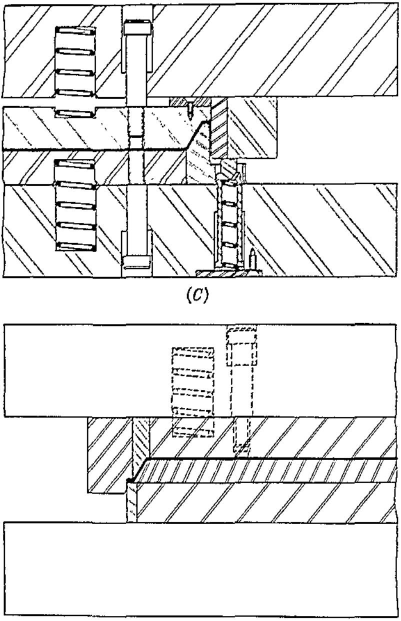


Fig. 12-41. Dies for serving tray: (*A*) Start of draw. (*B*) Mid-point of draw.

A flange around the center opening is drawn in the die shown in Fig. 12-39. The workpiece is placed over the locating ring (*D*1) fastened to the lower spring-loaded pressure pad. The closing of the die grips the part by the upper pressure pad (*D*2) against the draw ring (*D*3), while the punch (*D*4) draws the metal into the die. The next operation forms a curl on this flange as shown in Fig. 12-40. These dies are run simultaneously in the same press.

Dies for Forming Serving Trays. The dies for forming, curling, and flattening the curl around the edge of a serving tray are shown in Fig. 12-41. A developed blank is cut to shape in a blanking die and placed in the die as shown at view *A* for forming and



(*C*)

(*D*)

FIG. 12-41 (*Continued*). (*C*) Closed position for form and curl of tray. (*D*) Section through flange flattening die. (*Davey Products Co., Inc.*)

curling. The section of the die at view *B* is at the mid-point of the closing position showing the flange formed. View *C* shows the die completely closed to form the recess and flange. The section at view *D* is taken through the flattening die where the flange is folded in and flattened.

SECTION 13

RUBBER-PAD AND HYDRAULIC-ACTION DIES*

The use of rubber in conjunction with press tools takes advantage of a property it possesses in common with fluids, viz., its *ability to flow*. If a quantity of rubber is placed in a cylinder and pressure is brought to bear upon it by applying a force to a ram, any such force must set up a resultant reaction on every surface with which the rubber comes in contact.

Rubber also possesses the property of *cohesion*, or resistance to flow, not exhibited by a fluid, which plays a vital part in the working of materials. The cohesive property of rubber has its limits, and great care must be taken in the design of tools not to expect too much of the material; also, every assistance should be given to the rubber to enable it to maintain its form unbroken and so preserve its life.

The several rubber-die processes possess the common characteristic that only the male portion or punch is made. This lowers the tool cost considerably. The rubber pad is attached to the ram of the press and, as it is lowered, the rubber is made to flow *around the form block, forming the blank to the shape of the form block.*

GUERIN PROCESS

The Guerin process employs a rubber pad on the ram of the press and a form block to be placed on the lower platen. This process is the oldest and most widely used but

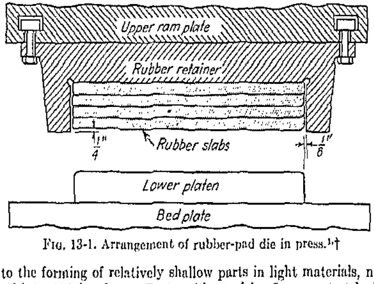


FIG. 13-1. Arrangement of rubber-pad die in press.[1,†]

is limited to the forming of relatively shallow parts in light materials, normally not exceeding 1¼ to 1½ in. deep. Parts with straight flanges, stretch flanges, and beaded parts formed from developed blanks are most suitable for this process.

Rubber Pressure Pads. These are held in a steel or cast-iron container with walls of sufficient cross section to withstand the pressure exerted upon it by the rubber. The thickness of the pad may vary from 6 to 12 in. The pads may be a solid type or

* Reviewed by Bernard Anscher, Sales Manager, Hydropress, Inc., and J. A. Whittingham, Superintendent, Sheet Metal Department, North American Aviation, Inc.

† Superior numbers relate to References at the end of this section.

a laminated type. The solid type is produced in two ways: (1) by curing as a homogeneous mass, or (2) by curing in sheets or slabs, usually 1 in. thick, then curing these sheets together in a single slab of the required thickness. The laminated type includes all pads made up of individual sheets placed one on top of the other in the press, but not cured into a solid mass. Laminated pads have the advantage that the working surface can be restored when worn by merely reversing the top layer or exchanging it with one of the others. Most users favor a pad hardness of 55 or 65 durometer hardness for forming work. When shearing or blanking is done with a rubber pad, a throw sheet with a 90 durometer hardness is sometimes placed over the blanks or cemented directly on the face of the pad. Figure 13-1 shows the arrangement of the rubber die and lower platen in the press.

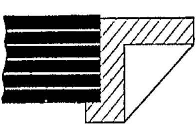


FIG. 13-2. Z-shaped frame for rubber retainer.

A way to hold the solid pad in place is to make it larger than the container in which it is to be used. The pad is then forced into the box by placing it on the bolster of the press and closing the press. One per cent minimum oversize on the length and width has been used successfully.

A framework whose sides are Z-shaped (Fig. 13-2) retains the rubber slabs without being cemented together. The retaining strip may be part of the framework or a

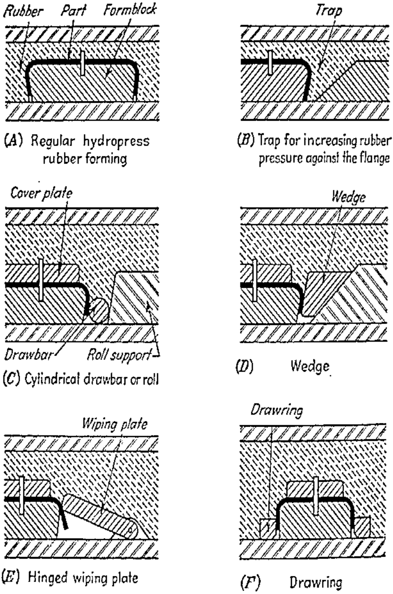


FIG. 13-3. Auxiliary rubber-forming tools.[5]

separate strip fastened on with cap screws. The dimensions of the lower platen should provide $\frac{1}{16}$- to $\frac{1}{8}$-in. clearance per side between it and the inside of the rubber retainer.

Form Blocks. The form block (Figs. 13-3 and 13-4) is the primary tool used in rubber forming. It is a contoured flat plate of sufficient height to accommodate the part. A minimum of two pins are placed in the form block to locate the blank in the proper position. The height of these pins should be kept at a minimum to prevent damaging the rubber pad. Most of the parts are formed on a one-piece block in one operation. The more complex shapes require more than one piece to the form block or more than one operation. C or Z flanges on parts usually fall in this category.

Cross sections of form blocks for rubber forming are shown in Fig. 13-3. View *A* illustrates how the block is undercut to allow for spring-back in the flanges. A trap as shown in *B* is a means of directing an increased amount of pressure against the flange.

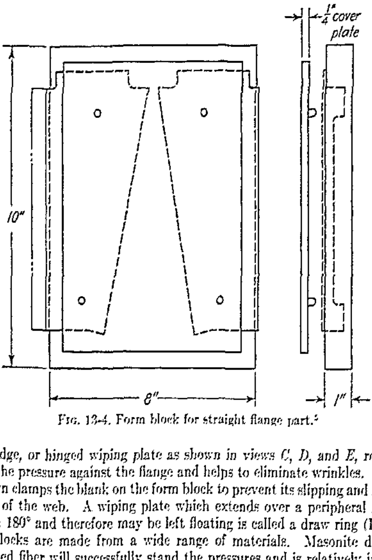


FIG. 13-4. Form block for straight flange part.[5]

A roll, wedge, or hinged wiping plate as shown in views *C*, *D*, and *E*, respectively, increases the pressure against the flange and helps to eliminate wrinkles. The cover plate shown clamps the blank on the form block to prevent its slipping and reduces the distortion of the web. A wiping plate which extends over a peripheral segment of more than 180° and therefore may be left floating is called a draw ring (Fig. 13-3*F*).

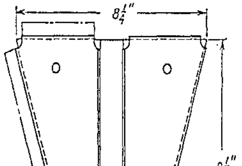
Form blocks are made from a wide range of materials. Masonite die stock or impregnated fiber will successfully stand the pressures and is relatively inexpensive. Masonite will break down rapidly if the block is made with sharp corners or has an overhanging section. In either of these two cases or a large number of parts, the block should be made of cast iron or steel. Kirksite, magnesium, and aluminum are also popular form-block materials. When hot-forming magnesium blanks, Kirksite has a tendency to flow at temperatures of over 450°F. Magnesium form blocks are easy to machine, light to handle, and have the same coefficient of expansion as the material being formed.

To increase the life of the rubber, form blocks should be kept as low as possible, and all corners that the rubber must flow down over should be rounded off as much as the part permits. When determining the height of the form block, consideration must be given to the fact that rubber will not form itself into sharp internal recesses or corners. For example, it will not form itself into the 90° corner between the side of the form block and the platen on which the block rests but will form a natural radius between

TABLE 13-1. MINIMUM FLANGE WIDTH FOR RUBBER FORMING[3]

Material	Minimum Flange Width, In.
24SO (75SO)	$\frac{1}{16} + 2.5T$
24ST	$\frac{1}{8} + 4T$
Annealed stainless steels	$\frac{3}{16} + 4.5T$
$\frac{1}{4}$-hard stainless steels	$\frac{5}{8}$

the two surfaces. Additional height must be added to the form block so that the bottom edge of the formed flange will be higher than the tangency point of this natural radius formed by the rubber. This distance is usually a minimum of $\frac{1}{8}$ to $\frac{3}{16}$ in. higher than the greatest height of the part.



Bend radii, spring-back, and bend allowances for rubber forming are the same as for die forming (see Sec. 8). The minimum flange widths for different metals and thicknesses T are shown in Table 13-1. These limits apply to simple rubber forming, but auxiliary devices may be used to form narrower flanges.

The simplest of all rubber forming is the forming of a straight flange by means of a single bend over a form block. Figure 13-4 illustrates a form block for forming a straight flange along one side of the blank. This form block is designed to flange a right- and left-hand part and uses a cover plate to reduce the distortion in the web.

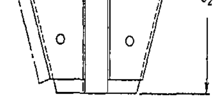


FIG. 13-5. Second-operation block for reverse flanges on part shown in Fig. 13-4.[5]

The second-operation block for forming flanges in the opposite direction in the part in Fig. 13-4 is shown in Fig. 13-5. The parts are placed on the form block, and a cover plate (not shown) is used to prevent the rubber from damaging the flange already formed. Flanges are formed along one side and an end of this part. The center portion of the form block is also removable to facilitate removing the finished part from the form block.

RUBBER-FORMED STRETCH FLANGES

Parts with stretch flanges are well suited for rubber forming. Often such parts can be produced more economically and more accurately by this process than by die forming. Stretch flanges may either be along concavely contoured portions of the part edges or around holes. There is no difference in forming requirements between the two types. The length of the outer flange is usually limited to a segment which is usually not larger than 180°, while hole flanges extend over the entire periphery of the hole.

Stretch flanges are obtained by being bent over a form block in the same manner as straight flanges. The width of the flange and the radius of the contour affect the bending of a stretch flange. Such a flange, having a large radius, can be formed in soft materials quite readily, but forming of sharply contoured flanges requires the use of pressure-increasing devices.

Aluminum alloys in either the annealed or as-quenched state are stretch-flanged in thicknesses up to $\frac{1}{8}$ in. Austenitic stainless steels up to 0.050 in. thickness in the annealed condition, and quarter-hard stainless-steel parts between 0.016 and 0.030 in. thick, can be stretch-flanged. The very thin quarter-hard stainless-steel parts develop an irregular wavy flange edge. A severely stretched flange of thick and hard material does not touch the block at all or possibly contacts it only at the flange edge. The forming limits of stretch-flanging different materials are discussed in more detail in Sec. 2.

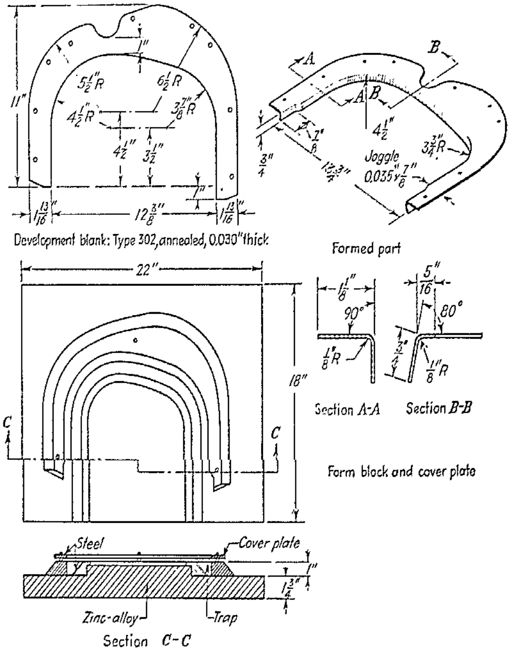


FIG. 13-6. Stainless-steel part with stretch flange.[5]

A part with a stretch flange of type 302 annealed 0.030-in.-thick stainless steel is shown in Fig. 13-6. The base of the form block is zinc alloy. A steel cover plate is required to avoid distortion of the web, and a steel trap was used to obtain sufficient pressure for forming the stretch flange. The joggle was partially formed on this block but required a hand operation to finish-form.

Rubber forming of various types of lightening-hole flanges is shown in Fig. 13-7. These flanges are usually formed from prepunched blanks without the aid of pressure-increasing devices.

The *J* flange is another type of stiffener around a lightening hole. This flange is formed in two operations. The first uses regular rubber forming which provides enough impression to locate an insert (Fig. 13-8). In the second operation, this insert accumulates the rubber pressure exerted on the whole area of the top surface of the insert and bridges it over so that this total pressure forces the flange into its final position.

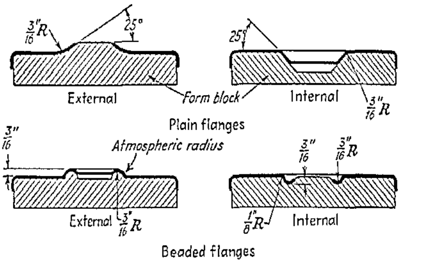


FIG. 13-7. Rubber-formed lightening-hole flanges.[5]

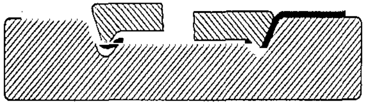


FIG. 13-8. Forming J flanges.[1]

RUBBER-FORMED SHRINK FLANGES

Many rubber-formed parts contain shrink flanges; however, they can be accurately produced only within narrow limits. A shrink flange on a part that was rubber-formed without any auxiliary mechanical device will tend to exhibit wrinkles. The extent of this wrinkling depends upon the intended shrink which increases with increasing flange width, increasing bend angle, decreasing contour radius and, up to a certain limit, increasing flange length. These wrinkles, if in soft metal and not too deep, can be worked out by hand.

To eliminate excessive shrinking at corners, a corner cutout entirely removes the otherwise severely shrunk flange corner. Flutes are often used as a means of controlling the wrinkles. Figure 13-9 shows a part which has flutes and its form block.

A part with a shrink flange having a large contoured radius is shown in Fig. 13-10. This part has a stretch flange which is formed in the first operation. The part is then placed on the second-operation form block with the cover plate to protect the already formed flange. The positioning of the two blocks on its base plate provides a trap which increases the pressure the rubber exerts on the blank, and aids in forming the short return bend on the shrink flange.

Parts that contain both stretch flanges and shrink flanges can be accurately formed by a special two-operation procedure termed "slip" forming. A part with both types of flanges and an extended shallow recess is shown in Fig. 13-11. To avoid distortion to the web, the recesses are formed first in the flat. Recesses near the stretch flanges were placed very close to these to allow some draw-in of the metal from the periphery. Recesses close to the shrink flanges are prevented from drawing metal from the periphery by a suitably shaped pressure pad. The flanges are turned over in the usual manner by a second form block. The edges of the blank in the area of the shrink flange are notched to aid in the shrinking.

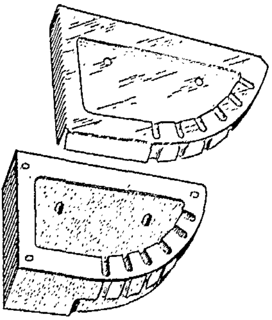


FIG. 13-9. Part with fluted shrink flange and its form block.

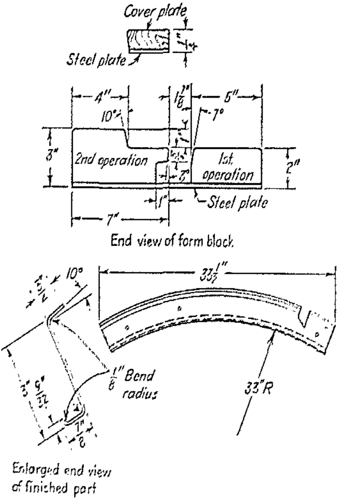


FIG. 13-10. A large-radius shrink-flange part.

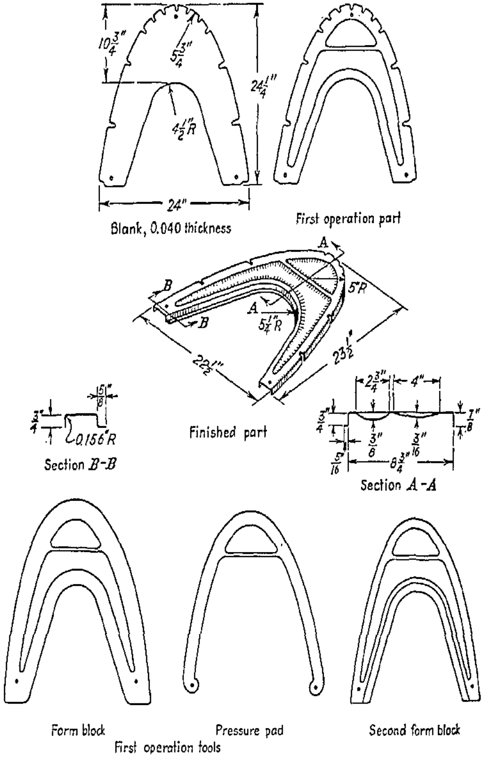


Fig. 13-11. An embossed part with shrink flanges and stretch flanges.

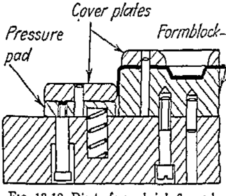


Fig. 13-12. Die to form shrink flange.[1]

A mechanical means of forming shrink flanges is shown in Fig. 13-12. The blank is placed on the form block and pressure pad; then cover plates are placed over the blank. The cover plate on the pressure pad acts as a floating draw ring as the rubber die descends.

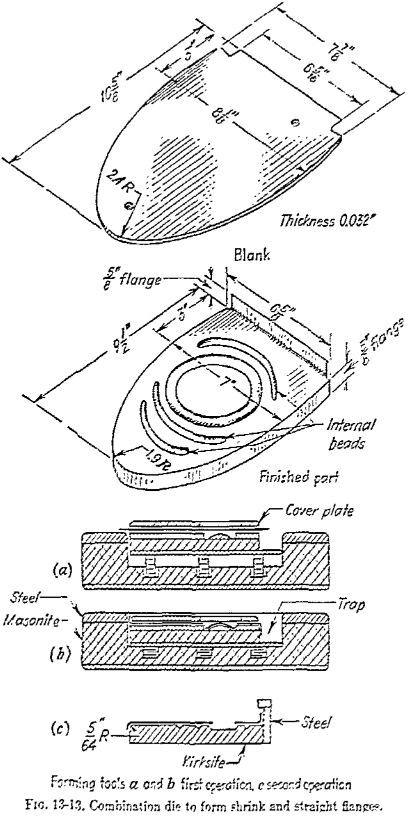


FIG. 13-13. Combination die to form shrink and straight flanges.

The use of a female form block and a spring-loaded male pressure pad is shown in Fig. 13-13. The cover plate aids the rubber to act as a punch. As the ram descends, the blank is drawn into the die, forming the shrink flange without wrinkling. The straight flange across the end is formed downward in the die with the aid of the trap. The first operation also blanks a hole in the web. The second-operation form block flanges the lightening hole and forms the internal beads.

DRAWING OF SHALLOW PARTS

The rubber-die process may also be used to draw shallow recessed parts. To prevent the flanges from wrinkling, the metal must be held firmly yet be allowed to move in the same manner as drawing in a mechanical press. The flange portion of the metal can be lubricated with paraffin or pressure-relieved by means of an undercut protecting block.

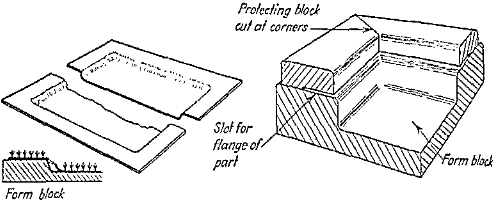


FIG. 13-14. Design of form block to relieve pressure on wide flanges.[1]

The part shown in Fig. 13-14 is a typical draw by the rubber-pad method. Without a lubricant or pressure-relieving block, the rubber locked the metal to the form block, causing the metal to crack almost continuously in the radius on all four sides of the pan. This was because the amount of metal required to fill the radius was greater than the amount of material allowed to flow, plus the elongation of the material. The undercut-protecting block allows the material to flow without wrinkling. Careful design of this block is essential. When the base is increased at the expense of the undercut, the rubber exerts more pressure to hold the protecting block firmly against the form block, and less pressure to hold the protecting block firmly against the flange of the blank. When the undercut is increased at the expense of the base, the opposite is true and more pressure is exerted against the flange of the blank. The height of the undercut is also important and should be 0.003 to 0.006 in. greater than the thickness of the metal blank.

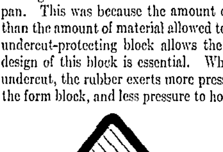


FIG. 13-15. Bending with external pressure vs. internal pressure.

When designing tools for rubber forming, it should be remembered that parts can be formed by external pressure that cannot be formed satisfactorily by internal pressure; *i.e.*, forming should take place over a projection rather than into a recess. For example, in Fig. 13-15 where a shape is to bend through a 90° bend, if external pressure is applied with a form block as shown at *A*, relatively little pressure would be required, because of the even distribution of the load, and a close fit will be obtained at the apex, irrespective of how large or small the radius may be at that point. It may not be possible to obtain a sharp corner at *B* with the internal form, because of the localized pressure and the locking of the metal to the flat surface of the form block by the rubber.

BLANKING WITH A RUBBER DIE

Blanking in rubber produces an edge that is better than obtained by band sawing and almost as good as that obtained by routing. Since blanking requires higher pressures than forming, the thickness of stock possible to blank depends upon the unit stress exerted by the rubber die. The rubber die is capable of blanking up to 0.032-in. 24S0 aluminum without difficulty, and in some cases up to 0.040-in. stock. Long curves and straight sides are easily blanked; also cutouts and reverse curves, if not too small, can be made. The minimum hole diameter or width of cutout possible is about 2 in.

The usual amount of metal wasted in rubber-die blanking is greater than for conventional steel blanking dies. A minimum edge distance of about 1½ in. is required between the edge of the cutout and the edge of the part or sheet. When cutting several blanks from a large sheet, the blocks should be spaced about 3 in. apart to ensure a good blanked edge.

To shear a blank or to trim a part, the form block is provided with sharp cutting edges. The sharp cutting edge required can be machined onto most of the metal form blocks, but the nonmetallic blocks require steel inserts at the cutting edge. Figure 13-16 illustrates the use of a bead as a locking ring around the blanking die to create a recess and to localize the pressure of the rubber at the cutting edge. The lock ring also prevents slippage of the workpiece before it is cut. The upper view shows the blank in place on the block, and the lower view shows the shape of the stock before the fracture occurs.

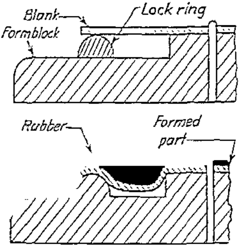


FIG. 13-16. Shearing (trimming) a rubber-formed part.[2]

When blanking the heavier-gage metals with a rubber die, an edge radius up to the thickness of material can be obtained. A grip plate shown in Fig. 13-17 provides two places to grip the material: on the grip plate and on the die. Between these two points is an unsupported section which is subject to the pressure of the rubber. Before the stock has had time to rupture at the cutting edge, the material has been drawn down over the cutting edge, giving the large radius peculiar to rubber-die blanking of thicker stock.

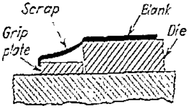


FIG. 13-17. Rubber blanking with grip plate.

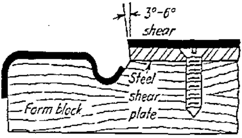


FIG. 13-18. Combination blanking and forming die.

The relationship of the height of the die to the grip plate has little effect on the edge radius but may have some effect on the pressure required to fracture the material. The grip plate should be about ½ in. wide and ¼ in. thick. It is not necessary to follow the intricate details of the contour of the die block. Pins for locating the blank on the die block should be used if possible. The die block may be positioned on the base plate by loosely fitting dowel pins so that other blocks may be used with the same base plate. Fastening the die block to the base plate is not necessary.

Combination Rubber-pad Dies. *Combination rubber-pad* blanking and forming dies are frequently used for lightening holes (Fig. 13-18). A preshaped blank is placed on the form block, which has a cutting edge for the cutouts, and is positioned by locating pins. As the rubber die descends, the center portion of the lightening hole is cut out, and the bead around the hole is formed at the same time as the flanges on the outside contour. Cover plates should be used where necessary to avoid distortion of the web.

Combination dies are frequently used on parts similar to the one shown in Fig. 13-11 for cutting the inside contour to avoid handling flimsy blanks.

DEEP DRAWING WITH RUBBER-PAD PROCESS

Methods have been developed for deep-drawing shells using the inexpensive tools possible with the rubber-pad process. The parts produced are comparable in quality with those produced in all-metal dies.

The Marform process and the Hidraw process employ a deep rubber pad on the ram of the press with a stationary punch on the bed of the press. A blankholder plate actuated by a specially controlled die cushion controls the pressure on the blank as it is drawn around the punch.

The descending platen automatically slows down as the pad contacts the blank to prevent deforming the work. As the platen continues to descend, pressure is generated in the rubber pad, which grips the blank between its face and the blankholder plate. The rubber acts as a fluid pressure, forcing the blank over the punch so that it

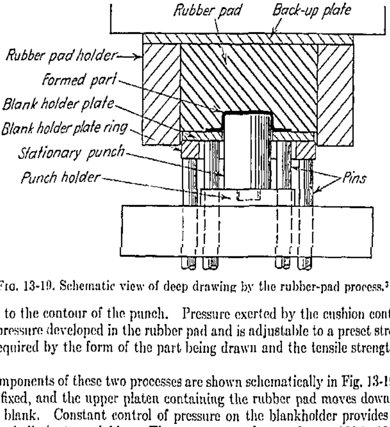


FIG. 13-19. Schematic view of deep drawing by the rubber-pad process.[3]

conforms to the contour of the punch. Pressure exerted by the cushion controls the forming pressure developed in the rubber pad and is adjustable to a preset stroke pattern as required by the form of the part being drawn and the tensile strength of the metal.

The components of these two processes are shown schematically in Fig. 13-19. The punch is fixed, and the upper platen containing the rubber pad moves downward to meet the blank. Constant control of pressure on the blankholder provides smooth forming and eliminates wrinkles. The pressures used range from 5,000 to 15,000 psi. The blankholder plate has about $\frac{1}{16}$-in. clearance between it and the rubber-pad holder to prevent the rubber from squeezing out of the holder.

The rubber-pad process of deep drawing usually allows a greater reduction percentage than by conventional drawing dies. It is apparent that, when one side of the material is gripped by the rubber and the other side by the steel blankholder, work hardening does not take place so rapidly as when the material is gripped and drawn between the two hard surfaces of a steel die. Thus the material will flow more readily, permitting the use of a larger blank. The variable draw radii in a rubber pad permit the material to draw more easily than the fixed radii of a steel die.

The maximum blank size for aluminum and steel cups drawn by the rubber-pad process may be found by multiplying the punch diameter by 2.34.

In the forming of square or rectangular-shaped boxes, it is not necessary to use a developed pattern; in fact, some tests have shown that best results are obtained by using a sheared blank the same shape as the box. The blanks must always be large enough to allow for trimming, since a portion of the draw radius is left on the end of the box or shell. The rubber is not able to straighten this out, as is done by a steel die.

The minimum corner radii for square and rectangular boxes drawn from the softer aluminum alloys and deep-drawing quality steel are normally not less than 25 per cent of the box width. The safe depth of draw for the same materials ranges from 75 to 100 per cent of the width.

The forming or draw radius is affected by the blank size, depth of draw, the material and its thickness, the flange left on the part after forming and the shape of the finished part. For a round cup, the radius is smaller when the final flange is narrow. In drawing square or rectangular-shaped boxes, the forming radius at the corners will be larger than along the straight sides.

The minimum flange radii for round cups and at the corners of square or rectangular boxes vary according to the hardness of the metal. For the aluminum alloys 2SO and 3SO, the radius is about 1½ times metal thickness; for 52SO and 61SO it is 2t; for 24SO and 75SO it is 3t. When the stock is deep-drawing steel, 4t should be the minimum radius.

When the parts being made require a sharper radius than is practical to produce by rubber forming, a restrike operation is necessary using a plate with the required radius.

The punch-nose radius depends upon the material, its thickness, and the ratio of the depth of draw to the diameter of the cup. The deeper the draw with reference to the diameter, the larger punch-nose radius required to prevent fracture of the part. The safe radius relative to material thickness for the softer aluminum alloys ranges from 1t to 4t for depth-to-diameter ratios ranging from 1:4 to 1:1, respectively. For steel the radius is 0.5t for the 1:4 depth-to-diameter ratio, and 2t for a ratio of 1:1.

According to tests made at 5,000 psi in forming cups from the softer aluminum alloys with a minimum diameter of 1½ in., the minimum stock thickness should be approximately 1 per cent of the cup diameter to obtain the maximum depth of draw. A minimum stock thickness of 0.015 in. is recommended for cups smaller than 1½ in. in diameter.

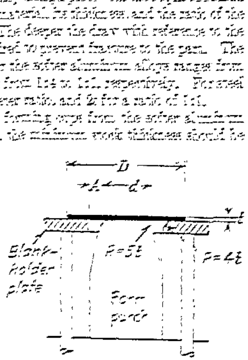


FIG. 12-20. Forming of tapered cups by the rubber-pad process is possible by proper design of punch and blankholder plate.

In the forming of tapered shapes, there is a limitation as to the size of the gap A (Fig. 12-20) between the top of the punch and the edge of the blankholder. If the metal is thin and the gap too large, the rubber pad will tend to shear the metal in the gap that is not supported by the punch or pressure plate. The maximum gap A varies as a percentage of the punch diameter d varies for different thicknesses of aluminum and steel. This percentage of punch diameter varies from 7½ to 30 per cent for 0.025- to 0.125-in.-thick aluminum alloys, and 15 to 55 per cent for similar thicknesses of deep-drawing steel. The percentages increase proportionally as the stock thicknesses increase.

When the maximum gaps shown are used, the depth of draw for the softer aluminums is equal to the punch diameter and about 75 per cent of the punch diameter for the harder aluminums and SAE 1010 deep-drawing steel. The values have been determined by using 5,000 psi, but it is apparent that deeper draws could be made at higher pressures.

HYDRAULIC-ACTION DIES

In the deep-drawing process called "Hydroforming" (Fig. 12-21), the ram is specially designed to act as a forming medium. This is accomplished by hydraulic fluid contained in a cavity in the ram, which exerts pressure on a rubber diaphragm. The forming tools consist of a punch machined to the required shape, and a pressure pad with a hole which closely matches the shape of the punch. The pressure pad is built up and is clamped on the bolster which is fastened to the press bed. The punch is fastened to a hydraulic-cylinder assembly located under the bed of the press. The top of the punch in the lowered position is flush with the top of the pressure pad.

The ram is lowered to clamp the metal blank between the rubber pad on the ram and the pressure pad. Hydraulic pressure is then exerted against the diaphragm to prevent *wrinkling of the metal during the forming operation. The punch moves* upward

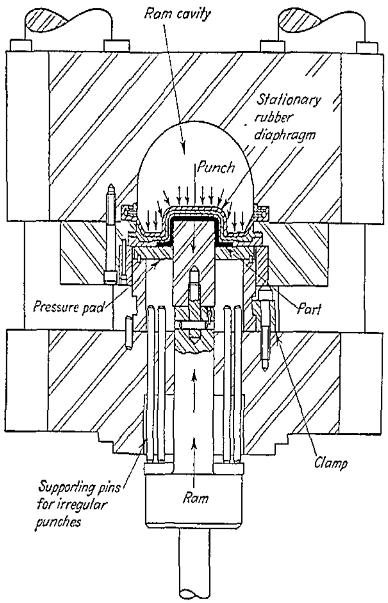


FIG. 13-21. The Cincinnati Hydroform process.[4]

causing the metal to flow around it and, as forming progresses, the compression of the fluid in the dome cavity causes higher forming pressures to develop against the top, radius area, and side walls of the formed part. The deep-drawing operations are carried out under pressures ranging from 5,000 to 15,000 psi.

When deep drawing with the hydraulic-action processes, the rubber diaphragm has a tendency to clamp the part as it is formed to the punch surfaces, thus preventing further stretching or straining of these formed areas, and at the same time causing the metal to flow in around the punch. Hydraulic-action forming also has a variable draw radius, and the high local strains introduced in the initial phase of the forming operation are minimized by the ability of the rubber pad to change its radius to suit the forming cycle. With the lower pressures at the beginning of the cycle, the draw radius is large, and it decreases as the forming pressure increases. The rubber pad does not produce any marks or scratches on the outer surface of the shell as a metal draw ring sometimes does.

The Wheelon forming process uses a method of applying direct hydraulic pressure to the rubber forming pad. The blanks are placed over simple male dies, similar to those used in the Guerin process, positioned in the press frame, and forming pressure is applied by hydraulically inflating a rubber bladder mounted in the immovable roof of the press. Figure 12-22 shows a cross section of the press frame with a die and blank in place, with the rubber bladder in the released and the forming positions. This

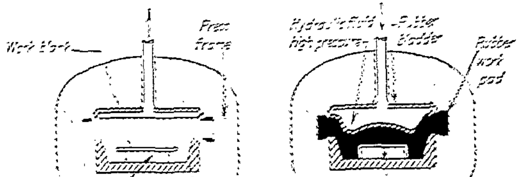


FIG. 12-22. The Wheelon forming process. (Verson Allsteel Press Co.)

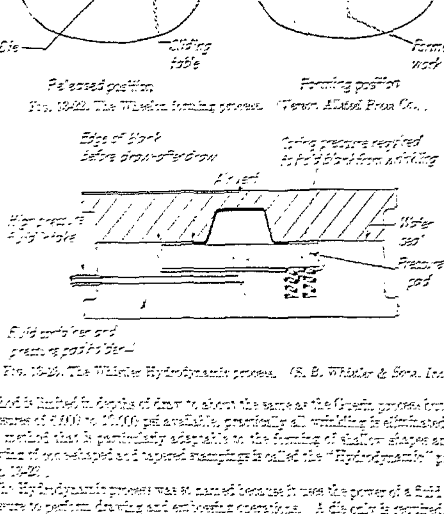


FIG. 12-23. The Wheeler Hydrodynamic process. (S. B. Whistler & Sons, Inc.)

method is limited in depths of draw to about the same as the Guerin process but, with pressures of 5000 to 10,000 psi available, practically all wrinkling is eliminated.

A method that is particularly adaptable to the forming of shallow shapes and the drawing of odd-shaped and tapered stampings is called the "Hydrodynamic" process (Fig. 12-23).

The Hydrodynamic process was so named because it uses the power of a fluid under pressure to perform drawing and embossing operations. A die only is required, since the fluid under high pressure is substituted for the punch. A predetermined size of blank is placed on the top face of the spring-loaded pressure pad, nested between spring-pin gages. The container, pressure pad, and blank are then raised by the hydraulic ram, until the underside of the die comes in contact with the top face of the container. High-pressure fluid is then admitted through the intake opening in the container. The fluid is forced up through the hole in the center of the pressure pad and acts as a fluid punch, exerting a uniform pressure over the entire surface of the blank, thus forming it to the desired shape. Air-vent holes are provided in the cavity of the die to permit the air to escape from the die cavity as the part is formed. Parts of tapered or conical shapes can be drawn in one operation by this method, whereas two or three operations are necessary by the conventional die methods.

References

1. Schulze, R. B.: "Aluminum and Magnesium Design and Fabrication," McGraw-Hill Book Company, Inc., New York, 1949.
2. Sachs, G.: "Principles and Methods of Sheet-metal Fabricating," Reinhold Publishing Corporation, New York, 1951.
3. Stocker, W. M., Jr.: Controlled Pressure Aids Deep Drawing, *Am. Machinist*, Dec. 10, 1951.
4. Lewis, G. B., and J. S. Corral: Hydroforming Aircraft Parts at North American, *Machinery*, October, 1951.
5. "Forming of Austenitic Chromium-nickel Stainless Steels," The International Nickel Co., Inc., 1948.

SECTION 14

COMPRESSION DIES*

Compression or squeezing dies change the form of a metal slug or blank by plastically deforming it through the directed application of compressive forces. Metal so strained by compressive stresses behaves like a viscous liquid; for practical purposes it is incompressible, so that a lessened volume in one direction will result if a volume is expanded in another direction. Very small increases or decreases occur in the total volume of the compressed metal depending upon its temperature, kind, and condition as well as the amount of applied force. The applied force, or total pressure needed for a successful compression operation, depends upon the area to be squeezed, the extent and speed of the squeeze, and the freedom of flow of the metal. It is therefore difficult to compute working pressures. Pressures needed (psi for a given area) for coining can amount to five times the compressive strength of metal or up to 3,000 times the Brinell hardness of the metal.

The nomograph (Fig. 14-1) may be used as an aid in estimating compression-die pressures. It is based primarily upon theoretical yield points and does not take into account degrees of restriction in metal flow (dependent on part and die contours), nor does it include allowances for resistance to flow due to strain hardening. Any given metal does not have a yield point that is fixed. The nomograph is used as follows:

Given: An area of 5 sq in. of yellow brass, having a theoretical yield point of 40,000 psi.

Connect point 5 on the A scale and point 40,000 on the S scale with a straight line, intersecting P scale, giving an approximate value of 100 tons for the press capacity required.

CLASSIFICATION OF COMPRESSION DIES

Compression operations on metals may be divided into four general classifications, according to the relative total amounts of all resistances to metal flow:

1. The sizing, or the flattening and smoothing, of areas of forgings, castings, and stampings by squeezing the metal to a desired dimension. There is little if any restriction to metal flow, and the volume of metal moved is relatively small compared with this volume of the workpiece.

2. Swaging (swedging) is somewhat more severe than sizing, since the shape of the blank or slug is considerably altered as part of it flows into the contours of the die; the remaining metal is unconfined and flows generally at an angle to the direction of applied force. Compared to sizing, there is greater restriction to metal flow, although more metal is moved, as in such operations as the swaging of small gears, cams, or other small parts of irregular contour. The upsetting of heads on bolts and many cold- and hot-forging operations are classified as swaging operations.

3. Coining operations usually force metal to flow within a die, but not out from it, so that all work surfaces are confined. The distances through which the metal flows are comparatively short, but most or all of the metal flows to form new surface contours, thus necessitating high pressures. Embossing of sharply defined, but relatively shallow, indented or raised letters, lines, or designs in thin metals with theoretically

* Reviewed by R. J. Wilson, Executive Engineer, Motor Wheel Corporation.

no change in metal thickness may require only moderate pressures; this is classified as a type of coining.

4. *Extruding* operations compress and force metal to flow plastically through a die orifice, generally into a continuous length of uniform cross section.

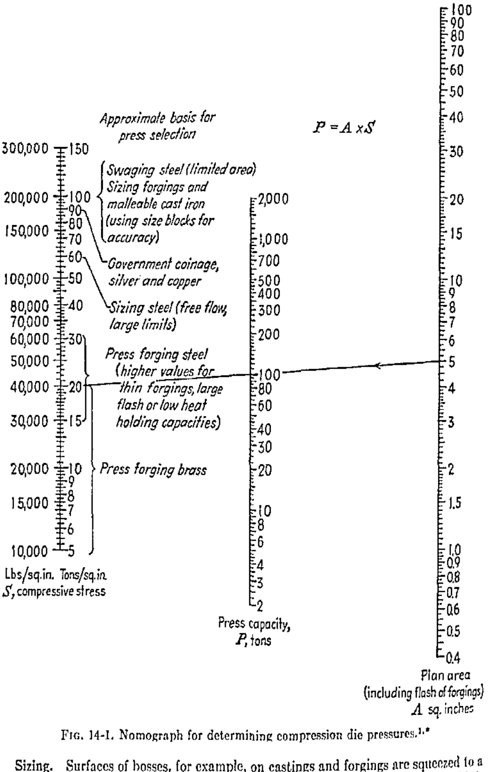


FIG. 14-1. Nomograph for determining compression die pressures.[1,*]

Sizing. Surfaces of bosses, for example, on castings and forgings are squeezed to a dimensional tolerance as close as plus or minus 0.001 in.[10,*] The *resulting finish* is comparable to a milled surface; excessive squeezing reduces surface quality.

Figure 14-2 shows a typical operation in which a casting or forging is compressed to size. The thickness to which the part is compressed is controlled by the depth of the die cavity or stop blocks placed in the die.

* Superior numbers relate to References at the end of this section.

Blanked parts such as the one shown in Fig. 14-3 are placed in compression dies to flatten certain areas to size. Steps machined in the surface of the die produced the 0.004-in. offsets in the surface of the part.

Swaging. A gear-swaging die is shown in Fig. 14-4 with the part produced in the die. The flange integral with the gear is trimmed to size in a later die. To produce this part, the blank is placed over the locating pin, and the press is tripped. The

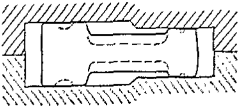


FIG. 14-2. Typical sizing die operation.[1]

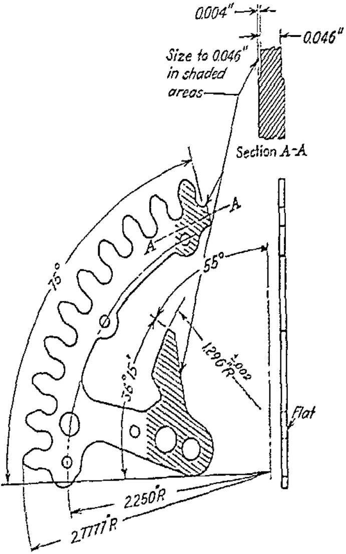


FIG. 14-3. A gear segment with portions of the surface flattened and sized in a die. (*National Cash Register Co.*)

punch or swaging block forces the metal to flow and fill the cavities or tooth spaces in the die. The ejector block is carefully machined to conform to the outline of the die cavity and to such a height as is required by the thickness of the gear. The press is set so that the punch bottoms hard against the die to produce uniform parts. The size of the blank in this case is not critical as long as it contains sufficient metal to produce the part, since the cavity in the punch is large enough to allow free flow of all surplus metal. A positive mechanism for ejection is built into this die, although any method of positive delayed-action ejection may be used.

Die for Swaging Type Segment. A die for swaging the bevel and two welding projections on a printing group-type segment reinforcing plate is shown in Fig. 14-5. The preblanked segment is placed in the die and, as the slide descends, the bevel and welding projections are swaged into the part. For ease of manufacture, the die is

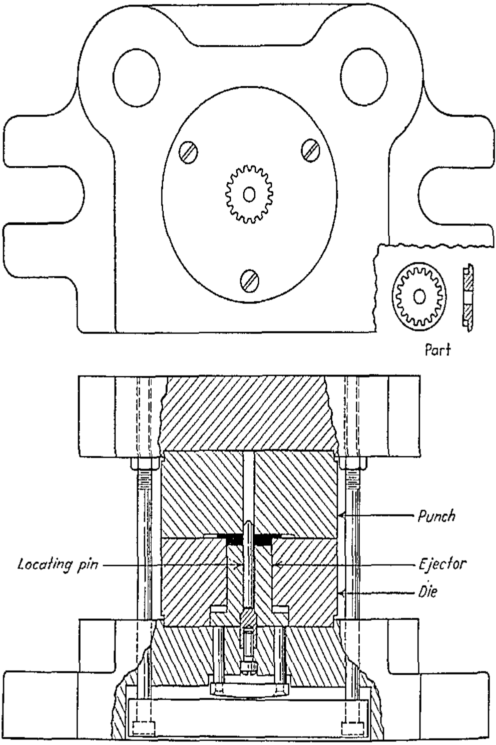


FIG. 14-4. Die to swage a gear with integral flange.[2]

made in sections. The impression is machined into the insert (*D*1)* which is set into the main die block (*D*2). This block is stepped to serve as a part locator. End stops (*D*3) are also fastened to the main die block. The hand-operated ejecting lever (*D*4) lifts the pin (*D*5) to eject the segment from the die cavity.

* *D* indicates detail number on drawing.

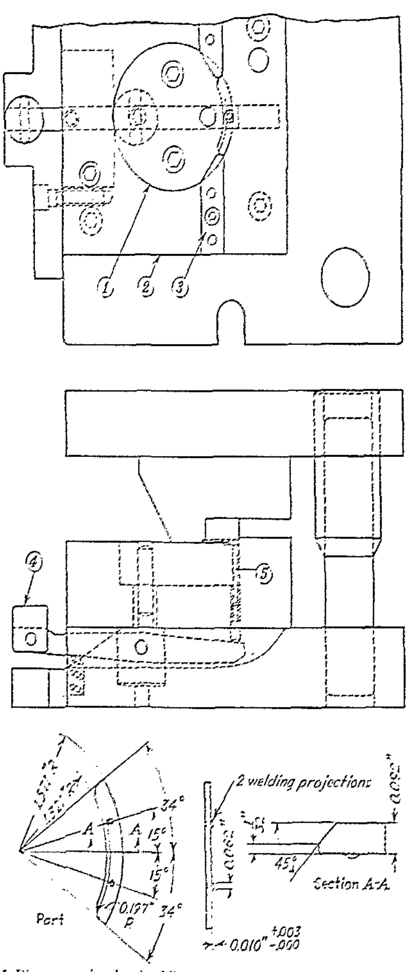


FIG. 14-5. Die to swage bevel and welding projections on a type segment. (National Cash Register Co.)

Part Swaged from Screw-machine Blank. A part which has been swaged on both sides is shown in Fig. 14-6. The blank at view *A* was prepared in a lathe or screw machine. The outline produced by the first swage operation is shown at view *B*. The plastic flow of the metal deformed the OD of the blank to some extent. The part was next semiturned in an automatic lathe to prepare a blank to be finish-swaged as shown at view *C*. This operation formed the gear teeth to shape, with the excess material flowing out into a scalloped outline as shown. To ensure integrally complete

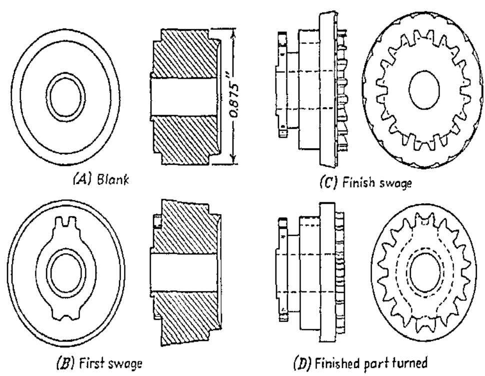
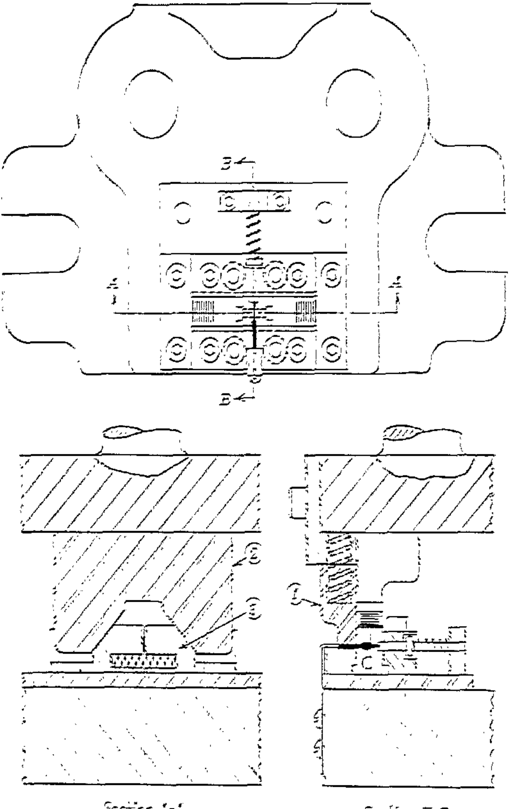


FIG. 14-6. A mild-steel part produced from a screw-machine blank in two swaging operations. (*Pitney-Bowes, Inc.*)

teeth on the gear, the blank was made with a rim on the outer edge higher than in the center, as shown by the sketch of the blank. After the final swage operation, the part was returned to the automatic lathe for finish turning and facing of the gear as shown at *D*.

Cam-operated Swaging Die. A cam-operated swaging die for a phonograph needle is shown in Fig. 14-7. A needle which has been cut to length and pointed is placed in this die to swage the flat area. The needle is held in the die by the spring-loaded hold-down (*D*1), while the cam (*D*2) forces the sliding swaging dies (*D*3) to close.

Universal Swaging Die. A universal die for swaging both sides of a blank in one operation is shown in Fig. 14-8. The die holders (*D*1) are identical so that the die inserts (*D*7) and (*D*8) may be interchanged between the upper and lower positions. The die-insert shedders (*D*2 and *D*3) are actuated by positive knockouts to ensure positive ejection. The blank is positioned in the die by the spring-loaded pin (*D*4) which is retracted by the fixed pin (*D*5) as the die closes.



Section A-A   Section B-B

Fig. 247. Double swaging die for a phonograph needle. (Hardy Mfg. Corp.

Timing of part ejection from the lower die can be adjusted to suit the part thickness by the threaded adapters (*D6*) in the upper shoe.

Swage Die for Dado Blade. The swaging of 0.125- or 0.250-in.-thick dado blades is accomplished in the die shown in Fig. 14-9. A 0.125-in.-thick spacer (*D1*) is removed from the die when swaging the 0.250-in.-thick blade. The sliding block (*D2*) is actu-

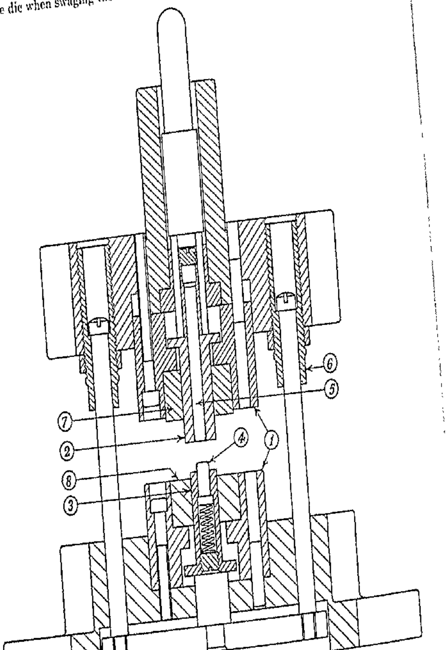


FIG. 14-8. Universal swaging die. (*Pitney-Bowes, Inc.*)

ated by the cam (*D3*) to clamp the blade in the vertical position. The spring-actuated plungers (*D4* and *D5*) position the blade endwise and hold it down in the die.

The fixed die blocks (*D6* and *D7*) support the swaging punch (*D8*) during the operation. These blocks are recessed into a mounting plate, and this assembly is recessed into the lower die shoe. Safety stops prevent overtravel of the die. Alignment of the upper and lower shoes is maintained by two guide posts engaging long, shouldered guide bushings. The part is turned end for end in the die for swaging the second surface.

Swaging and Coining Type Bar. The single-piece type bar shown in Fig. 14-10*A* is made in five operations. The blank is produced from strip stock in a conventional blanking die in the first operation. The notched section of the blank is the area in which the characters are formed and required considerable experimentation to develop.

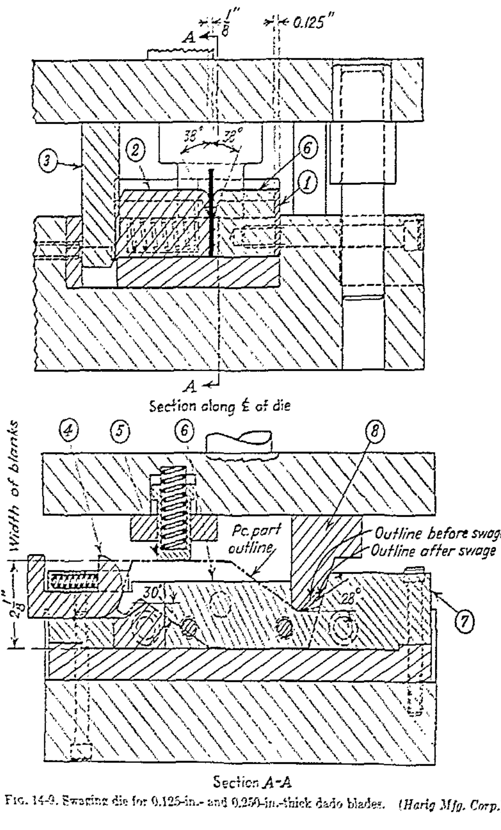


FIG. 14-9. Swaging die for 0.125-in.- and 0.250-in.-thick dado blades. (*Harig Mfg. Corp.*)

The blank is 0.050 in. thick, and the swaged surface upon which the 0.021-in.-high characters are coined is trimmed to 0.124 in. wide.

The operation is performed in a split die using a spring-loaded wedge cam to actuate the sliding block shown in Fig. 14-10*B*.

In order to obtain sharp characters of uniform contour, the first operation coins the characters with an included angle of 67° and a height of 0.031 in., and the second coining operation produces characters with an included angle of 82° and 0.021 in. high. This required a set of readily interchangeable punches. The type bars are also made with several different character combinations requiring interchangeable punches.

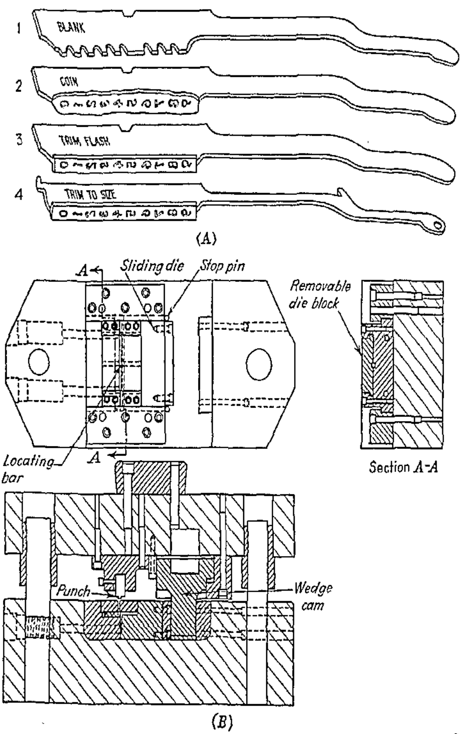


FIG. 14-10. Swage and coin die for single-piece type bar. (*Monroe Calculating Machine Co.*)

Swaging Die for a Cup. The operations required to produce a cup are shown in Fig. 14-11,*A*. The swaging die for making the flared cup from a flat blank is shown in Fig. 14-11,*B*. The washer-type blank is placed over the spring-loaded pilot (*D1*). The punch (*D2*) is used to size the center hole while the die (*D3*) is swaging the flange to shape and thickness around the punch (*D4*). The knockout sleeve (*D5*) bottoms *in the upper die at the end of the downstroke to flatten the bottom of the cup.* The ironing of the side wall of this part is described in Sec. 17 and the coining of the bottom later in this section.

Dies for Producing Generator Pole Shoe. The group of dies shown in Fig. 14-12 produces the part as shown. It is first bent from a flat blank. In the bending of the

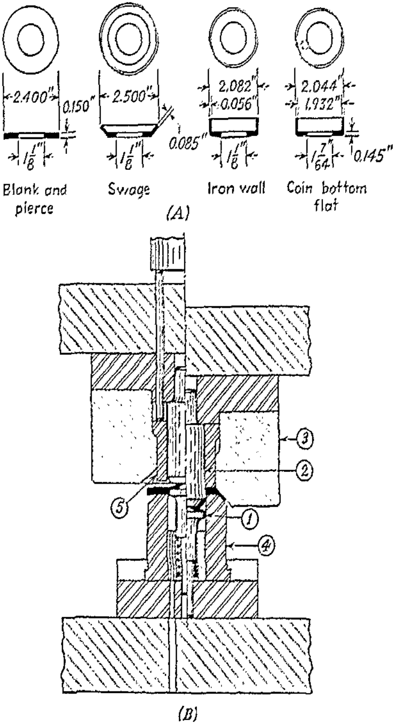


FIG. 14-11. Part development and swaging die for thin-walled part. *(Coinez, Inc.)*

part, depressions were produced at the junction of the wings and body by concentrated pressures.

The final operations were: (1) prebend the blank (view *A*); (2) pierce and countersink one side of the screw hole; (3) swage the wings surrounding the body of the part (view *B*); (4) coin the center section to thickness (view *C*); and (5) drill and tap the pierced hole.

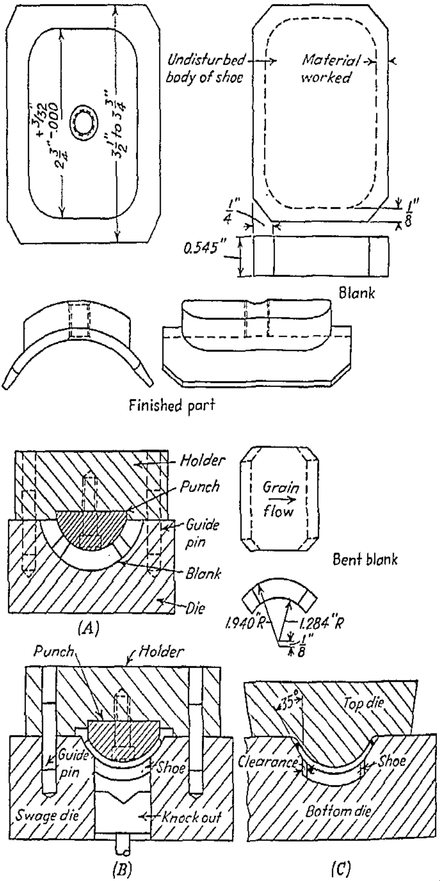


FIG. 14-12. Dies for producing generator pole shoe: (*A*) preform blank; (*B*) swage wings; (*C*) coin center section to thickness. (*Delco-Remy Division, General Motors Corp.*)

COINING

Coining is a very severe pressworking operation, since the flow of the metal is entirely confined in the die cavity. Portions of a blank or workpiece may be coined: corners of previously formed or drawn cups may be built up or filled in, or indented or raised sections of a blank may be formed by coining dies.

Die to Coin Indent. The die to coin the indent in the bottom of a cup (Fig. 14-11A) is shown in Fig. 14-13.

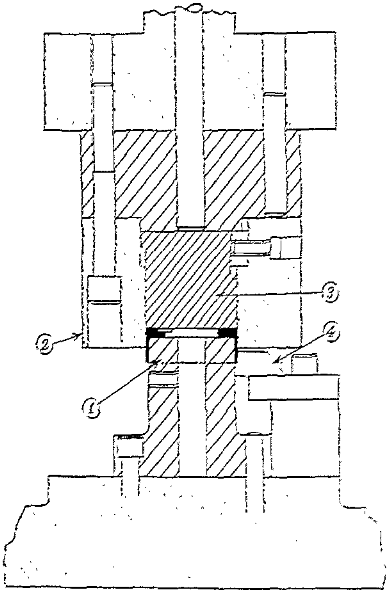


Fig. 14-13. Die to coin indentations in bottom of a cup. (Coinex, Inc.)

The part is placed on the post (D1), and the coined area is confined by the die ring (D2), while the coining punch (D3) indents the bottom of the cup. The coining punch is designed to slide up and down inside the die ring and is actuated by the positive knockout bar to eject the part from the die. The locator D4 properly positions the part in a previously cut notch. The parts of this die are made of oil-hardening tool steel mounted on a standard two-post die set.

Die to Coin Serrations. The coining of serrations on both sides of a 0.060-in.-thick part is shown in Fig. 14-14. The serrating dies are inserted in hardened-steel plates. A nest on the lower die locates the part accurately while it is being serrated. The depth of the serrations is controlled by two safety stop blocks. To assist in the removal of the part after the operations, a small pick-off slot is machined in the lower

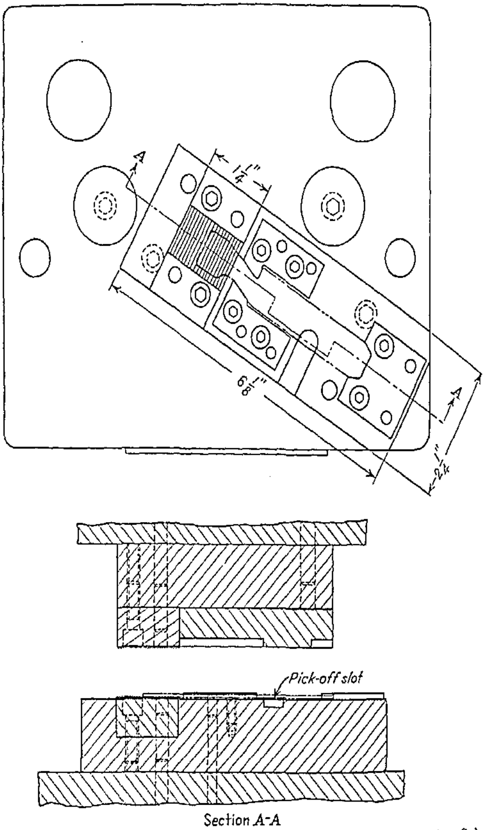


Fig. 14-14. Die to coin serrations on both sides of a part. (*National Cash Register Co.*)

die block. The insert mounting block on the upper shoe is modified to the contour of the part to clear the nesting plates which are thicker than the part.

Coining Serrations in Two Operations. The part shown in Fig. 14-15 has the serrations coined in two operations. The first coining die shown upsets the rim of the segment and forms the crowned section. This area is serrated in a succeeding coining die.

The die is made in three pieces inserted into the lower die shoe. The center section is movable in order to eject the workpiece from the die. The die for coining the serrations is of similar construction, the punch being so designed as to coin proper-shaped serrations.

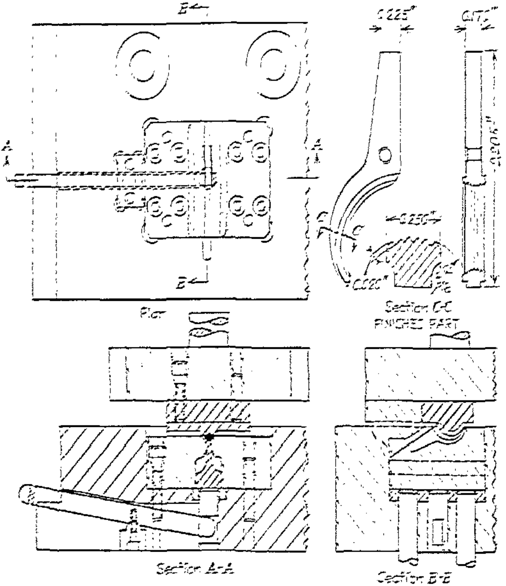


Fig. 14-15. Part coined in two operations and the first-operation coining die. (Borth Corp.)

Coining Die for Pipe Union. The die for coining a part of a pipe union is shown in Fig. 14-16. The preliminary operations produce the sleeve, which is placed in this die, from 0.343-in.-thick and 6 1/4-in.-wide hot-rolled, pickled, and annealed SAE 1008 stock. The 440-ton coining pressure required to produce this part calls for a heavily constructed die.

The left-hand portion of the illustration shows the die open, with the ejector in the "up" position and a blank in place. The closing of the die allows the ejector ring to slide down, forming part of the cavity into which the metal in the blank is forced to flow. The right-hand portion shows the die closed with the part formed. The heavy ring surrounding the die on the lower shoe also acts to confine the portion of the die

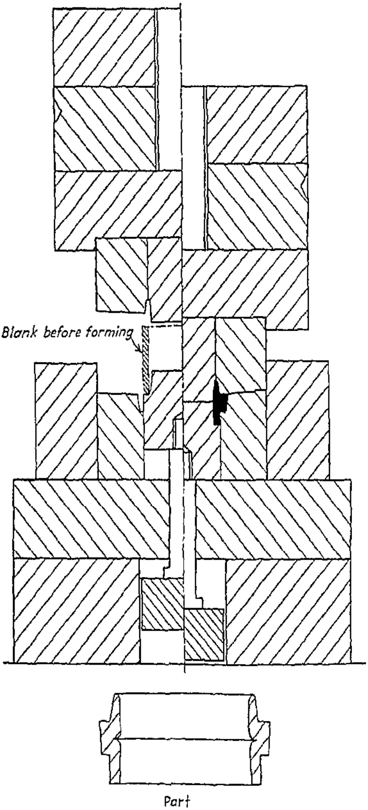


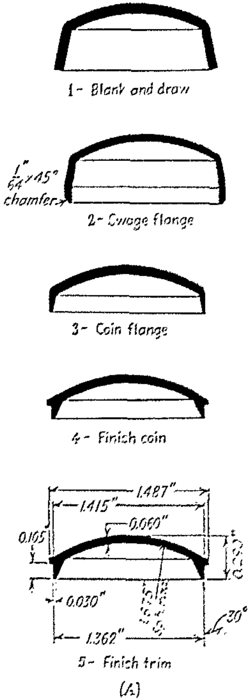
FIG. 14-16. Die for coining part for a pipe union. (*Worcester Pressed Steel Co.*)

attached to the upper shoe, preventing its expansion during the operation and producing out-of-tolerance parts.

Die for Coining an Expansion Disk. The part shown in Fig. 14-17, view *A*, prior to being fabricated in dies, had been produced as a screw-machine part at a very high cost and with considerable difficulty.

The first operation is a conventional combination blanking and drawing operation. The second, a swaging operation, reshapes the flange and puts a small chamfer around the outside edge to help prevent a fin from forming in the following operation. Operation 3 coins the part to fill out the corner and to produce the initial taper on the inside of the flange. The die for this operation is shown in view *B*. The forming punch (*D1*) is recessed into the lower die shoe. The forming ring (*D2*) coins the metal into the contour of the punch, and the knockout (*D3*) bottoms at the end of the stroke against a hardened plate inserted in the upper shoe to form the top of the part.

In the final coining die shown at view *C* (operation 4), the flange is produced as well as coining the other dimensions to size in the confined die space. The die cavity is made in two pieces with the center part (*D4*) acting also as an ejector.



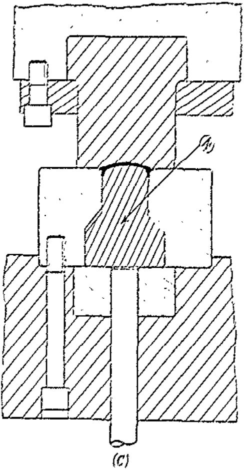


FIG. 14-17A. View *A*, coined cup produced in die of Fig. 14-17*B*; view *C*, final coining die.

The top flange is made oversize in this die to ensure a fully formed part, and this excess material is removed in a trimming die.

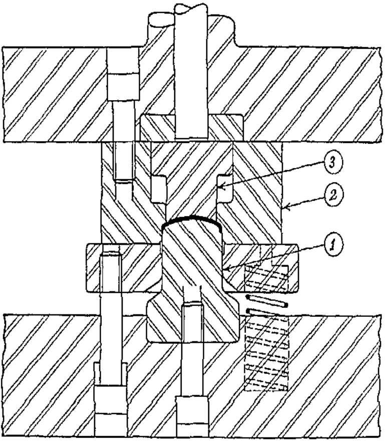
The part is made of 0.053/0.057-in.-thick cold-rolled steel annealed to Rockwell B70.

Embossing. An embossing die forms raised letters, areas, or designs in relief on the surface of sheet-metal parts. Embossing differs from forming in that the designs are comparatively small or shallow, and usually in the nature of relief work upon a surface.

Embossing differs from coining in that the latter usually has different designs on each side of the part. An embossment has the same design on both sides, one being the reverse of the other; *i.e.*, one side has the depressed design and the other side the raised design.

There is a local stretching and compressing of the metal in all embossing operations; the amount depends upon the design and how much it extends above or below the surface.

Dies to Emboss Bowl of a Coffeepot. The forming of four small rectangular, one larger rectangular, and one circular embossment in the bottom of a shell is done in the die in Fig. 14-18. The open end of this coffeepot bowl is smaller in diameter than the diametral position of the four small rectangular embossments, thus requiring that their



(B)
FIG. 14-17B. View B.

embossing punches be retractable so that the shell may be placed in working position. These embossing punches ($D1$) are pivoted and expanded into position by the spring-loaded center portion of the die ($D2$). Because of their size and shape, the bottoms of the die cavities for these embossments are inserts ($D3$). The embossing punches ($D4$ and $D5$) for the other two embossments are also inserts in the upper portion of the die. The position of the embossments and the relative location of the section through the die are shown in the bottom view of the part.

A die for embossing another area in the coffeepot bowl is shown in Fig. 14-19. This operation embosses water-level marks in the side of the coffeepot while it is supported on a horn. The embossing and stamping punches are inserted into the punch-holder plate and retained by setscrews.

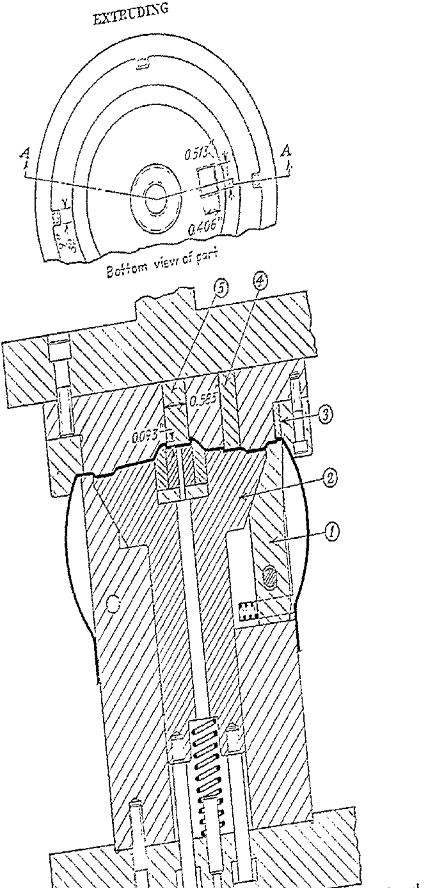


FIG. 14-18. Die to emboss the bottom of the lower bowl of a coffeepot. (*Knapp-Monarch Co.*)

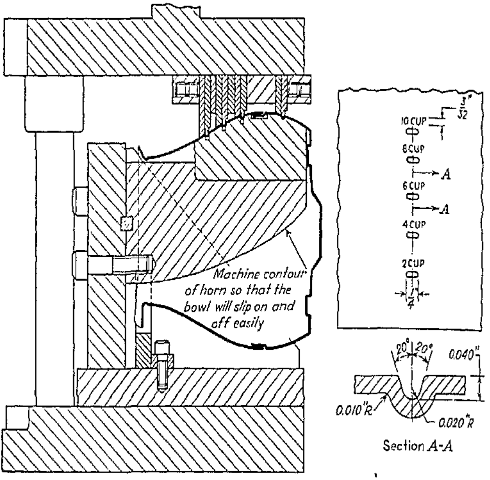


FIG. 14-19. Embossing water-level marks on a coffeepot lower bowl. (*Knapp-Monarch Co.*)

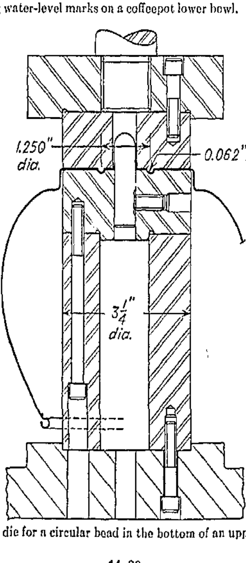


FIG. 14-20. Embossing die for a circular bead in the bottom of an upper bowl of a coffeepot. (*Knapp-Monarch Co.*)

The above-described dies perform operations on the lower bowl of a coffeepot while the die in Fig. 14-20 embosses a circular bead in the upper bowl of the same coffee maker. The bowl is placed upside down in the die and is positioned by the center locating pin while the bead is being formed.

EXTRUDING

One of the most severe of press operations is the cold-extrusion method of shaping metal. Articles produced by this method range from collapsible tubes and continuous shapes in the softer metals to heavy artillery shells, cold-formed from steel billets. The cross-sectional shapes which can be cold-extruded are square and rectangular as

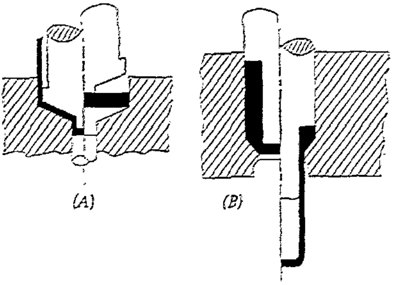


Fig. 14-21. Schematic representation of extrusion process: (A) impact or backward extrusion; (B) uniform pressure or forward extrusion.

well as round shapes. The so-called extruded items are often a product of a series of operations which may combine coining, backward and forward extruding, ironing, and embossing. The success of cold extruding depends upon product design, raw materials, lubrication, tool design, and heat treating, either individually or in combinations. Failures in lubrication can appear to be due to other factors such as impractical product design, tooling, annealing, or defective raw materials.

Less expensive metals may be used for cold extrusion, because excellent strength developed in the low-carbon steels from the high deformations attained in the process. There is a considerable saving of raw material, since almost every ounce of metal present in the original blank is present in the final extruded article. Additional savings can be realized by using blanks from hot-rolled bar stock instead of from hot-rolled plate.

An extruding process is defined as either forward or backward extrusion, corresponding to the direction of metal flow with respect to the direction of the applied force (Fig. 14-21). Backward-extruding dies force metal to flow between the punch and die in a direction opposite to the direction of the force on the punch. Forward-extruding dies force the metal to flow ahead of the punch through the die orifice.

Any lack of symmetry in the side walls of a shell creates lateral pressures which force the punch out of alignment. For this reason, ribs or similar designs on the inside or outside walls of a shell should be symmetrical. Bosses, indentations, or cavities on the inside or outside of the bottom of cup shapes, not symmetrically located, create irregular metal flow which tends to force the punch out of alignment. Typical shapes illustrating these points are shown in Fig. 14-22.

Reductions up to 85 per cent of cross-sectional area by extrusion on cold steel billets in one operation have been successfully made. Under normal conditions, it is good practice to limit the first reduction to approximately 60 per cent, and subsequent operations to about 40 per cent. The average hardness of steels before extrusion should not be over Rockwell B60.

TABLE 14-1. EXTRUSION PRESSURES FOR COMMON METALS[1]

Material	Pressure, Tons, Psi
Pure aluminum "extrusion grade"	40.70
Brass (soft)	30.50
Copper (soft)	25.70
Steel C1010 "extrusion grade"	50.165
Steel C1020 (spheroidized)	60.200

The pressure required in extrusion work depends upon the yield point of the material before and after extrusion, and the varying amounts of friction or resistance to flow depending upon the size and contour of the die. Higher operating speeds create additional loading on the tools. When there is little restriction to flow, and speed is low, the press load can be based on the yield point after work hardening. The pure metals can be worked at lower pressures than the alloys. Table 14-1 lists extrusion pressures for common metals. The pressures listed cover a considerable range depending upon the alloy, its microstructure, the restrictions to flow, and the severity of work hardening.

The pressures required for extrusion also depend upon the percentage of reduction in area. When the percentage of reduction of area, for parts made of various alumi-

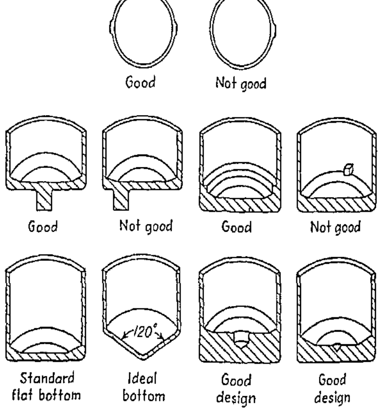


FIG. 14-22. Design considerations which affect the extruding of metals.[4]

num alloys, is known, the required pressure may be taken from Fig. 14-23. Although the alloys mentioned are usually extruded at room temperature, a reduction in press pressure can be achieved by extruding at elevated temperatures. Closely related to, and a factor in establishing, reduction of area is part wall thickness. The increasing effect on punch pressure required as the wall becomes thinner is illustrated in Fig. 14-24.

The relationship between reduction of area and extrusion pressures for a series of plain carbon steels is shown in Fig. 14-25. The steels referred to in the different curves have carbon content in the range of 0.05 to 0.50 per cent, and less than 0.03 per cent each of sulfur and phosphorus. Steel 11 contained 0.58 per cent chromium, 0.11 per cent carbon, and 0.35 per cent manganese, and 0.03 per cent each sulfur and phosphorus.

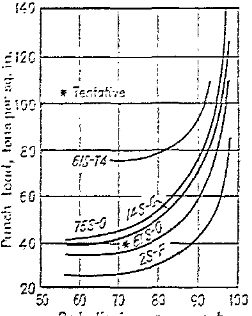


FIG. 14-23. The effect of reduction in area to the punch load in extruding.[5]

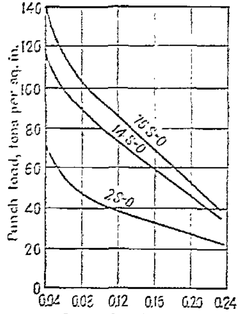


FIG. 14-24. The effect of extruded wall thickness on the punch load.[5]

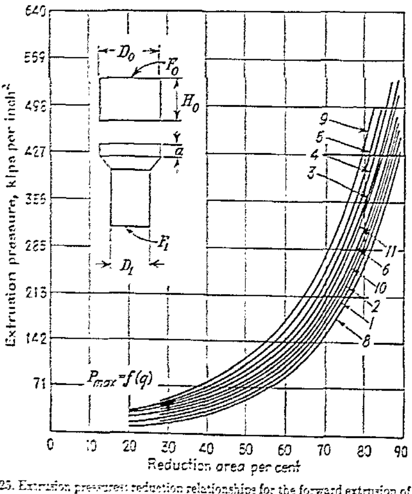


FIG. 14-25. Extrusion pressures: reduction relationships for the forward extrusion of a series of steels with carbon contents in the range 0.005 to 0.50 per cent.[7]

Correct lubrication in extrusion work considerably lowers the pressures required. Ordinary die lubricants break down because of the high pressures and excessive surface heat attending extruding operations. A bonded steel-to-phosphate layer overlaid with a bonded phosphate-to-lubricant coating is satisfactory for the heat and pressures encountered. The phosphate layer serves as a parting layer to reduce metal-to-metal welding or pickup, and as a carrier for the lubricant.

Tool Design. The magnitude of the forces in extruding are very large, since the workpiece is stressed to its elastic limit in compression, resulting in lateral pressure on the die walls, which is additional to the pressure caused by the actual plastic deformation. Under these high pressures there is danger of local collapse and plastic deformation of the tool surfaces. To prevent this, the surface hardness must be approximately Rockwell C60.

Resistance to bursting is frequently achieved by shrinking the tool-steel die ring into a massive die shoe so that the ring is normally in compression. These compressive forces must be overcome before the die ring is stressed in tension.

Various tool steels are suitable for extrusion dies, the choice depending partly upon the required die life. A steel which, in heat treating, acquires a hard wear-resisting case supported by a softer but strong and tough core is useful for cold-extrusion dies. Since there is a possibility of extruded parts leaving the die at a temperature of nearly 550°F, the steel should resist softening due to tempering if heated.

Careful heat treating of the die elements is necessary because high working stresses are encountered. Proper grinding wheels and procedures must be used to avoid grinding checks and surface cracks that will become more prominent when the part is stressed in use. Die steels that are especially sensitive to grinding cracks and checks should not be used.

The length of a backward-extrusion punch is governed by the punch diameter and the yield strength of the workpiece material. The practical limit of the length of the punch for extruding steel should be about three times its diameter, four times the punch diameter for 75S aluminum, and six times for 61S aluminum. These proportions may be increased by using guide bushings. The die cavity should be ¼ to ½ in. longer than the desired part, since the extrusion does not come out with uniform length and may require trimming or sizing. It is not necessary that the blank closely fit the die cavity; it should be of such a shape as to make it impossible to place it off center and thus lose concentricity in the finished part.

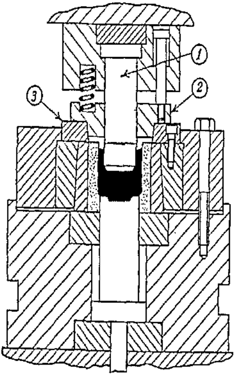


FIG. 14-26. A typical backward-extrusion die with a carbide insert.[7]

A typical backward-extrusion die is shown in Fig. 14-26, in which the metal flows in the opposite direction to punch movement. The carbide insert and its ring are tapered in the holder which is *built up of two members shrunk together.* The taper should be about 1° per side. The holder ring requires an adequate number of holddown screws to prestress the carbide ring in order to minimize its expansion and fatigue failure. The carbide insert and its ring are supported by toughened steel plates to distribute the high local loads. The extruding punch (*D*1) is guided by a spring-loaded guide plate (*D*2) which is positioned by piloting in a ring (*D*3) on the lower die. Ejection of the part from the die is by a delayed-action stripper which lifts the bottom portion of the die cavity.

A backward-extrusion die with the extrusion die ring extended to serve as a guide for the punch is shown in Fig. 14-27. The punch has a tapered shank and is retained in the upper shoe by a bushing within a threaded nut. This design facilitates interchangeability and reduces die costs.

The outside retainer ring of cast or forged steel is shrunk on the OD of a hardened insert to provide some compression on the insert. The hardened insert is ground to a 1 to 2° taper per side on the ID corresponding to the taper on the OD of the die ring. The retainer assembly is pulled tightly over the die ring by means of clamps or cap screws to compress the die ring. This compression preloads the die ring so that it can better withstand the forces tending to expand and crack the die.

Included in the illustration are enlarged views of the extrusion die and punch. The striking or working end of the punch is developed as a cone with a side angle of 5 to 7° for steel, and 1 to 2° for aluminum. The corners have a small radii of 1/64 to 3/64 in., and the punch is relieved above a short bearing to assist in part removal.

The radius at the outer edge of a punch should be kept as small as possible because a large radius tends to create a wedging action. The inside corner radius (on parts requiring a large outside radius) may be reduced by using an angular fillet of a height equal to the radius on the outside bottom of the shell and at an angle of 15° from the bottom.

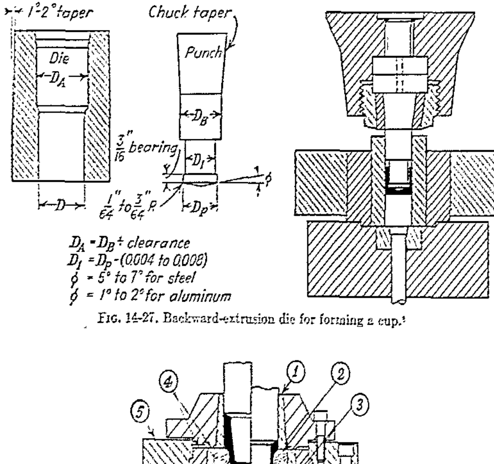


FIG. 14-27. Backward-extrusion die for forming a cup.[1]

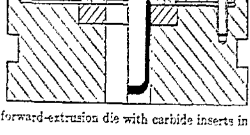


FIG. 14-28. Typical forward-extrusion die with carbide inserts in a compression ring.[1]

A forward-extrusion die, in which the metal flows in the same direction as the punch travel but at a faster rate because of the change in cross-sectional area of the part, is illustrated in Fig. 14-28. The stroke of the press is of sufficient length to allow a preformed slug to be inserted in the nest (*D*1) above the die ring (*D*2). This nest also serves as a guide for the punch during the operation. The die ring and a secondary guide ring (*D*3), added to help produce a straight part, are encased in a pair of tapered rings (*D*4). These rings are retained and clamped to the lower shoe by an outer ring (*D*5) so that only the inner ring is bearing on the lower shoe. This mounting ensures that the die and guide rings *will always be held in a shrunk-in state.* The taper of the mandrel is calculated to suit the elongation and the desired taper on the inner wall of the extrusion.

The forward-extrusion-die insert in Fig. 14-29 is placed in a retainer assembly similar to the one shown in Fig. 14-27. The punch can be attached to a taper shank with a through bolt so that a similar upper shoe may be used. The punch shown is made of a lower portion and an upper portion; the lower portion is subject to wear. The diameter D_1 of the die insert is such that it properly positions the preformed cup or slug. The bearing diameter *D* produces the desired OD of the extruded section. Below this bearing, the die is relieved to reduce frictional resistance, and a guide is placed on the lower end to maintain straightness as the extruded section flows out ahead of the punch.

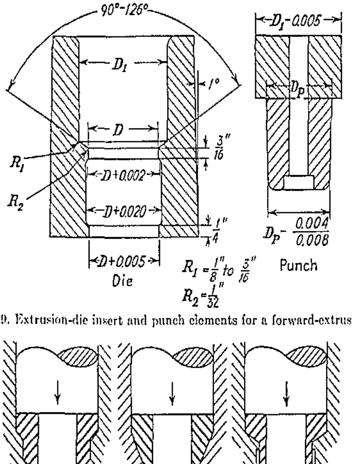


FIG. 14-29. Extrusion-die insert and punch elements for a forward-extrusion die.[3]

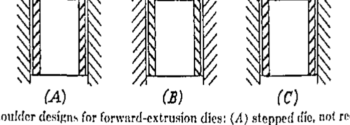


FIG. 14-30. Shoulder designs for forward-extrusion dies: (*A*) stepped die, not recommended; (*B*) long approach, not recommended; (*C*) short approach, good design.[3]

The radius R_1 should be fairly large to aid metal flow and carry lubrication around this point. The included angle of the shoulder should be between 90 and 126°. Although the wider die angles increase tonnages to some extent, they are of great advantage in reducing radial forces and in maintaining lubrication at the work areas. The die angle also influences the amount of work hardening imparted to the work; the wider the included angle, the larger the amount of work hardening. The radius R_2 is very small. The bearing is short and has a slight back rake to provide clearance for the extruded metal.

The stepped dies in Fig. 14-30*A* and the die with small included angle in view *B* impose limitations on the amount of cold work practical in one operation. The top bearing of a stepped die cannot be relieved with back rake because of the compressive forces imposed by the approach to the second step; the metal would tend to upset into the relief area, making stripping impossible. The principles of good design are shown in view *C*.

Two methods of obtaining stepped diameters on a part by forward extrusion are shown in Fig. 14-31. At view *A* is a slug with a diameter of D_1. It is placed in a die and it is forward-extruded to diameter D_2. The workpiece is then placed in another die using the same punch and it is then extruded to diameter D_3. In view *B* a slug is "sized" to the diameter D_2 in a coining die, and is then placed in an extruding die to form the diameter D_1. The final operation upsets the head to diameter.

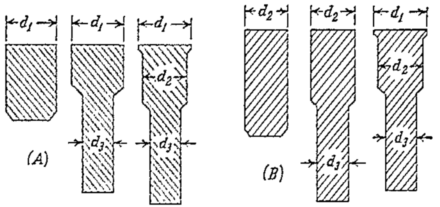


FIG. 14-31. Two methods of obtaining stepped diameters by forward extrusion.[3]

Extruding Die for a Generator Frame. The die in Fig. 14-32 forward-extrudes a portion of an automotive generator frame. The blank for the frame has a tongue and slot for locking purposes. After extrusion, the seam does not open, thus eliminating a conventional welding operation. After the ⅜-in.-thick stock is grit-blasted to remove scale and provide pockets to hold lubricant, the cylindrical blank is produced in five operations on a transfer press. The operations are: cutoff, notch, form to an oxbow shape, V-form, and finish form.

This die is constructed with a floating arbor which allows it to move forward with the flow of the metal, which may be faster than the speed of the press stroke. The punch in this die surrounds the arbor and forces the metal to flow through the carbide extrusion ring. Since the punch is attached to the stripper assembly, it acts to strip the part from the arbor, and a knockout attached to the die cushion ejects it from the die cavity.

Impact Extrusion of Magnesium. The process for producing magnesium impact extrusions is basically the same as for other metals, except for the temperature of the metal during the operation. Depending on the alloy, this temperature may vary from 350 to 700°F.

The success of impact extruding of magnesium depends largely on a uniform thickness of a lubricant film on the blank. If the film is uneven or is left off part of the blank, a product with uneven wall thickness will result because of nonuniform flow of metal. Tumbling or spraying of heated magnesium slugs with colloidal graphite has been successful, but dipping of the slugs has never attained a thin, even lubricant film.

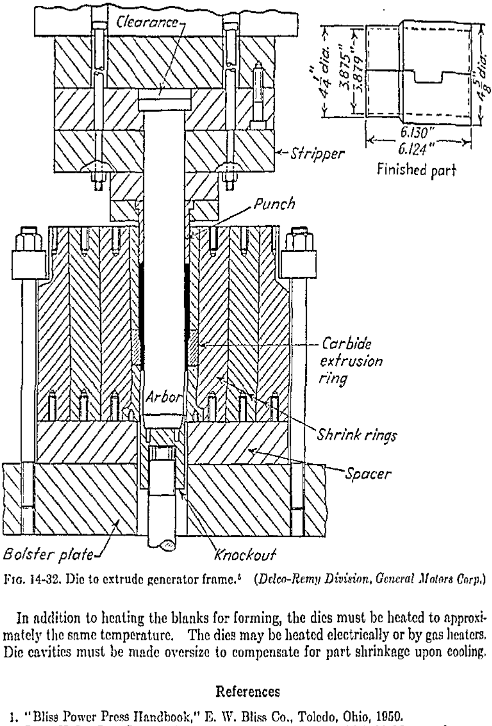


FIG. 14-32. Die to extrude generator frame.[5] (*Delco-Remy Division, General Motors Corp.*)

In addition to heating the blanks for forming, the dies must be heated to approximately the same temperature. The dies may be heated electrically or by gas heaters. Die cavities must be made oversize to compensate for part shrinkage upon cooling.

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SECTION 15

PROGRESSIVE DIES*

A progressive die performs a series of fundamental sheet-metal operations at two or more stations during each press stroke in order to develop a workpiece as the strip stock moves through the die. This type of die is sometimes called "cut-and-carry," "follow," or "gang" die. Each working station performs one or more distinct die operations, but the strip must move from the first through each succeeding station to produce a complete part. One or more idle stations may be incorporated in the die, not to perform work on the metal but to locate the strip, to facilitate interstation strip travel, to provide maximum-size die sections, or to simplify their construction.

The linear travel of the strip stock at each press stroke is called the "progression," "advance," or "pitch" and is equal to the interstation distance.

The unwanted parts of the strip are cut out as it advances through the die, and one or more ribbons or tabs are left connected to each partially completed part to carry it through the stations of the die. Sometimes parts are made from individual blanks, neither a part of, nor connected to a strip; in such cases, mechanical fingers or other devices are employed for the station-to-station movement of the workpiece.

The operations performed in a progressive die could be done in individual dies as separate operations but would require individual feeding and positioning. In a progressive die, the part remains connected to the stock strip which is fed through the die with automatic feeds and positioned by pilots with speed and accuracy.

SELECTION OF PROGRESSIVE DIES

The selection of any multioperation tool, such as a progressive die, is justified by the principle that the number of operations achieved with one handling of the stock and produced part is more economical than production by a series of single-operation dies and a number of handlings for each single die.

Where total production requirements are high, particularly if production rates are large, total handling costs (man-hours) saved by progressive fabrication compared with a series of single operations are frequently greater than the costs of the progressive die.

The fabrication of parts with a progressive die under the above-mentioned production conditions is further indicated when

1. Stock material is not so thin that it cannot be piloted or so thick that there are stock-straightening problems.
2. Overall size of die (functions of part size and strip length) is not too large for available presses.
3. Total press capacity required is available.

STRIP DEVELOPMENT FOR PROGRESSIVE DIES

Individual operations performed in a progressive die are often relatively simple, but when they are combined in several stations, the most practical and economical strip design for optimum operation of the die often becomes difficult to devise.

* Reviewed by F. G. von Brecht, Manager, Manufacturing Engineering Division, White-Rodgers Electric Co.

The sequence of operations on a strip and the details of each operation must be carefully developed to assist in the design of a die to produce good parts.

A tentative sequence of operations should be established and the following items considered as the final sequence of operations is developed:

1. Pierce piloting holes and piloting notches in the first station. Other holes may be pierced that will not be affected by subsequent noncutting operations.
2. Develop blank for drawing or forming operations for free movement of metal.
3. Distribute pierced areas over several stations if they are close together or are close to the edge of die opening.
4. Analyze the shape of blanked areas in the strip for division into simple shapes so that punches of simple contours may partially cut out an area at one station and

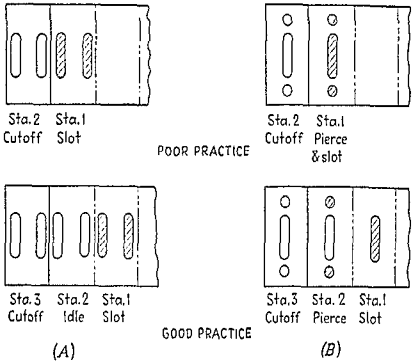


FIG. 15-1. Use of three-stage die to avoid weak die blocks: (A) pierced hole close to edge of part; (B) pierced holes close together.

cut out remaining areas in later stations. This may suggest the use of commercially available punch shapes.

5. Use idle stations to strengthen die blocks, stripper plates, and punch retainers and to facilitate strip movement.
6. Determine if strip grain direction will adversely affect or facilitate an operation.
7. Plan the forming or drawing operations either in an upward or a downward direction, whichever will assure the best die design and strip movement.
8. The shape of the finished part may dictate that the cutoff operation should precede the last noncutting operation.
9. Design adequate carrier strips or tabs.
10. Check strip layout for minimum scrap; use a multiple layout if feasible.
11. Locate cutting and forming areas to provide uniform loading of the press slide.
12. Design the strip so that scrap and part can be ejected without interference.

Figure 15-1 illustrates the use of a three-station die to avoid weak die blocks. At *A* the pierced hole is near the edge of the part where it is cut off, thereby weakening the die block at this point. If an idle station is added so that the piercing operation is moved ahead one station, the die block is stronger and there is less chance of cracking in operation or fabrication. At *B*, the pierced holes are centered on the strip but close together. In this case the holes should be pierced in two stations to avoid thin sections in the die block between the holes. The adding of stations also provides better support for the piercing punches.

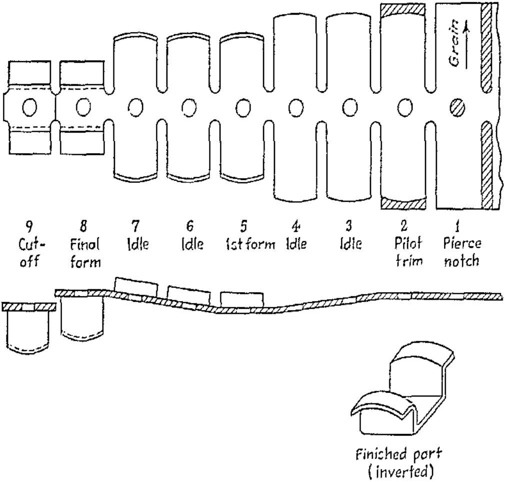


Fig. 15-2. Strip development for a flanged channel. *(C. R. Cory.)*

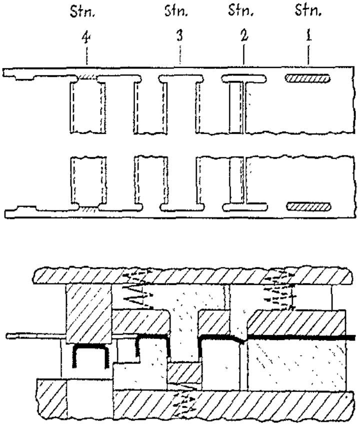


Fig. 15-3. Channel forming progressive die. *(C. R. Cory.)*

The layout of the strip for a flanged channel shown in Fig. 15-2 illustrates several of the points in preliminary layouts of progressive dies. A hole is pierced in station 1 which can be used in any succeeding stations as a pilot hole. Notching the strip with two punches in the first station and trimming the rounded edge of the part in the second station will avoid the use of a delicate J-shaped punch. The first forming operation is done in station 5, with two idle stations on each side to allow the strip to drop below the level of the other stations to form the flanges upward. Final forming is done at station 8 and a shear cutoff is achieved at station 9. The carrier strip is through the center of the strip development.

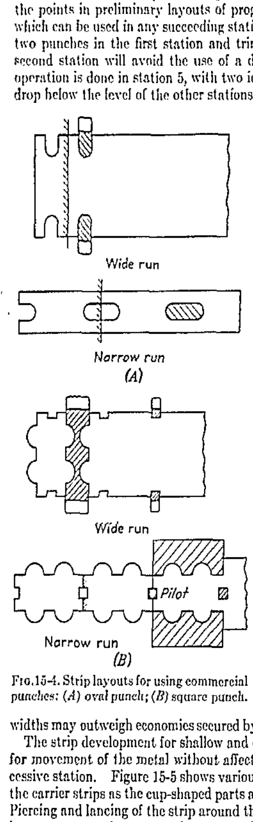


FIG. 15-4. Strip layouts for using commercial punches: (A) oval punch; (B) square punch.

The strip development for a channel-shaped part, and a section through the die, is shown in Fig. 15-3. Slots are cut in station 1 of sufficient length to allow the flanges of two adjoining parts to be formed at one time in station 3. The strip is lanced and one flange partially formed in station 2. The part is cut from the two side carrier strips in station 4. This part could be laid out to progress through the die lengthwise instead of crosswise if the grain of the material would allow the lengthwise bending.

The layouts of Fig. 15-4, using wide and narrow stock widths, illustrate the use of commercial punches and special heeled punches. Commercially available piercing punches should be used where possible to eliminate special heeled punches. Figure 15-4*A* shows a part made from a wide stock strip using two special heeled punches and the same part made from a narrow strip using an oval punch that can be purchased. In both cases a shear-type cutoff punch is used. Figure 15-4*B* shows a wide strip using two heeled rectangular notching punches and a slug-type trim and cutoff punch. The narrow strip development for the same part uses a square piercing punch, heeled trimming punches, and a shear-type cutoff punch. Costs of various stock widths may outweigh economies secured by punches commercially available.

The strip development for shallow and deep drawing in progressive dies must allow for movement of the metal without affecting the positioning of the part in each successive station. Figure 15-5 shows various types of cutouts and typical distortions to the carrier strips as the cup-shaped parts are formed and then blanked out of the strip. Piercing and lancing of the strip around the periphery of the part as shown at *A*, leaving one or two tabs connected to the carrier strip, is a commonly used method. The semicircular lancing as shown at *B* is used for shallow draws. The use of this type of relief for deeper draws places an extra strain on the metal in the tab and causes it to tear. The carrier strip is distorted to provide stock for the draw. A popular cutout for fairly deep draws is shown at *C*. This double lanced relief suspends the blank on narrow ribbons, and no distortion takes place in the carrier strips. Two sets of single rounded lanced reliefs of slightly different diameters are placed diametrically opposite each other to produce the ribbon suspension. The hourglass cutout in *D* is an eco-

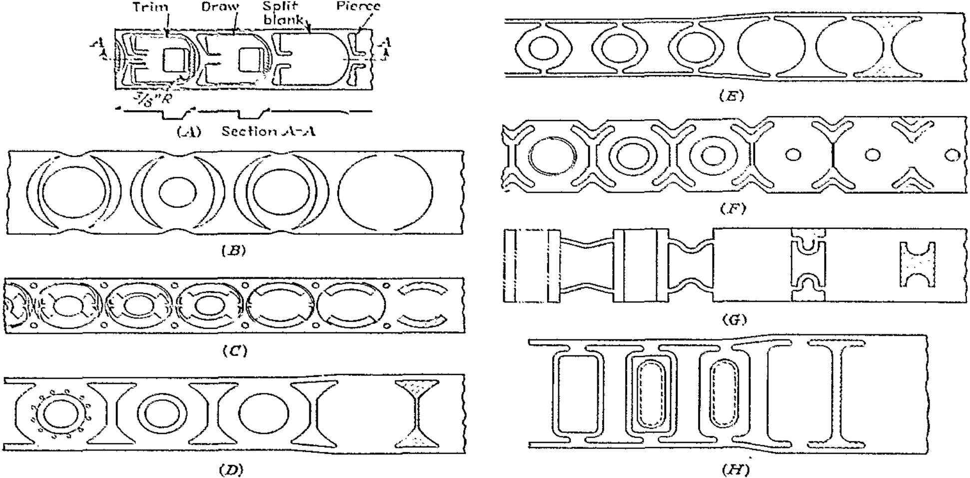
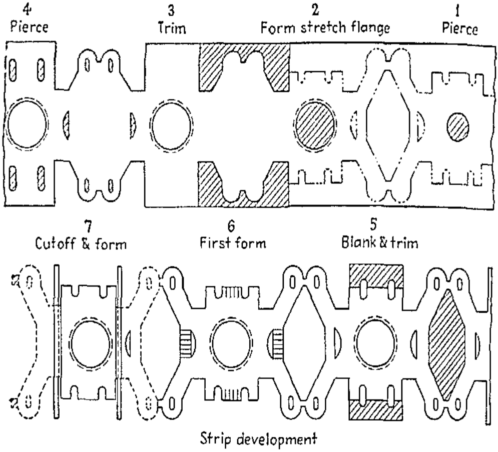


FIG. 15-5. Cutout reliefs for progressive draws: (A) lanced outline; (B) circular lance; (C) double lanced suspension[2]*; (D) hourglass cutout; (E) wide-base hourglass cutout; (F) cutout providing expansion-type carrier ribbon for circular draws; (G) cutout providing expansion-type carrier ribbon for rectangular draws[1]; (H) I-shaped relief for rectangular draws.

* Superior numbers relate to References at the end of this section.



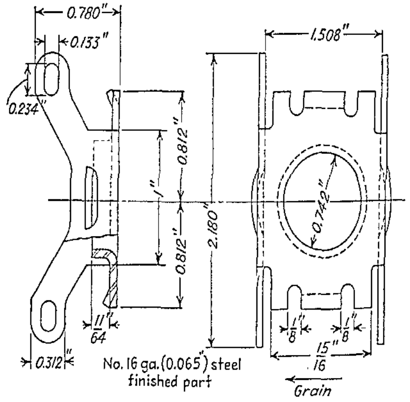


FIG. 15-6. Strip development and part drawing for actuator bracket. (*The Emerson Electric Mfg. Co.*)

nomical method of making the blank for shallow draws. The connection to the carrier strips is wide, and a deep draw would cause considerable distortion. An hourglass cutout for deep draws is shown in E, which provides a narrow tab connecting the carrier strip to the blank. The cupping operations narrow the width of the strip as the metal is drawn into the cup shape.

The hourglass cutout may be made in two stations by piercing two separated triangular-shaped cutouts and lancing or notching the material between them in a

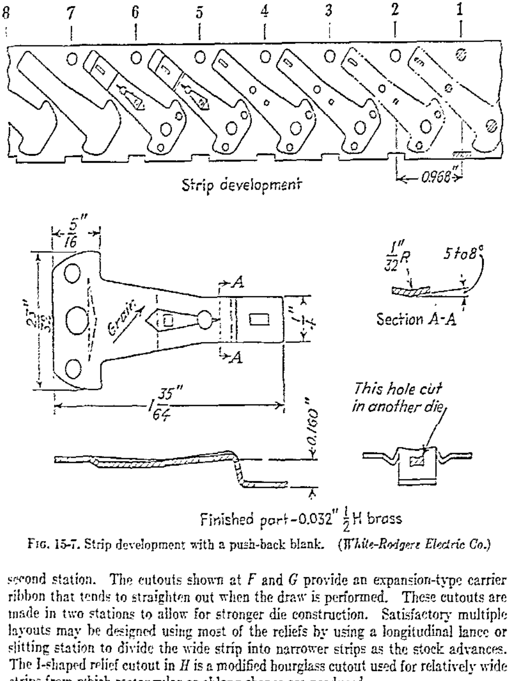


FIG. 15-7. Strip development with a push-back blank. (*White-Rodgers Electric Co.*)

second station. The cutouts shown at F and G provide an expansion-type carrier ribbon that tends to straighten out when the draw is performed. These cutouts are made in two stations to allow for stronger die construction. Satisfactory multiple layouts may be designed using most of the reliefs by using a longitudinal lance or slitting station to divide the wide strip into narrower strips as the stock advances. The I-shaped relief cutout in H is a modified hourglass cutout used for relatively wide strips from which rectangular or oblong shapes are produced.

Straight slots or lances crosswise of the stock are sometimes used on very shallow draws or where the forming is in the central portion of the blank. On the deeper draws, this type of relief tends to tear out the carrier strips or cause excessive distortion in the blank and is not too satisfactory to use.

Multioperation Layout. A layout of the sequence of operations employing a variety of operations for producing an actuator bracket is shown in Fig. 15-6. At the first position a center hole is pierced. The hole is used to pilot the strip for each successive operation. At the second position a circular stretch flange is formed around this hole to part print dimensions, and the strip is notched to the outline of part of the left leg.

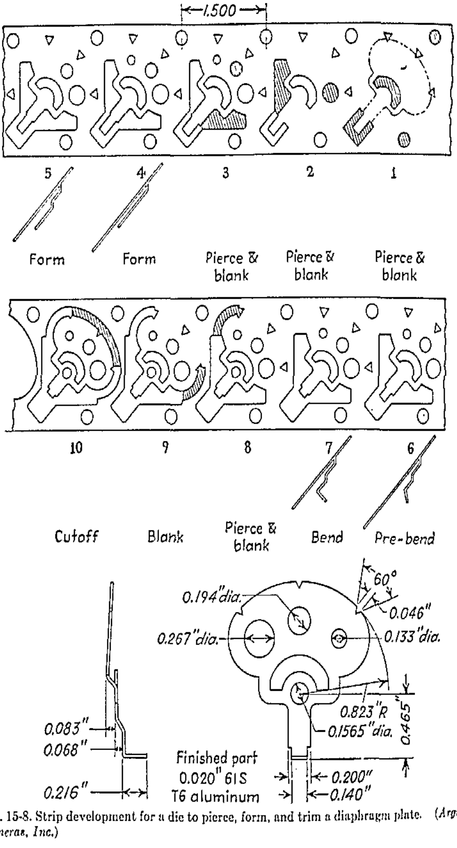


FIG. 15-8. Strip development for a die to pierce, form, and trim a diaphragm plate. (*Argus Cameras, Inc.*)

At the third position similar notching for the right leg and cutting of three slots in the left leg occur. At position 4, similar slots are cut in the right leg and in the central portion, as well as the completed outline of the left leg. The right leg's outline is completely cut out and the central portion is trimmed to length at position 5. The bulges in the sides are formed up and tabs on the center section are formed down in the sixth position. In position 7 the part is severed from the strip, the carrier tabs on the left side are cut off, and the legs are formed downward.

The die for this part is made of high-carbon high-chrome steel with hardened backup plates for the punches and die blocks. Air-operated lifters elevate the strip for advancing to the next station. An air-operated ejector removes the part from the form block. The die operates at a speed of 75 strokes per minute producing about 150,000 parts per grind.

Push-back of Blank into Strip. The nature of the forming or the size or shape of a part sometimes requires that the blank be completely severed from the strip before forming. The blank is then pushed back into the strip so that it can be advanced properly to the succeeding stations. A strip development of this type is shown in Fig. 15-7. The strip is pierced and notched in the first two stations and in station 3 the blank is severed from the strip; then, by the action of a spring-loaded pressure pad, it is pushed back into the strip. In station 4, the blank is spanked to flatten and secure it into the strip. The first forming is done at station 5, and finish forming and removal from the strip are achieved at station 7. Station 6 is idle to add strength to the die. In addition to the piloting hole, a notch is cut along the edge to engage a locator operating a limit switch. The switch is connected to the electrical circuit controlling the press clutch to prevent press operation if the strip is improperly positioned.

The strip development and part drawing for a camera diaphragm plate are shown in Fig. 15-8. Stock is 0.020-in.-thick by 1⅞-in.-wide 61ST6 aluminum. The strip development allows the periphery of the part to be trimmed in several steps to simplify punch shapes and also to prevent concentration of stresses which would tend to warp the workpiece. This arrangement facilitates fabrication of the sectionalized die blocks. The dies for the triangular-shaped cutouts are round inserts made in two pieces for ease and accuracy of grinding.

GENERAL DIE DESIGN

A progressive die should be heavily constructed to withstand the repeated shock and continuous runs to which it is subjected. Precision or antifriction guide posts and bushings should be used to maintain accuracy. The stripper plates (if spring-loaded and movable), when also serving as guides for the punches, should engage guide pins before contacting the strip stock. Lifters should be provided in die cavities to lift up or eject the formed parts, and carrier rails or pins should be provided to support and guide the strip when it is being moved to the next station. A positive ejector should be provided at the last station. Where practical, punches should contain shedder or oil-seal-breaker pins to aid in the disposal of the slug. Adequate piloting should be provided to ensure proper location of the strip as it advances through the die. For more die-design considerations, see Sec. 3.

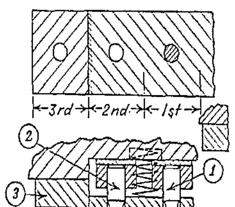


FIG. 15-9. Pierce, pilot, and cutoff die. (*C. R. Cory*)

Scrapless Die. An elementary pierce, pilot, and cutoff die is shown in Fig. 15-9. A hole is pierced in the strip stock at the first station by the punch (*D*1).* The strip is accurately located in station 2 by the pilot (*D*2) and the finished blank is cut off from the stock strip in station 3 by the cutoff punch (*D*3) shearing the metal against the edge of the die (*D*4). The part slides off the die along the inclined surface. The use of a shear-type cutoff die saves stock since there is no scrap. The parts, however, are not so accurate in width as those from a blanking die since the width of the strip stock varies. This inaccuracy could be remedied by adding trimming punches to trim the sides of the stock strip.

* *D* indicates detail numbers on drawing.

Forming Dies. Parts with straight edges may be formed in a shear-type cutoff die as shown in Fig. 15-10. The strip is pierced in station 1, then moved against the stop (*D*1), sheared by the cutoff punch (*D*2), and formed over the inverted V-shaped punch (*D*3). A spring-loaded pressure pad prevents the strip from moving while the part is cut off and acts as a stripper for the piercing punch.

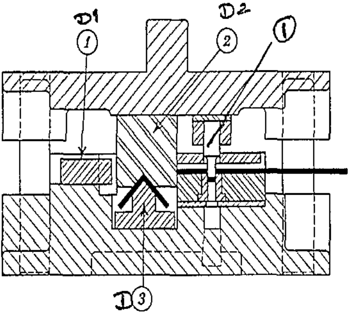


FIG. 15-10. Progressive forming die with shear-type cutoff.[3]

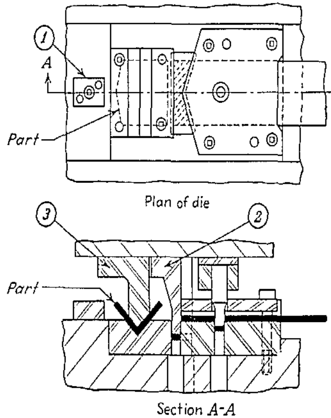


FIG. 15-11. Progressive forming die with slug-type cutoff.[3]

When the edges of the blank are not straight, a slug cutoff die as shown in Fig. 15-11 may be used. The shearing forces in a slug-type cutoff punch are balanced since metal is cut by both edges. This type of die uses a little more stock but the scrap falls through the die out of the way. In this die, the strip is pierced in station 1 and moved against the stop (*D*1) to be cut off by the punch (*D*2) and formed by punch D2. The die can be used on an inclined press and the part ejected at the rear by a jet of air.

The die shown in Fig. 15-12 can produce the same part shown in Fig. 15-11 and uses a little less stock since only two triangular-shaped scrap pieces are left. With this die the scrap is left on top of the die and must be removed before the stock is advanced.

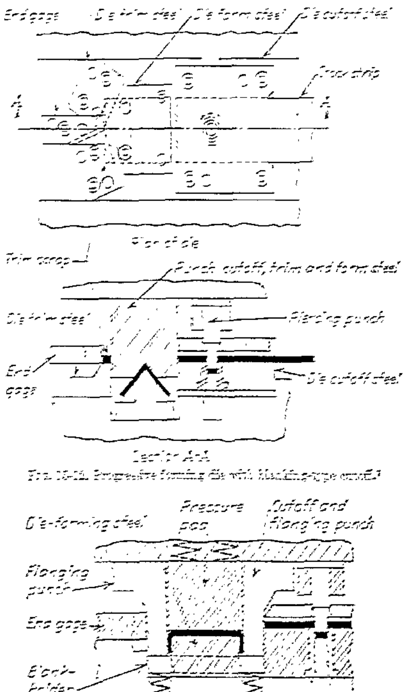


Fig. 15-12. Progressive forming die with blanking-type cutoff.

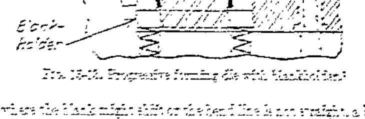


Fig. 15-13. Progressive forming die with blankholder.

In dies where the blank might shift or the bend line is not straight, a blankholder is used. The die shown in Fig. 15-13 uses a spring-loaded blankholder pad D1 to hold the blank during the forming of the flange, and to eject the part from the die after forming. The one-piece shear-type cutoff punch also forms the flange; an inserted adjustable shear blade in a combination cutoff and form punch eliminates regrinding the form radius after resharpening the shearing edge.

Cam-action Forming Die. The die shown in Fig. 15-14 performs three forming operations. The first forms a slight offset, the second forms a crown, and the third forms a flange of over 90°. A hinged forming punch (*D1*) engages a 45° cam surface at the lower part of the stroke, which forces it against the right-angle flange to set it to 110°. The amount of forming of this flange and the offset are controlled by adjustable tapered wedges (*D2* and *D3*). The strip is pierced and trimmed to width in station 1, positioned in station 2 by a pilot (*D4*), and on the upstroke of the press the strip is

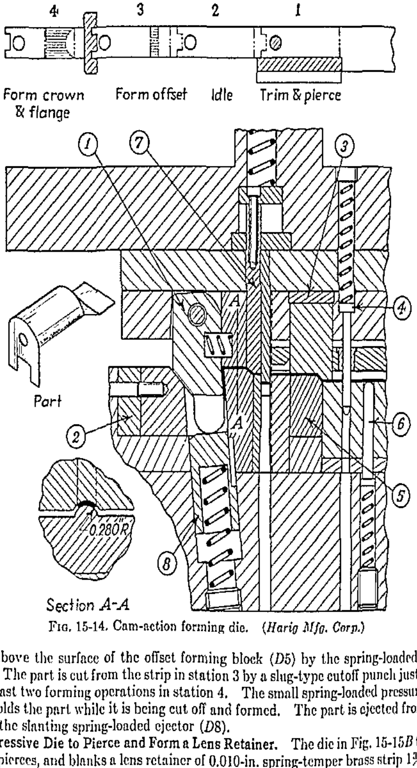


FIG. 15-14. Cam-action forming die. (*Harig Mfg. Corp.*)

lifted above the surface of the offset forming block (*D5*) by the spring-loaded lifter (*D6*). The part is cut from the strip in station 3 by a slug-type cutoff punch just prior to the last two forming operations in station 4. The small spring-loaded pressure pad (*D7*) holds the part while it is being cut off and formed. The part is ejected from the die by the slanting spring-loaded ejector (*D8*).

Progressive Die to Pierce and Form a Lens Retainer. The die in Fig. 15-15*B* trims, forms, pierces, and blanks a lens retainer of 0.010-in. spring-temper brass strip 1$\frac{3}{16}$ in. wide. A center and two side piloting holes are pierced in the first station and the area around the tabs is trimmed in the next three stations by six rectangular-shaped punches. Station 4 shears the end of the tabs from the strip and partially forms them, and the following operation sets them to shape. The 0.654-in.-diameter center hole is pierced in station 6, and in station 7 the part is blanked from the strip and drops through the die. The unnumbered idle stations are provided to increase die strength;

actually the first part is completed on the eleventh press stroke. The strip is piloted in the forming stations by the center holes, and in the cutting stations by the side piloting holes. Spring-loaded stock lifters elevate the stock to avoid interference of the formed tabs with the die. The punches and die inserts are held in position by flats machined on the inserts to fit recesses in the retainers. Recesses are machined deep enough behind all cutting elements to allow them to be resharpened and spacers to be placed behind them to bring them back to height. The punches are guided by the spring stripper which is in turn guided by leader pins.

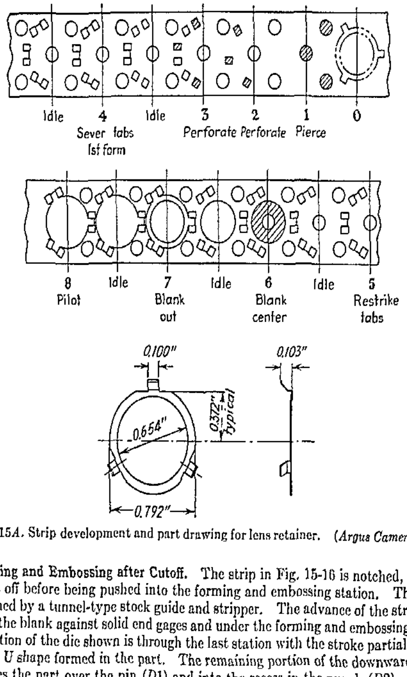
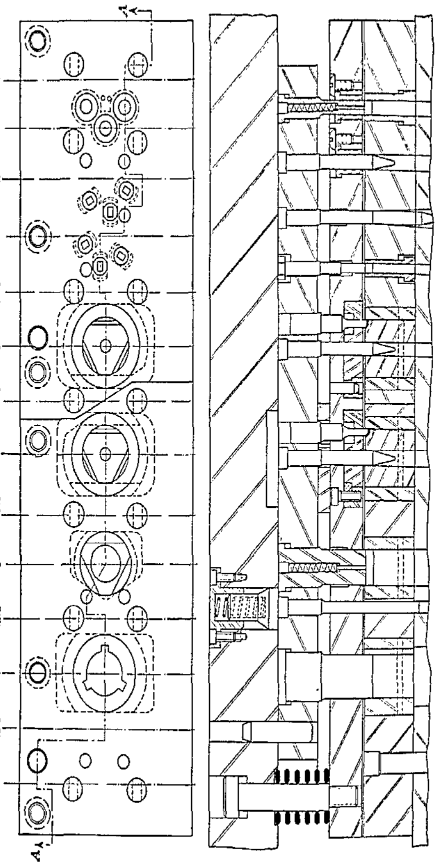


FIG. 15-15*A*. Strip development and part drawing for lens retainer. (*Argus Cameras, Inc.*)

Forming and Embossing after Cutoff. The strip in Fig. 15-16 is notched, pierced, and cut off before being pushed into the forming and embossing station. The blank is confined by a tunnel-type stock guide and stripper. The advance of the strip stock pushes the blank against solid end gages and under the forming and embossing punch. The section of the die shown is through the last station with the stroke partially down and the *U* shape formed in the part. The remaining portion of the downward stroke embosses the part over the pin (*D1*) and into the recess in the punch (*D2*). On the upstroke of the press the part is ejected from the die by the ejector (*D3*) and stripped from the punch by (*D4*). The stock is fed from front to back, and the inclined position of the press enables the part to fall out the back.

Cupped Washer Made in Progressive Die. The small part of Fig. 15-17 is carried on a side web through the die. The contour of the first perforating punch allows the subsequent forming of the flange with its sharp corner. Then the notching punch trims the metal around the two adjacent tabs. Cutting of this outline using two punches in two operations simplifies punch design by eliminating the sharp corners



Section A-A

FIG. 15-15B. Progressive die to trim, form, pierce, and blank brass lens retainer.

required on one punch for single-operation cutting. The perforating of the 0.175-in.-diameter hole follows. The punch (D4) pilots, cuts off, and draws the washer to shape. The washer is stripped off this punch by two spring-operated stripper arms (D1) mounted in the die backup plate (D2). A scrap cutter (D5) is incorporated. An inexpensive yet rigid way of mounting all punches in the punch pad or retainer (D3) is provided by the use of low-melting-point alloy.

Progressive Die Fabrication of Small Brass Connecting Links. The brass strip is conventionally perforated and trimmed at the first two stations (Fig. 15-18). Section

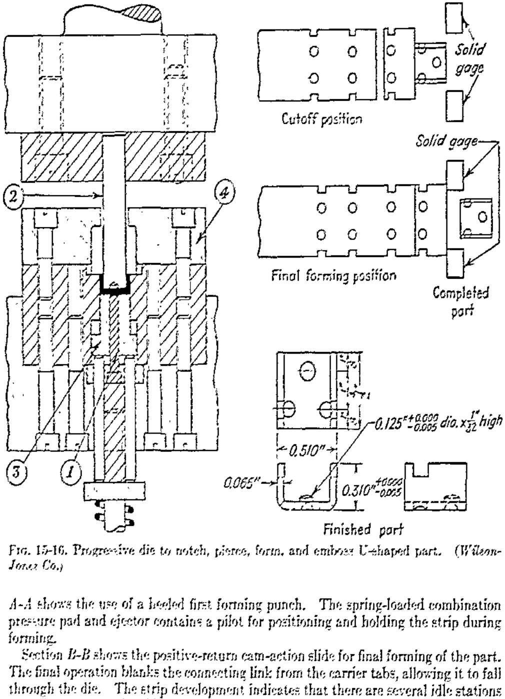


FIG. 15-16. Progressive die to notch, pierce, form, and emboss U-shaped part. (*Wilson-Jones Co.*)

A-A shows the use of a heeled first forming punch. The spring-loaded combination pressure pad and ejector contains a pilot for positioning and holding the strip during forming.

Section B-B shows the positive-return cam-action slide for final forming of the part. The final operation blanks the connecting link from the carrier tabs, allowing it to fall through the die. The strip development indicates that there are several idle stations to add strength and rigidity to the die. The form block or mandrel at the forming stations and the die section at the cutoff station are inserts to simplify construction and replacement.

In station 1 of this die the pilot hole is perforated and the strip trimmed to width on either side. The trimming of the stock provides two projections which serve as stops during its progression through the die. The projections require a little more material, particularly when they are cut on both sides, but they do allow the thin strip to be

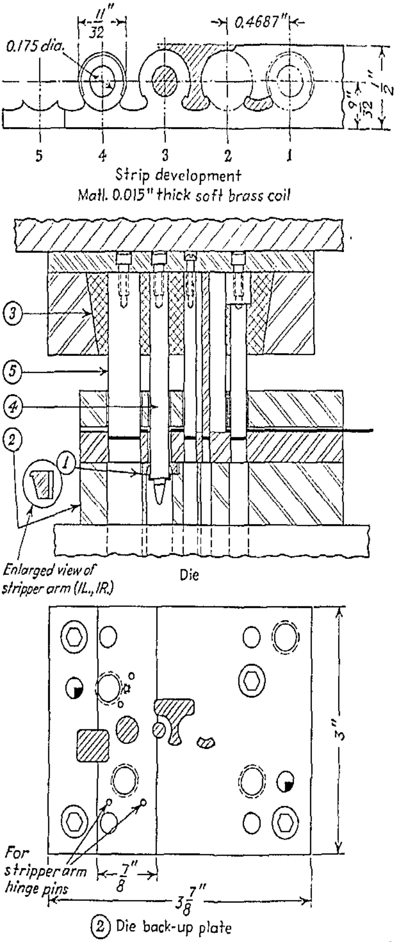


FIG. 15-17. Die to produce cupped washer in four stations. (*Century Electric Co.*)

pulled straight through the die without shifting. These projections are commonly called "shear stops." In station 2 the six small holes are perforated. Normally, it is a bad practice to have such small punches so close together, but it ensures accurate hole location and spacing. The area around the part, except for a connecting tab along the axis of progression, is trimmed in station 3. Station 4 is an idle station. The carrier tab falls through the die as the part is severed by the slug-type cutoff

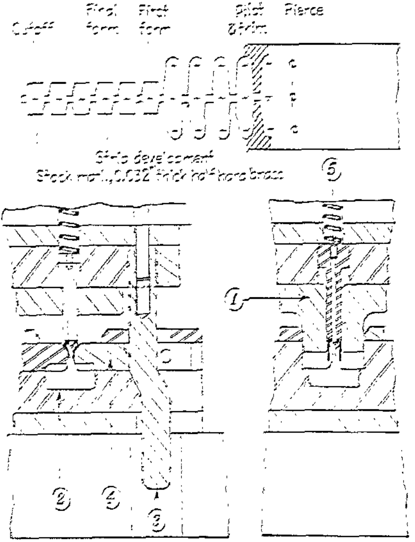


FIG. 15-15. Positive-return cam-action forming die for small brass connecting link. (Hartig Mfg. Corp.)

punch. This cutoff and a forming operation are combined in station 5. Ejection is by air blast.

Progressive Die for Stainless-steel Part. The part shown in Fig. 15-16 is made of 0.036-in.-thick, type 302 full-hard stainless steel. The perforating punches for the small rectangular slots are readily removable from the main punch block, since the perforating of such hard metal readily dulls them and they need frequent replacement. The die is made of hardened and ground sections screwed, doweled, and keyed to a hot-rolled steel sub plate which in turn is screwed and doweled to the die shoe. The die clearance angles are 0.25° included angle for the round hole and 0.25° for side and other holes. The part is piloted in each station through the center hole to assure accurate trimming and forming. A spring-actuated ejector containing oil-seal breakers is used in the forming station to eject the part from the die. Because of the thin hard metal and the precision required in the finished part, a heavy-duty four-post die set is used to assure accurate alignment.

Two-station Pierce, Cutoff, and Form Die. A progressive die to pierce, pilot, cut off, and form a small channel shape with semicircular cutout at the edge of each flange is shown in Fig. 15-20. The stock, 14-gage hot-rolled steel, is confined in a closed stock guide and stripper. A 0.460-in.-diameter hole is pierced in the first station, and the strip is piloted, cut off, and formed in station 2. Instead of having a separate piloting station, *the semicircular pilot (D1) is inserted adjacent to the combination*

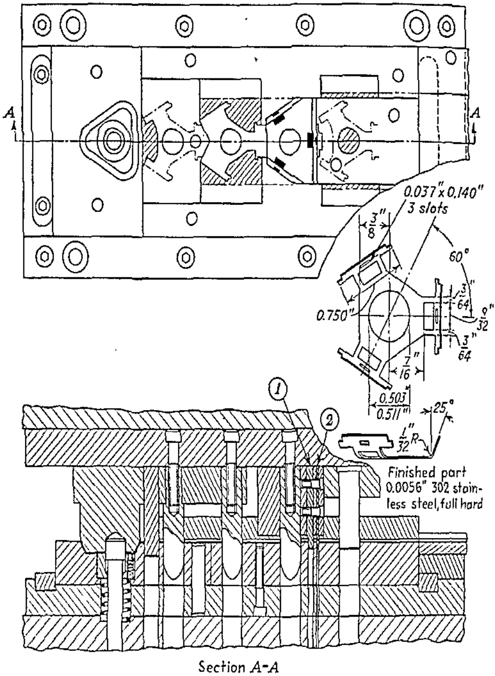


FIG. 15-19. Progressive die for stainless-steel part. (*White-Rodgers Electric Co.*)

cutoff and form punch (*D*2). The pilot is stepped beneath the cutoff and form punch to enable its full diameter to position the metal correctly before it is cut off. The strip is firmly gripped between the cutoff punch and the pressure pad (*D*3) during the cutoff and form operation. The part is flattened between the form block (*D*4) and the positive knockout pad (*D*5) at the end of the forming strokes. Ejection from the form block is done by the pressure pad and from the punch by the positive knockout. This die can be fed by hand or by an automatic feeder. The forming punch heel block (*D*6) forms a positive stop for the strip.

Progressive Die with a Cam-operated Final Forming Station. The blank for the part shown in Fig. 15-21 is cut off from the strip by a slug-type cutoff and pushed

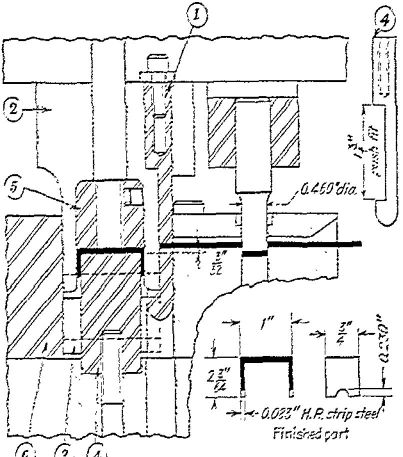


FIG. 15-20. Two-station die for channel-shaped part. *(Harig Mfg. Corp.)*

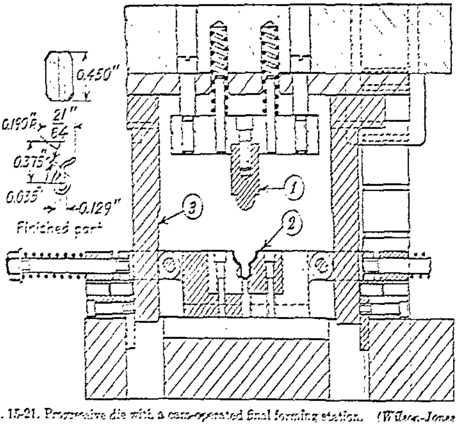


FIG. 15-21. Progressive die with a cam-operated final forming station. *(Wilson-Jones Co.)*

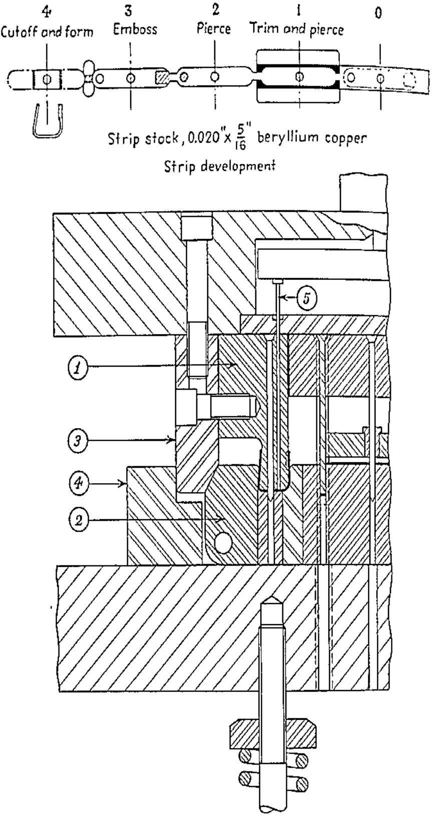


FIG. 15-22. Hinged cam to overform part in a progressive die. (*Harig Mfg. Corp.*)

progressively along the top of the die to the forming stations by the advancing stock strip. The drawing shows a section through the last forming station. The forming punch (*D*1) is mounted on a spring-loaded pad and forms the open U of the part. The part is further formed as the continued downward motion of the ram closes the dies (*D*2) which are spring-returned by cams (*D*3). Finished parts are pushed off the die by the blanks moving to the left.

Overforming by a Hinged Cam. A small beryllium copper part has its center piloting hole pierced in the first station of the die of Fig. 15-22. In the same station the

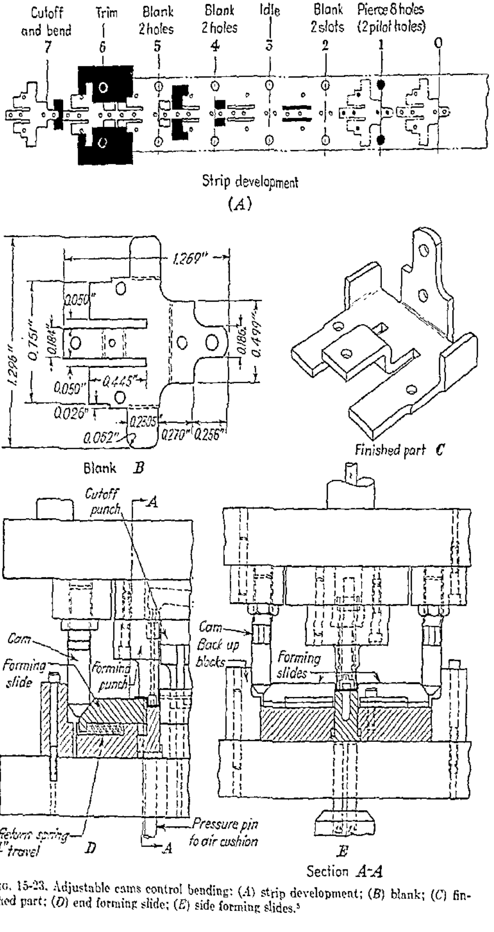


FIG. 15-23. Adjustable cams control bending: (A) strip development; (B) blank; (C) finished part; (D) end forming slide; (E) side forming slides.[5]

part is trimmed to width and the ends cut to a partially rounded outline, leaving connecting tabs. A small hole in the left-hand end of the workpiece is pierced in station 2; an embossment in the opposite end is formed in station 3. In station 4 the part is cut off by a slug-type cutoff punch prior to forming around the form punch (D1). The hinged member (D2) is actuated by a descending cam (D3), backed up by a heel

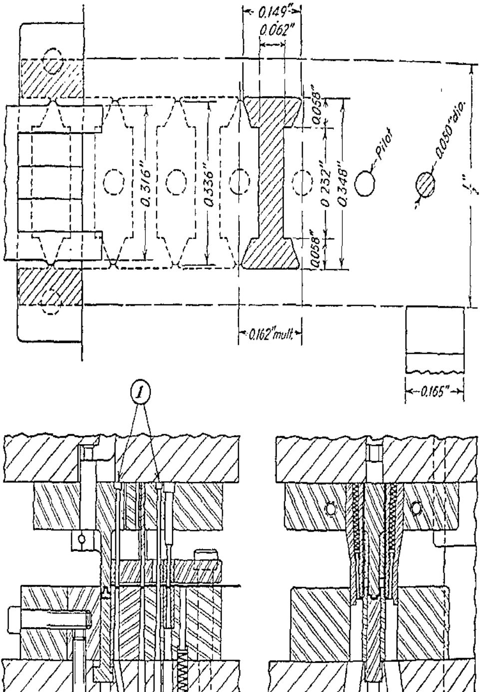


FIG. 15-24. Strip development and section through forming station to produce lead-wire anchor staple. (Harig Mfg. Corp.)

block (D4). The finished part is stripped from the forming punch by stripper pins (D5) actuated by a positive knockout bar.

Adjustable Cams Control Bending. The 0.036-in.-thick half-hard brass part shown in Fig. 15-23C is made in seven stations in a progressive die. Cams threaded into the upper shoe and secured with locknuts provide a means of adjusting the travel of the forming slides to control spring-back due to different hardnesses, tensile strengths, and thicknesses of material.

In the first station, the six holes in the part are pierced in addition to two strip piloting holes. Two slots 0.050 in. wide are blanked in station 2; station 3 is idle to provide space for stronger die construction. Stations 4, 5, and 6 progressively trim the outline of the blank. A slug-type cutoff punch cuts off the blank and trims the partial contour on the rear tab in station 7. The forming of five right-angle bends to complete

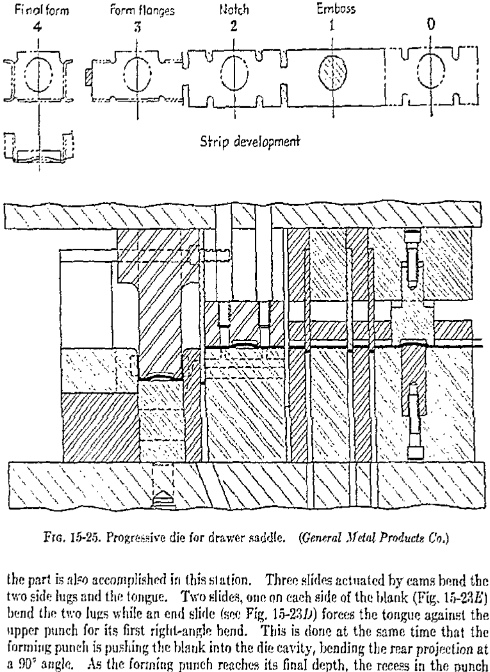


FIG. 15-25. Progressive die for drawer saddle. (*General Metal Products Co.*)

the part is also accomplished in this station. Three slides actuated by cams bend the two side lugs and the tongue. Two slides, one on each side of the blank (Fig. 15-23*E*) bend the two lugs while an end slide (see Fig. 15-23*D*) forces the tongue against the upper punch for its first right-angle bend. This is done at the same time that the forming punch is pushing the blank into the die cavity, bending the rear projection at a 90° angle. As the forming punch reaches its final depth, the recess in the punch forces the tongue into a second 90° bend over the end forming slide. An air cushion applies pressure to a pad under the punch to keep the part flat and eject the finished part from the die cavity.

Die for Leadwire Anchor Staple. A small part made of 0.010-in.-thick brass is blanked and formed in a three-working-station progressive die (Fig. 15-24). The first station trims the stock to width and pierces a piloting hole. Station 2 blanks the contour of one side of two adjacent parts. Station 3 blanks the part from the carrier strip and forms it to shape. At this station the carrier strips are cut into slugs and fall through the die. Small shedder pins are incorporated in these punches to ensure the

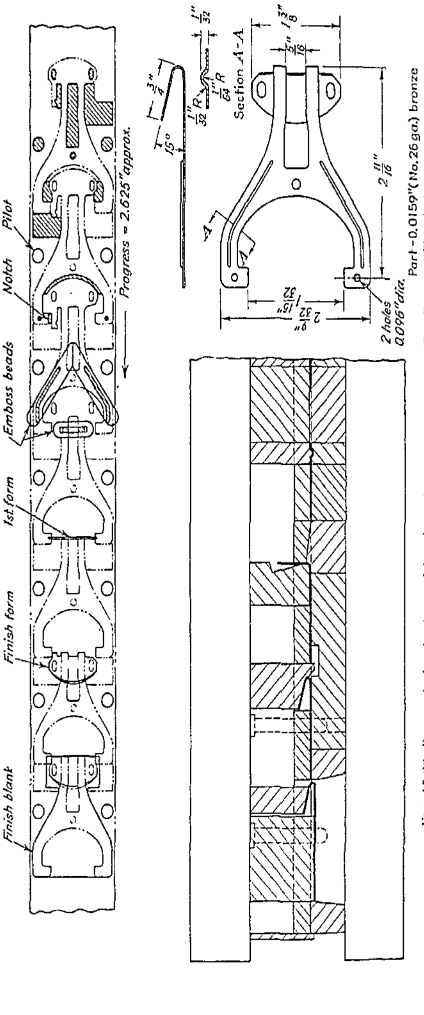


FIG. 15-26. Progressively piercing and forming a bronze switch arm. (The Emerson Electric Mfg. Co.)

ejection of the slugs. Two pilots (D) position the strip. Four idling stations are incorporated because the part is very small.

Progressive Die for Fabricating a Drawer Saddle. A progressive die which embosses, notches, and forms a drawer saddle is shown in Fig. 15-25. The strip is embossed in station 1, and four round-end notches and two square-end notches for piloting are cut at the second station. The metal between the square notches serves as a carrier tab. The flanges are formed down in station 3. The cutoff and final forming operations are performed at the fourth station. The punch and die are made

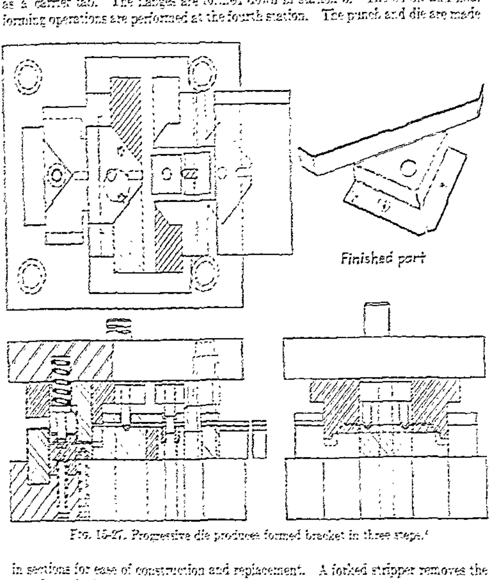


FIG. 15-27. Progressive die produces formed bracket in three steps.[4]

in sections for ease of construction and replacement. A forked stripper removes the part from the forming punch.

Progressively Piercing and Forming Spring Bronze. A switch arm is made of spring-temper bronze 0.0159 in. thick as shown in the layout in Fig. 15-26. Two [illegible]-in.-diameter pilot holes are pierced in the scrap area of the carrier strips to be used for piloting at all stations. The die plate is sectioned for ease of sharpening and maintaining relationship between cutting and forming stations. The punches are divided into several simple shapes to avoid thick and thin sections and sharp corners. Inserts are used for the embossing operations.

A feature of this die is the forming of the tab to a 15° closed angle. The first forming operation produces a groove across the part. The next station has a flat punch which hits home on the groove, causing the tab to bend up from a horizontal plane to approximately 100°. The following station operation pushes the tab down to 165° from its starting point. In the next operation the formed piece is blanked through the die. The scrap is cut into small pieces by a shear blade at the left-hand end of the die. The die is operated with an automatic slide feed and a stock straightener at a speed of 75 strokes per minute.

Progressive Fabrication of a Triangular-shaped Flanged Part. A progressive die to produce a triangular-shaped flanged bracket in three stations is shown in Fig. 15-27. The operations in station 1 are: pierce pilot hole, which later becomes a bolthole, pierce slot, and notch out metal on one side of the flanges and ears. Station 2: emboss the

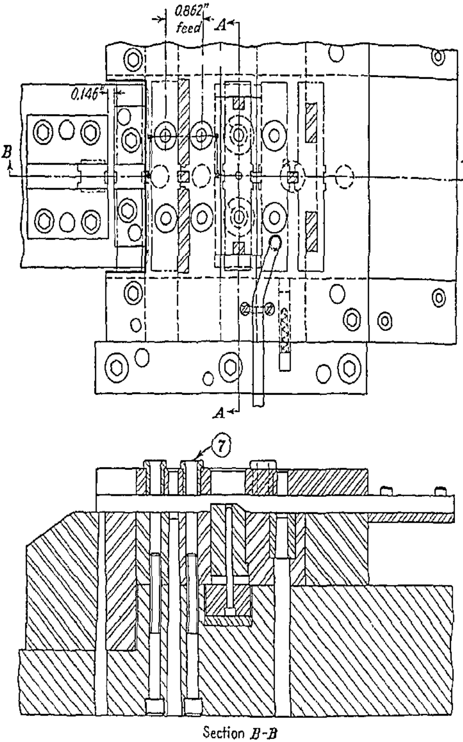


FIG. 15-28A. Die to pierce, emboss, and form lock part. (*Sargent & Co.*)

half-spherical indentations and bend ears. In station 3 the bracket is cut off, the flanges formed, and the tab bent up.

Die to Pierce, Emboss, and Form a Lock Part. In the die shown in Fig. 15-28A, the part is completely formed before it is cut off from the carrier strip. In station 1, two rectangular slots are cut as well as one square hole. A finger stop is provided to start a new strip in station 1. Station 2 is a piloting station using the previously pierced rectangular slots. In the third station, two pilots position the part while the two projections on the sides are lanced and formed. The 0.225-in.-diameter by 0.050-in.-high projection, located in the center of the part, is also embossed in this station. The section A-A is taken through the station which performs the latter operations.

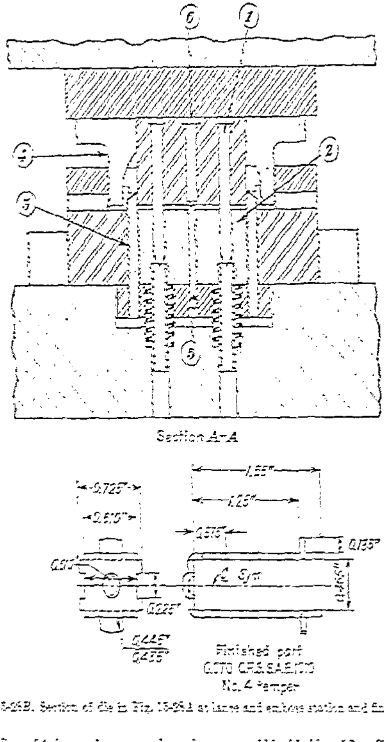


FIG. 15-25B. Section of die in Fig. 15-25A at lance and emboss station and finished part.

The pilots $D1$ locate the part on the spring-actuated blankholder ($D2$). The lancing of the tabs is done by a punch $D3$ which also forms them around the punch ($D4$). The embossing punch and die are shown as $D5$ and $D6$, respectively. In station 4 the strip is located and trimmed to width, except for the tabs left between the square hole and the slots cut in this station. Station 5 is a piloting station. Station 6 trims the blank to length and forms it to shape. A spring-loaded pin with an indentation to receive the embossment locates and holds the blank for the operation in station 6. In station 7, a slug-type parting punch cuts off the formed part which slides off the

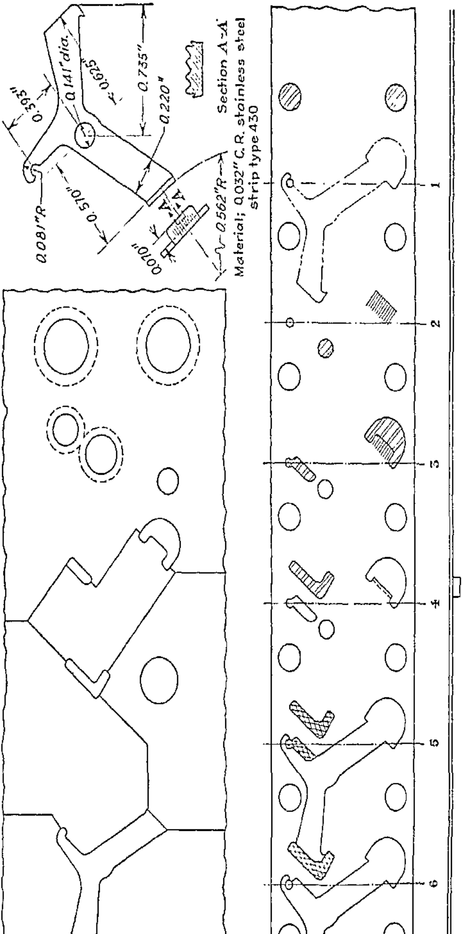


FIG. 15-29. Progressively coining and forming a flange on a stainless-steel part. (*Argus Cameras, Inc.*)

inclined end of the die (see section B-B). Except in station 2, the pilots are guided by bushings D7 pressed into the fixed stripper plate.

Progressive Die for Coining, Piercing, and Forming a Flange. The part, strip development, and view of sectional die blocks are shown in Fig. 15-26. This part is a rewind pawl for a camera and is made of 0.032-in. cold-rolled stainless steel. Serrations are coined in the flange in station 2 and the scrap around the flange is blanked out in station 3. In station 4, this flange of 90° is formed. A 0.032-in. concave radius is also formed in this flange by a punch which has the identical serrations as previously

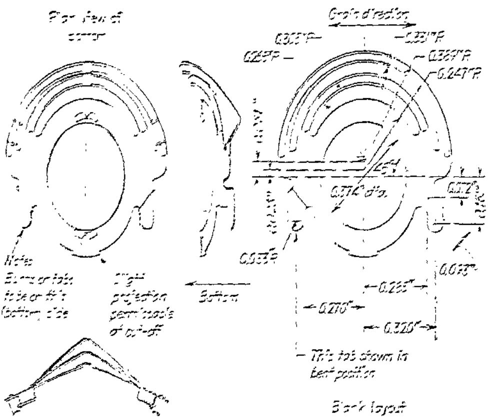


FIG. 15-30. Phosphor bronze contact spring produced in a nine-station progressive die, and layout of the blank. (*John Tollert Metal Stampings, Inc.*)

coined in the strip. In station 5 final blanking of the part is completed. The positioning of the cutouts in the strip simplifies the construction of the sectional die blocks shown.

Nine-station Die for a Contact Spring. The die in Fig. 15-30 produces contact springs made of grade D phosphor bronze strip, 0.010 in. thick by 1.000 in. wide, at the rate of 5,000 to 6,000 per hour. The strip layout shows the steps which are taken to produce the part.

The punches are held in a split plate which is hardened and ground to suit the profile of the individual punches. The two halves are fastened together and screwed and doweled to the upper die shoe. The nine die stations are made of sectional ground dies held together in a hardened and ground U-shaped channel by end plates. The die used for piercing the circular segment in station 3 consists of a hardened and ground shouldered plug (D1) surrounded by a bushing (D2). One side of the plug is ground to form the inner half of the circular segment, while the contour of the outer half is ground on the inside of the bushing. These two pieces are pressed together in the correct relation, and set into the die. The assembly is doweled in place to prevent shifting or turning. The trimming operations in stations 4 and 5 are performed by the combined action of the ground inserts (D3 and D4). The strip is piloted in stations 2 and 3 through the 0.278-in.-diameter hole pierced in station 1. The forming is done in stations 6, 7, 8, and 9, with cutoff also accomplished in station 9.

Progressive Curling of a Hinge. Stainless-steel strip can be manually or automatically fed into the die of Fig. 15-31. Three rivet holes and two holes for piloting holes are cut at the first station by quilled punches (*D*1), as well as an edge notch (used by the automatic stop). The central M-shaped hole is also cut at the first station. Forming punches (*D*3, *D*4, *D*5) and forming dies (*D*6, *D*7, *D*8), respectively, first-form, second-form, and finish a cylindrical curl in the part. Four pilots (not shown)

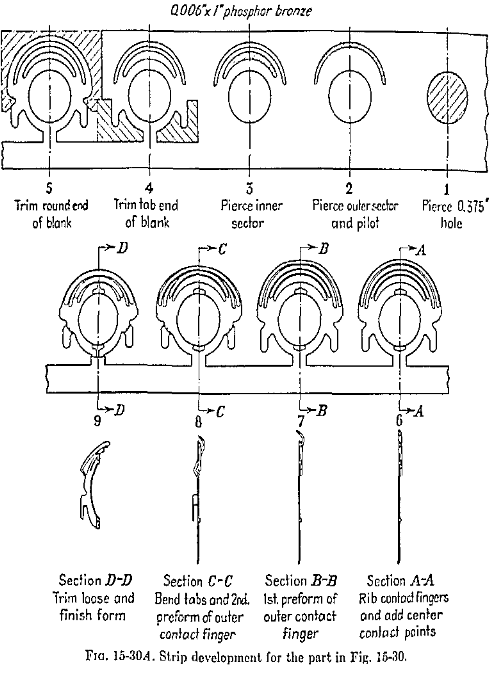


FIG. 15-30*A*. Strip development for the part in Fig. 15-30.

are used for positioning the part at the second and third stations; at the last station the part is bowed to a $3\frac{9}{32}$-in. radius and cut off from the scrap skeleton. Production in 50-ton OBI press is 900 parts per hour (manual feeding) and 1,200 parts per hour with an automatic feed. Ejection of part and scrap is by air jet.

Progressive Production of a Brass Bracket. Four perforating punches (*D*10) and four notching punches (*D*4, *D*5) cut the holes and the outline of the part in the die of Fig. 15-32. Six pilots (*D*3) and a pressure pad (*D*9) align and clamp the part (a bracket) as the legs are bent down and around a form block (*D*8). Two punches (*D*2) slide inwardly in holders (*D*1) actuated by cam blocks (*D*7) to form the part. A cut-

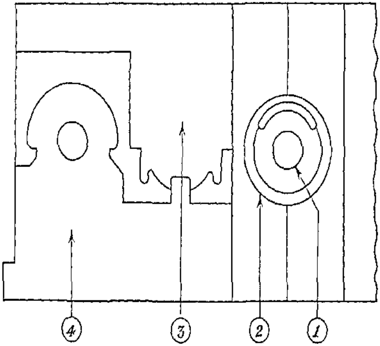
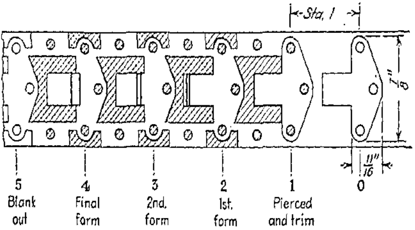


FIG. 15-30B. Layout of die in Fig. 15-30 at the cutting stations 3, 4, and 5.



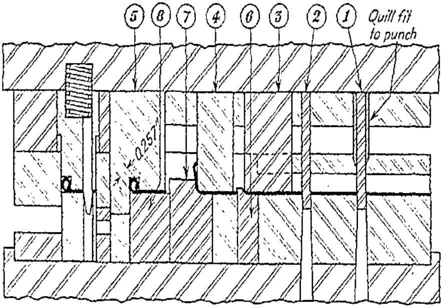


FIG. 15-31. Progressive curling of a hinge. (*Knapp Monarch Co.*)

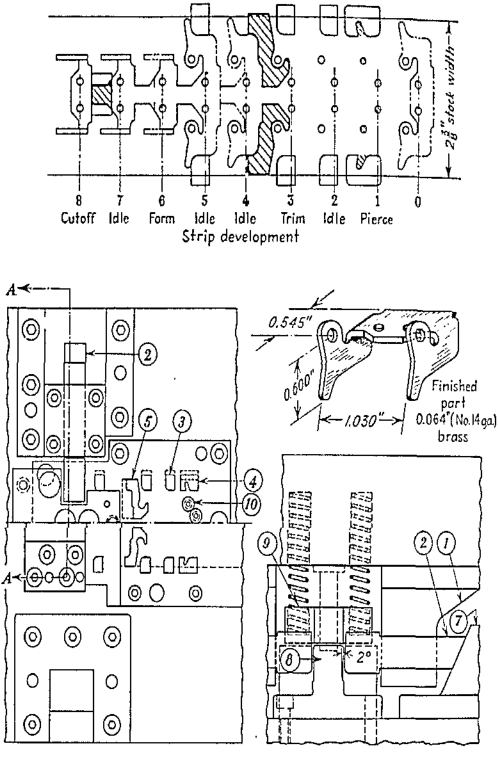


FIG. 15-32. Strip development and die for progressively producing a brass bracket. *(The Emerson Electric Mfg. Co.)*

off punch (*D6*) severs the part from the strip. Stock ($2\frac{11}{32}$ in. wide) is slide-fed into this die of 10-in. shut height, which is used in a press having a 3-in. stroke.

Progressive Die for Cover. A U-shaped cover of 0.036-in. cold-rolled steel is pierced, notched, trimmed, flanged, and formed in three progressive stations as shown in Fig. 15-33. Heeled trimming punches in station 1 trim the strip to the required outline and notches are cut, forming the carrier tab and freeing the metal for flanging in the next station. Station 1 also contains piercing punches for the piloting hole in the carrier tab and punches for the two 0.072-in.-diameter holes. These punches are guided by the stripper. Individual die buttons are installed in the die block for each of these punches. In station 2 the flanges are formed along each side of the strip. In station 3 the blank is parted from the strip, the carrier tab is sheared off, and the U-shaped part is formed. The right-hand side of view A is through station 1 and the

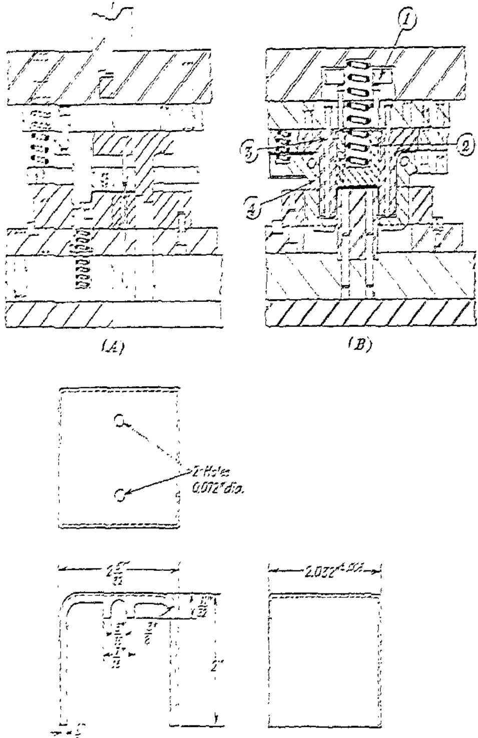


FIG. 15-33. Progressively formed U-shaped cover. (White-Rodgers Electric Co.)

left-hand side is through station 2. View B shows the stripping action in the final station. The lever (1) is actuated at the top of the stroke by a positive knockout. The lowering of this lever ejects the part from the die by the knockout (2). This lever also depresses the shedder pins (3), which causes the bell-crank-shaped stripper (4) to rotate, allowing the part to fall out.

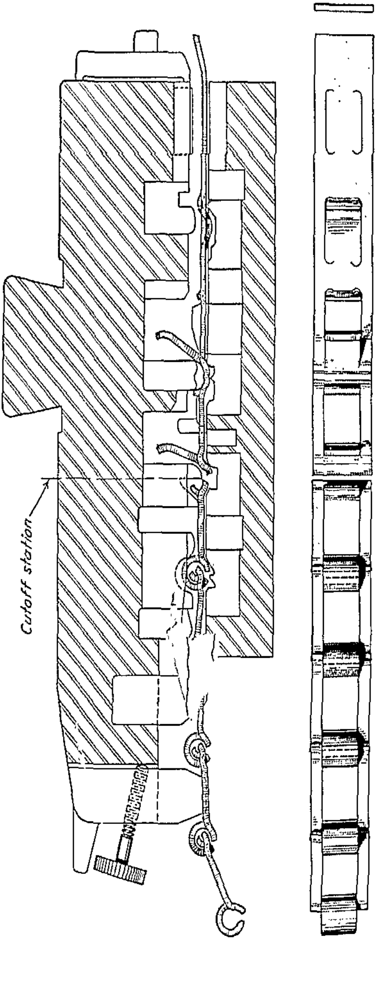


FIG. 15-34. Progressive die produces sprocket chain.

Die to Produce a Sprocket Chain. Sectional hardened-tool-steel punches and die elements progressively score, lance, notch, form, curl, and assemble a series of connected links for a sprocket chain from 0.062-in. cold-rolled-steel strip. The strip is conventionally fed until it reaches the cutoff station. In order to move the chain to the next station which assembles the links, a sprocket (not shown) actuated by the press slide pulls the chain into the curling or assembling station (Fig. 15-34).

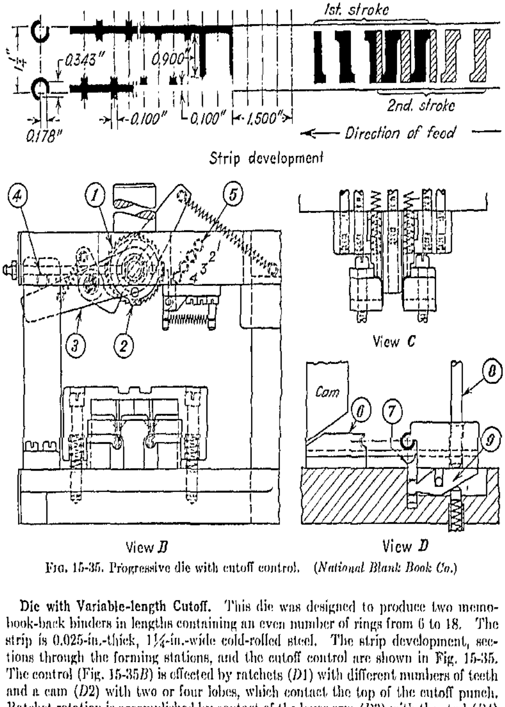


FIG. 15-35. Progressive die with cutoff control. (*National Blank Book Co.*)

Die with Variable-length Cutoff. This die was designed to produce two memo-book-back binders in lengths containing an even number of rings from 6 to 18. The strip is 0.025-in.-thick, 1¼-in.-wide cold-rolled steel. The strip development, sections through the forming stations, and the cutoff control are shown in Fig. 15-35. The control (Fig. 15-35*B*) is effected by ratchets (*D*1) with different numbers of teeth and a cam (*D*2) with two or four lobes, which contact the top of the cutoff punch. Ratchet rotation is accomplished by contact of the lever arm (*D*3) with the stud (*D*4) at the top of the press stroke. The number of teeth picked up on each stroke can be varied by moving a stop stud (*D*5) any one of four positions. The cam shown has four lobes, being made in two pieces with two lobes each. By removing a dowel pin and rotating one cam 90°, a cam with only two lobes is obtained. The versatility of the cutoff control is such that, by using a 36-tooth ratchet and a two-lobe cam, and by placing the stop stud in position 3, skipping three teeth on the ratchet, a binder with 12 rings is cut off. Using the same position of the stop stud, in conjunction with a four-lobe cam, a 6-ring binder will be cut off by the die. Figure 15-35*C* shows the first

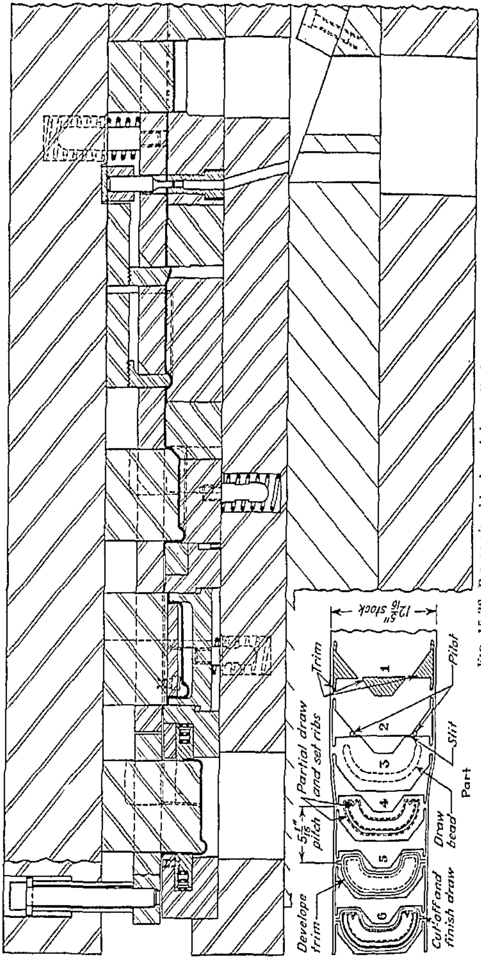


FIG. 15-30. Progressive blank and draw die for armrest.

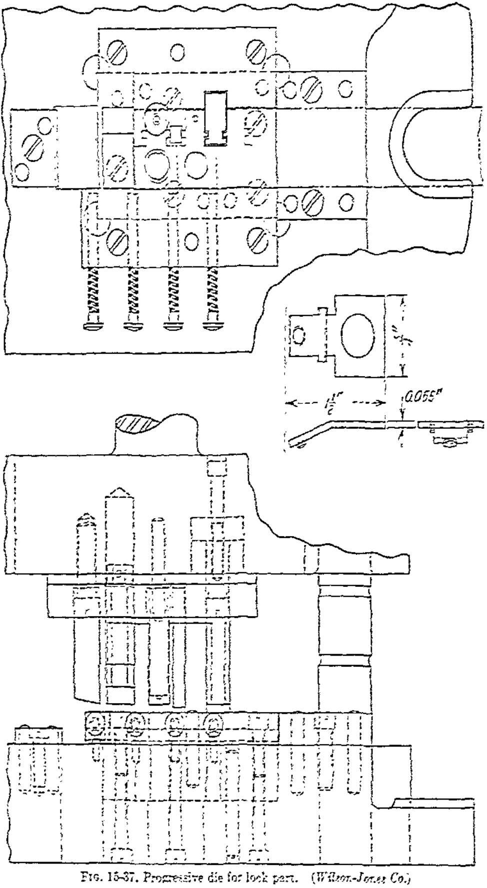


FIG. 15-37. Progressive die for lock part. (*Wilson-Jones Co.*)

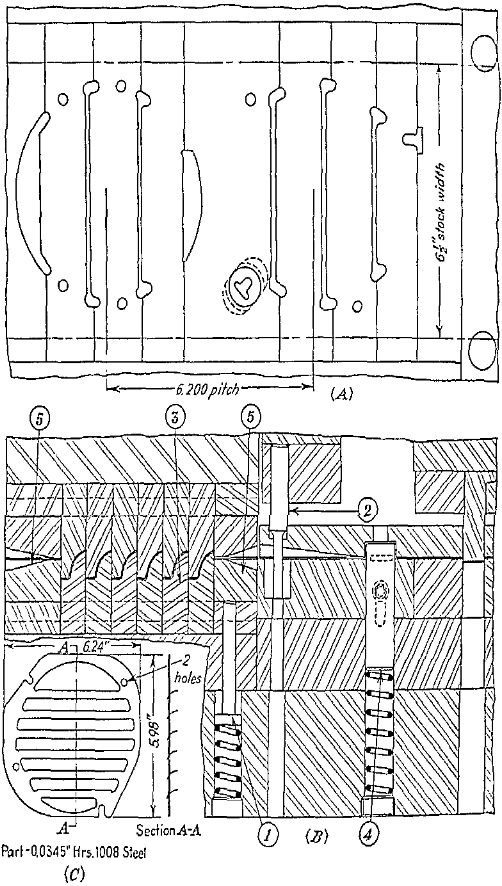


FIG. 15-38. Progressive louvering die: (A) plan view of piercing stations; (B) section through louvering station; (C) part. (*Buick Division, General Motors Corp.*)

forming operations on the ring: Fig. 15-35D shows the final forming operation. The slide D7 moves across the die to form the second quarter of the ring and the upward motion of D7 completes the form. The form block D7 is actuated by the rod D8 and the lever D9.

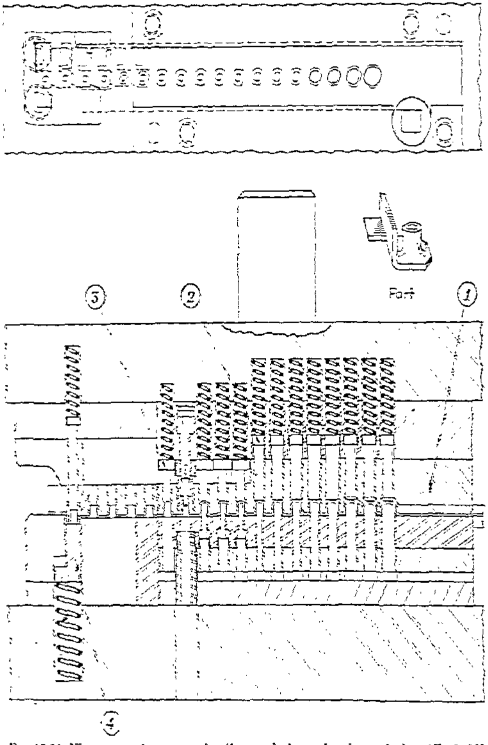


Fig. 15-39. Nineteen-station progressive die to make brass electric terminals. (Harig [illegible] Mfg. Corp.)

Progressive Blank and Draw Die. The strip development and a section through the die for an automobile front-door armrest are shown in Fig. 15-36. The stock strip is 0.0945-in. cold-rolled steel $12\frac{5}{8}$ in. wide. The blank is trimmed at station 1 and piloted at station 2. The strip is slit to provide two-point suspension for the blank and the bead is formed in station 3. Station 4 accomplishes the first draw operation.

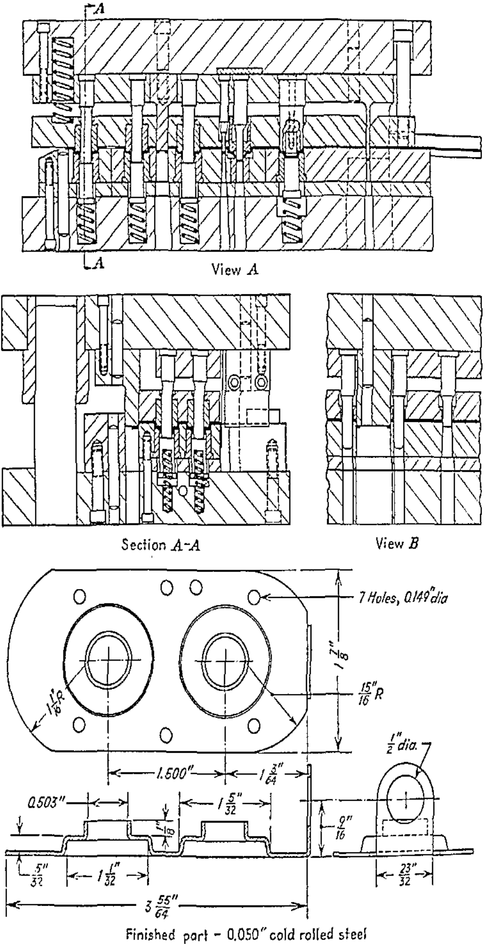


FIG. 15-40. Die to draw, pierce, flange, and blank out a steel plate. (*White-Rodgers Electric Co.*)

station 5 the trim operation for the excess stock, and station 6 the cutoff and final draw operation. Spring-loaded strippers remove the part from the punch, allowing it to drop through the die.

Progressive Die for a Lock Part. This four-station die (Fig. 15-37) notches, pierces, embosses, forms, and shears off a part of 0.065-in.-thick cold-rolled steel. The stripper is a fixed type attached to the die block and contains four spring-loaded stops for

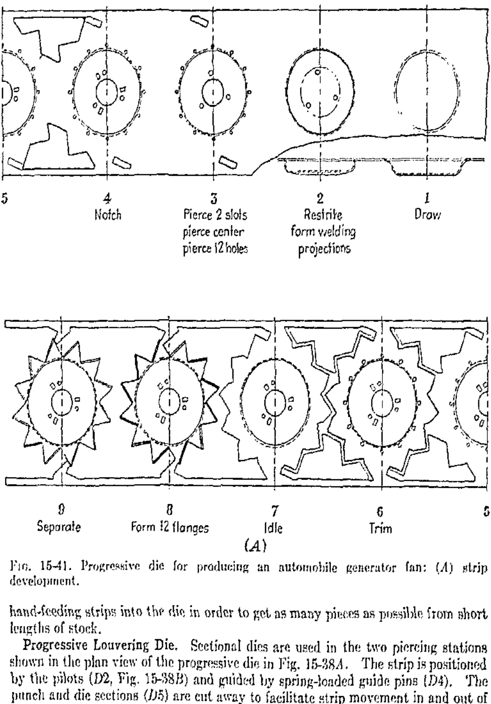
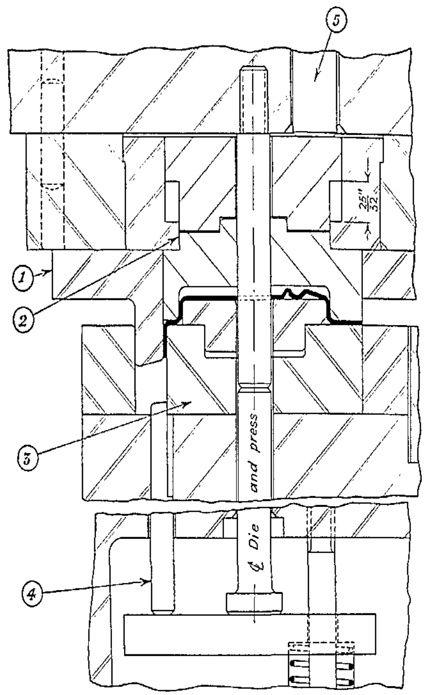


FIG. 15-41. Progressive die for producing an automobile generator fan: (A) strip development.

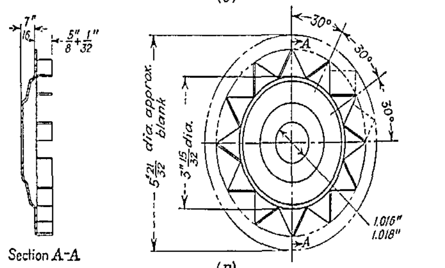
hand-feeding strips into the die in order to get as many pieces as possible from short lengths of stock.

Progressive Louvering Die. Sectional dies are used in the two piercing stations shown in the plan view of the progressive die in Fig. 15-38A. The strip is positioned by the pilots (D2, Fig. 15-38B) and guided by spring-loaded guide pins (D4). The punch and die sections (D5) are cut away to facilitate strip movement in and out of the louvering station which contains six sets of mating forming members (D3). This station incorporates spring-loaded lifter pins (D1). The completed part is blanked out and drops through the last station (not shown). The part is shown in view C.

Nineteen-station Die for Brass Terminal. This progressive die (Fig. 15-39) to make a brass electrical terminal of 0.040-in. brass has 18 stations plus a notching station which trims the edge of the strip and thereby creates a notch for locating purposes. A spring-loaded stripper plate upwardly strips the part from the drawing



(C)



(B)

FIG. 15-41 (*Continued*). (*B*) Part drawing; (*C*) flanging station. (*Chevrolet Division, General Motors Corp.*)

punches mounted in the lower punch retainer plate. The stripper plate raises the stock strip above the ends of the drawing punches to provide unimpeded stock travel through the die. Shedder pins (*D2, D3*) push the part down and out of the die cavities in the upper draw die (*D1*). A spring-loaded pressure pad and ejector (*D4*) clamps and ejects the part in the final cutoff and flanging station.

The small diameter of the cup allows it to be pierced in air (without die support) at station 12. A blast of air through the punch assures that the slug will drop down through the die instead of clinging to the punch. After forming the cylindrical portion, the strip is trimmed and a flange formed. At the last station, the part is cut off and an additional flange formed with the aid of a spring pressure pad which also ejects the part from the die.

Die to Draw, Pierce, and Flange a Plate. The part and sections through the die for producing the parts are shown in Fig. 15-40. This die pierces an hourglass cutout in the strip at the first station; in the second station two stepped-diameter cups are drawn. Station 3 pierces a hole in the bottom of each cup, seven 0.149-in.-diameter holes and one 0.5-in.-diameter hole in the face of the plate. In station 4 the sides of the 0.503-in.-diameter portion and of the 1⅟₃₂-in.-diameter portion are set to depth and diameter. At station 5 a side of two adjacent plates is trimmed and in station 6 the part is blanked from the side carrier strips and the tab bent downward. All punches are guided by a pin-guided stripper plate. The cup-sizing punches are bushed in the stripper plate. All the stations use inserted die buttons where space permits.

A previous but not satisfactory design produced the 1⅟₃₂-in.-diameter cup in several draw operations. The bottom of the cup was pierced and the tubular portion formed. The operation was too severe and caused excessive thinning and cracking.

Progressive Production of an Automobile Generator Fan. The strip development in Fig. 15-41*A* shows the results of the die operations that produce the part shown in view *B*. A flanging punch (*D1*, view *C*) forms the 12 blades downward against a forming ring (*D3*). Ejector pins (*D4*) push the part up and off the ring on the upstroke. A hold-down ring (*D2*) actuated by a positive knockout rod (*D5*) strips the part from the punch.

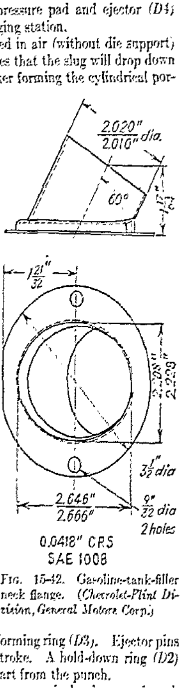


FIG. 15-42. Gasoline-tank-filler neck flange. (*Chevrolet-Flint Division, General Motors Corp.*)

Progressive Die to Produce a Tank Flange. A progressively drawn, pierced, flanged, and trimmed gasoline-tank-filler neck flange, produced in a 10-station die (one idle station) is shown in Fig. 15-42. The strip development is shown in Fig. 15-42*A*. The strip remains horizontal during the operations. Because the tubular portion position slopes from back to front, a cam-operated punch is needed to pierce the bottom of the cup prior to the tube-sizing operation, which is also cam-operated. The strip is carried through the die on a spring-loaded strip carrier which travels upward 1¾ in. to enable the cups to clear the die cavities. The first station uses a double-concave or hourglass-shaped punch to produce a partially circular blank with carrier strips on each edge. The first draw is performed in station 2 producing a half spherical cup. Figure 15-42*B* is a section through station 3, the second drawing operation which reshapes the cup. The blankholder (*D1*) and the die (*D2*) are composed of individual sections in each station, a good practice from the standpoint of maintenance and possible change in design. The punch (*D3*) in all forming stations is made

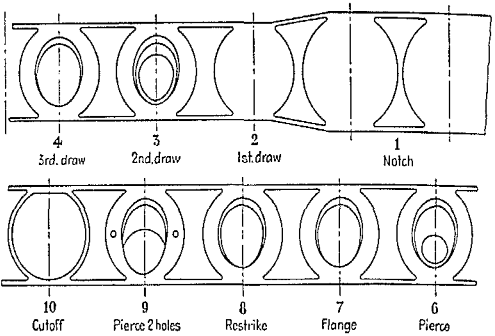


FIG. 15-42A. Strip development for tank-filler neck flange.

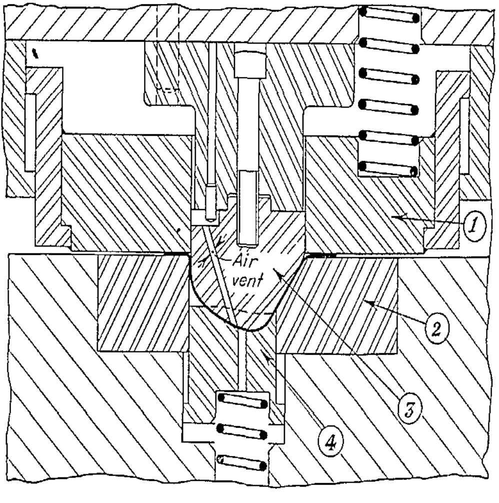


FIG. 15-42B. Section through second-draw operation on neck flange.

of two pieces of hardened tool steel to enable a smaller piece to be changed in case of wear or design change. A spring-loaded ejector (*D4*) is used in all forming stations to lift the cup out of the die cavity. The tubular section is further shaped, the bottom flattened, and the bead formed in the third draw at station 4 (Fig. 15-42*C*).

The bottom is pierced out of the cup with the inclined cam-operated punch shown in Fig. 15-42*C*. Stations 7 and 8 straighten and restrike the tubular portion to size. The forming punch (*D5*) shown in Fig. 15-42*D* is mounted in a sliding holder. The downward movement of the ram moves the sliding holder along the inclined surface (*D6*). A spring-loaded blankholder (*D7*) holds the strip firmly during the descent of

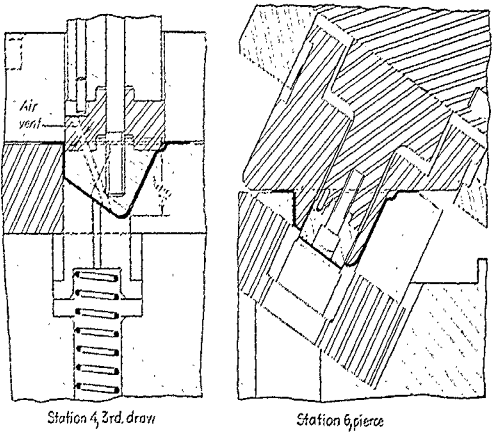


FIG. 15-42*C*. Section through third-draw operation on neck flange, and a piercing station.

the ram and strips the part from the punch on the ascent. The piercing operation at station 6 uses the same sliding toolholder arrangement. The spring-loaded die (*D8*) is split on its longitudinal center line and remains open while the ram is up so that the strip can be raised vertically. The cam (*D9*) attached to the punch holder locks the die closed for the forming operations. Two $\frac{3}{32}$-in.-diameter holes are pierced in the flange in station 9. At station 10 the flange is blanked to shape and the part drops through the die and bolster plate. This die is mounted in a heavy cast-alloy-iron die set with four guide posts. The general construction of the die is heavy, using good steel and hardened parts to withstand the high production requirements.

Die for Fabricating a Spark-plug Seat Gasket. This progressive die produces five seat gaskets at a press stroke. The strip pattern shows alternate rows of three and two gaskets across a strip of 0.020-in.-thick SAE 1008 sheet steel $5\frac{3}{4}$ in. wide. The part and a section through the die showing the development are shown in Fig. 15-43. The blank advances approximately $1\frac{1}{4}$ in. at each stroke of the press and there is an idle station between each working operation to allow more space in the die for heavy working stations. Station 1 shears the blank from the strip except for a small tab on each side to carry it through the die. Station 2 draws a cup; station 3 forms a bead around the cup, and station 4 pierces the flat section from the bottom of the cup. The remaining radiused portion of the bottom is formed into a straight tube in station

5. The curling operation is done in station 6. The part is closed tightly in station 7, and the part is blanked and dropped through the die in station 8. All the punches and the die inserts are backed up by a ⅜-in.-thick hardened and ground steel plate. Spring-loaded lifters push the part out of the die cavities and spring-loaded stock carriers hold the strip up while advancing to the next station. Limit switches stop the press in case of misfeeding.

Die for Producing a Typewriter Part. This die (Fig. 15-44) produces a typewriter part with close tolerances at high production rates. The part is made of 0.040-in.-thick cold-rolled steel ½ in. wide. The first five stations of the die are for marking,

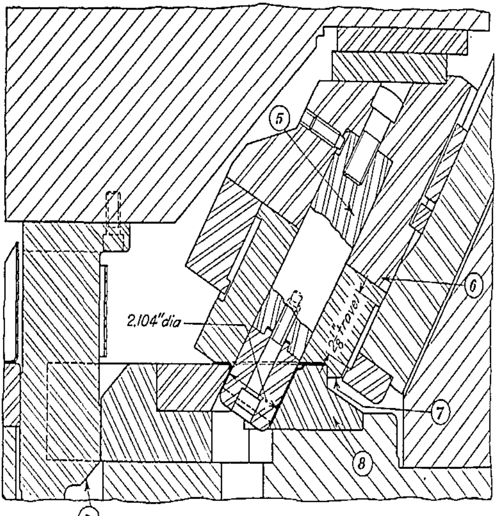


FIG. 15-42*D*. Straightening and restriking the tubular portion of neck flange.

notching, and piloting the strip. Station 6 curls the tabs on the end of the blank. The next station pierces and extrudes the hole in the same area. The small pointed extruding punch is mounted in a quill (*D*1) and guided by a bushing in the stripper plate. In the same station another operation performed on the blank is the bending of one tab up and another down (section *C-C*). In this operation the blank is held by the hold-down (*D*2) while the punch (*D*3) bends a tab downward. At the same time a tab on the other side of the blank is bent upward by the punch (*D*4) actuated by the rocker assembly (*D*5). In the final operation in station 8 the part is cut off and formed down on two sides, and one of these sides is bent under to form the final closed rectangular shape. The cutoff and form are accomplished by the punch (*D*6, section *A-A*) over the cam-actuated retractable mandrel (*D*7) shown in sections *A-A* and *B-B*. The forming of the final shape is accomplished by the air-cylinder-actuated punch (*D*8) which wraps the metal under the mandrel (*D*7). On the upstroke of the press the mandrel and punch retract, allowing the part to fall through the die.

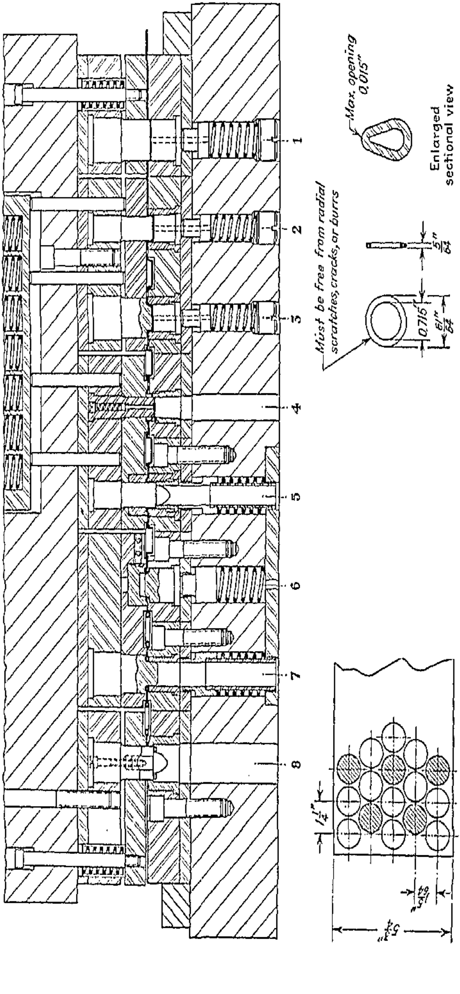


FIG. 15-43. Progressive die for producing spark-plug seat gaskets. (*AC Spark Plug Division, General Motors Corp.*)

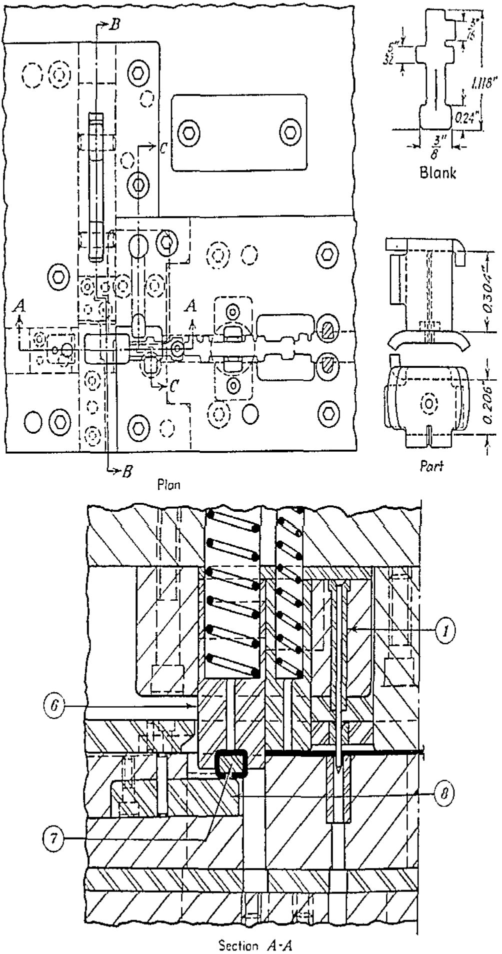


FIG. 15-44. Blanking and forming a small typewriter part.

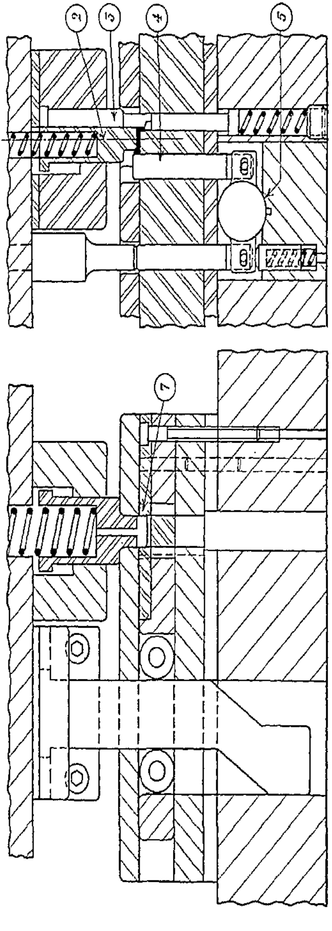


FIG. 15-44 (*Continued*).

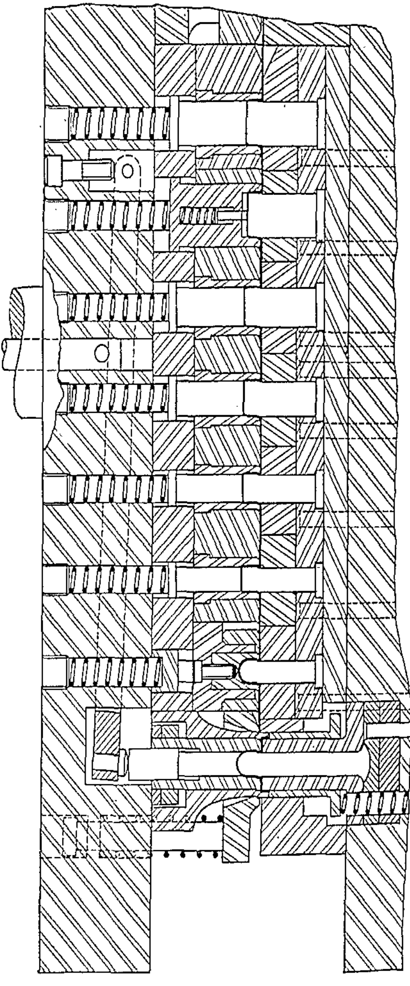


FIG. 15-45. Progressively drawing a cup of 0.005-in.-thick aluminum. (*Harig Mfg. Corp.*)

Progressively Drawing an Aluminum Cup. The progressive die shown in Fig. 15-45 draws a cup of 0.005-in.-thick aluminum alloy. In station 1 a pilot hole is perforated. In station 2 the stock is piloted against a stock lifter which, along with the spring-loaded stripper, raises the stock approximately ¼ in. to allow the stock to progress as the various cups are drawn in subsequent stations. Station 3 blanks out a typical hourglass cutout. Stations 4 through 10 progressively lengthen the depth of draw. In station 11 the part is blanked completely, seven radial lines are stamped, and a circular flange is drawn. In the final station the part is shedded by a mechanical knockout bar with a lever operating from the center of the die. The part is stripped by pressure pins from the bottom. One of the better features of this die is that the cups are formed upside down, so that spring-loaded strippers return the strip to its normal operating plane on each stroke of the press and allow it to advance over a smooth stripper surface.

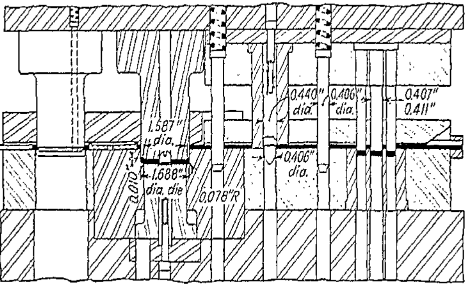


FIG. 15-46. Progressive die to produce a coined brass part. (*Harig Mfg. Corp.*)

Progressive Die to Produce a Coined Brass Part. The die design (Fig. 15-46) shows conventional piercing in station 1 for the 0.125-in.-thick brass strip. In station 3 a punch coins a small counterbore around the center hole. A hardened-steel bushing surrounds the punch to keep the top surface of the blank flat. In station 5 the opposite side of this same hole is chamfered and the top surface of the blank is coined to a 1.587-in. diameter and to a 0.010-in. depth. Before the coining operation this station blanks the part to a 1.688-in. diameter. On the upstroke of the press the blank is returned to the strip. The strip then advances to station 7 where the part is pushed through the bottom of the die. Stations 2, 4, and 6 are idle stations.

Progressive Die to Pierce, Blank, and Shave. Distortion of parts as they move from station to station is minimized by piercing an expansion slot in the strip at the first station (Fig. 15-47). Pilot holes are also pierced on each side of the strip to ensure accuracy and a good finish in the blank and shave stations. The hole is pierced and the complete outline, with 0.004-in. shave allowance per side, is blanked to the fracture point in the next station; then the blank is returned to the strip by spring pressure. At the shaving station two sets of pilots, one on either side of the station, accurately position the blank, and the hole and outline are shaved simultaneously. The part is air-ejected out the back of the die. Strip stock is 0.045-in.-thick hard cold-rolled steel.

Progressive Die to Produce a Release Cam. The progressive pierce, shave, form, and blank die shown in Fig. 15-48*A* produces a 0.035-in.-thick stainless-steel release cam in nine operations. The strip is partially blanked in such a manner that only four small tabs remain to be sheared to release the cam from the strip. The shaving operation in station 5 shaves the entire periphery of the previously blanked hole to balance the cut.

Section *A-A* shows the construction of the piercing punches for the circular segments in stations 2 and 3. Section *B-B* is a section through the final forming station 8 and also shows the construction of the stripper-plate guide posts. There are two each

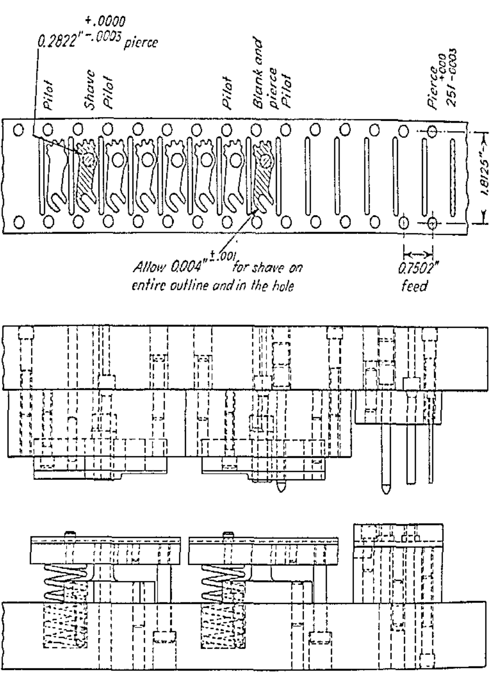


FIG. 15-47. Progressive die to pierce, blank, and shave. (*National Cash Register Co.*)

of the long and short guide pins in the die. The die set contains four antifriction guide posts and bushings. The high-carbon, high-chrome hardened-steel die blocks are fitted into a groove in the lower shoe, and their endwise location is held by keys in addition to the screws and dowels in each section.

Progressive Die with Carbide Inserts. The use of carbide for the forming elements as well as cutting elements is shown in Fig. 15-49. The part is a track tie for a toy electric train made of 0.022-in.-thick by 1.312-in.-wide strip steel. The strip development in view *A* shows the steps through which the strip progressed. View *B* shows the sectionalizing of the die block making the three H-shaped cutouts, and the notching of the strip. The punches were made of solid carbide rectangular bar stock

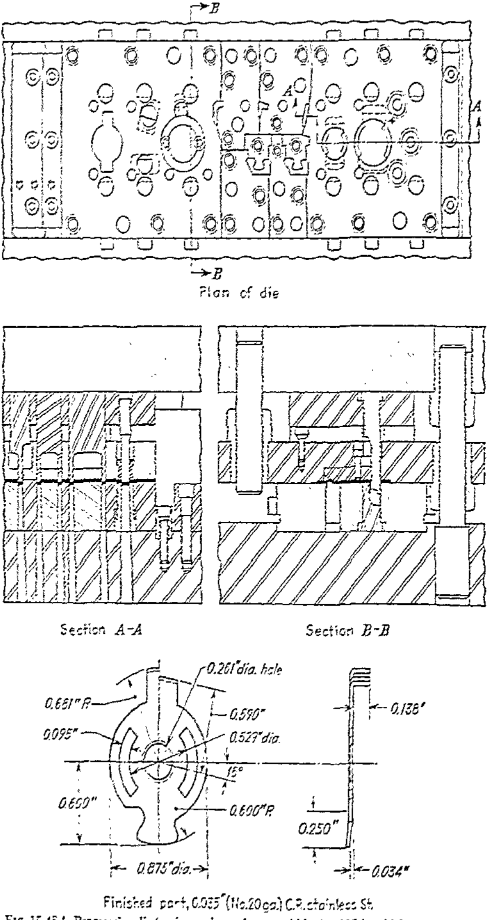


FIG. 15-48A. Progressive die to pierce, shave, form, and blank 0.035-in.-thick stainless steel. (Argus Cameras, Inc.)

machined to shape. The punch-holder plates corresponding to view *B* are also sectionalized for easy and accurate machining. Individual carbide punches and a die made of four carbide sections are used to form the flanges. The punch is in the lower shoe and the die in the upper shoe (view *C*). A spring-loaded stripper fits around the punch so that, on the upstroke, the projections or flanges in the strip are formed upward, making it easy to advance the stock. The carbide punch and die used to curl the edges of the track tie are shown in view *D*. A spring-loaded combination hold-down and ejector is fitted between the two punches, and four spring-loaded lifter pins carry the part out of the forming die. View *E* shows the pilot pin and a fixed stripper for the cutoff punch. View *F* shows the stripper and stock guide beyond the cutoff punch. The die block is inserted in a groove machined in the lower shoe as shown in

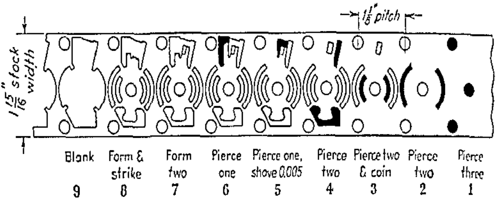


FIG. 15-48*B*. Strip development for part in Fig. 15-48*A*.

view *D*. Four antifriction guide bushings are inverted in the die shoe to guide the punch holder which has the leader pins attached to it.

Progressively Forming Wire Springs. The die shown in Fig. 15-50 uses a rotating punch to form small spring rings from 0.078-in.-diameter wire.

A V bend is formed in the wire in station 1 by the forming punch (*D1*). The wire is then moved against a stock stop in station 2 and is held by the spring-loaded rotating punch (*D2*) while it is cut off by the punch (*D3*). The lower end of the rotating punch is grooved to fit over the wire. The bushing (*D4*) in the upper die contains two dog-point setscrews (*D5*) which project into helical grooves in the rotating punch so that, as the bushing descends, the punch is forced to rotate.

Also contained in the upper die are two cams (*D6*) which, on their descent, move the sliding wiper blocks (*D7*) toward the punch to confine the wire while it is being formed.

The die member (*D8*) directly under the rotating punch also rotates, because the wire stock keys the members together while the press slide is down. The lower die member does not return to its starting position after each stroke but is held in a position 180° from its starting position by a spring-loaded ball nesting in an indentation in the side of the die member. Two indentations are located directly opposite each other to ensure correct alignment of the die with the punch. On the upstroke the punch rotates back to the original position and rises away from the die, leaving space for the completed work to be blown out of the die.

LAMINATION DIES

A great variety of sizes and shapes of laminations are made on progressive dies. Many of these dies are made with carbide cutting elements. The added cost of carbide is justified by the high production requirements and by the fact that the laminations are usually made of highly abrasive steels.

The design of a carbide die does not differ basically from that of an all-steel die except that the guide pins and the die set are made heavier to ensure accurate alignment and prevent deflection. The tolerances on the carbide sections are usually held closer than those of a steel die.

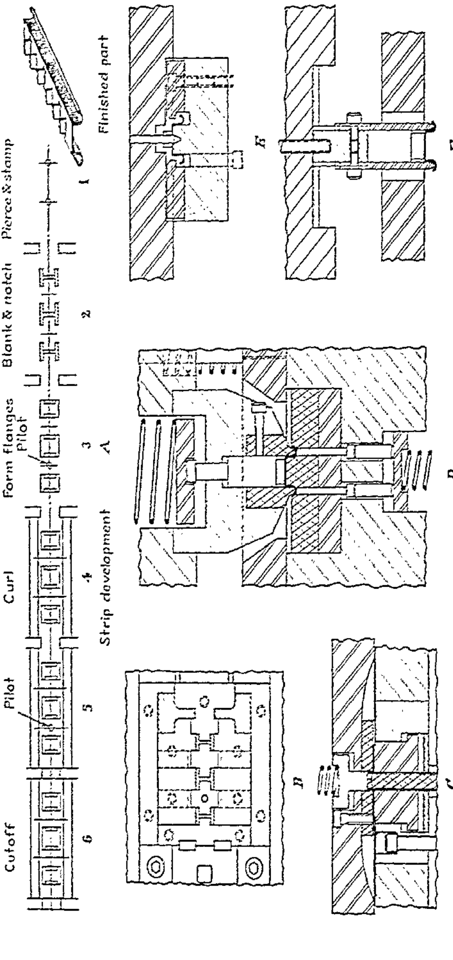


FIG. 15-40. Carbide piercing, forming, and cutoff die for electric-train track tie. (Eglinton Carbide Products, Inc.)

Fabricating E and I Laminations Progressively. A simple die and strip development for E and I laminations is shown in Fig. 15-51. This is a three-station die in which the first station pierces all the holes and trims the strip to width; station 2 blanks out the I laminations and the third station shears the E laminations from the strip. View *B*, a section through the second station, shows the blanking of the I laminations and a spring-loaded tension device to keep the stock against the stock guide. View *C* shows the parting of the E laminations in which one falls through the die and the other passes off the end of the die. This is an all-steel die.

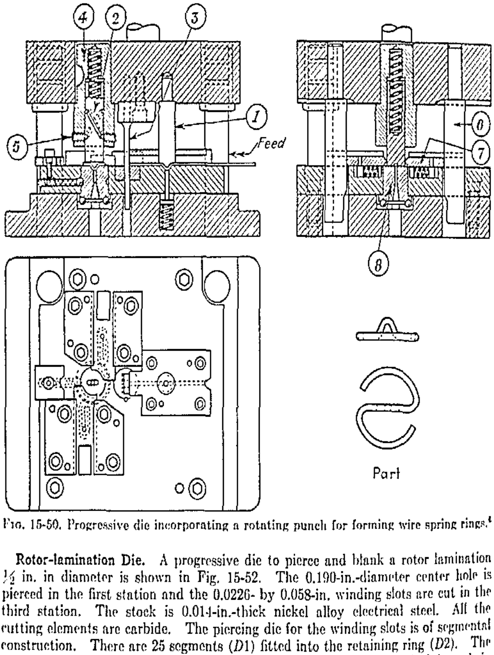


FIG. 15-50. Progressive die incorporating a rotating punch for forming wire spring rings.[4]

Rotor-lamination Die. A progressive die to pierce and blank a rotor lamination ½ in. in diameter is shown in Fig. 15-52. The 0.190-in.-diameter center hole is pierced in the first station and the 0.0226- by 0.058-in. winding slots are cut in the third station. The stock is 0.014-in.-thick nickel alloy electrical steel. All the cutting elements are carbide. The piercing die for the winding slots is of segmental construction. There are 25 segments (*D*1) fitted into the retaining ring (*D*2). The center sleeve (*D*3) is a bushing for a pilot. A hardened-steel backup block is made in two pieces (*D*4 and *D*5) to facilitate machining slots for slug disposal. The slot piercing punches are held in position by a retaining ring and plug. These slender punches are also guided by the stripper plate. The next cutting station blanks the part and returns it to the strip for push-out two press strokes later. In the first station, a sleeve under the head of the carbide piercing punch is used to adjust the punch to height after resharpening. The first spring-loaded piloting punch has a tapered groove around the top. In case of a misfeed, this pilot strikes solid metal, causing it to retract, moving a rod to actuate a limit switch, thereby opening an electric circuit and thus stopping the press.

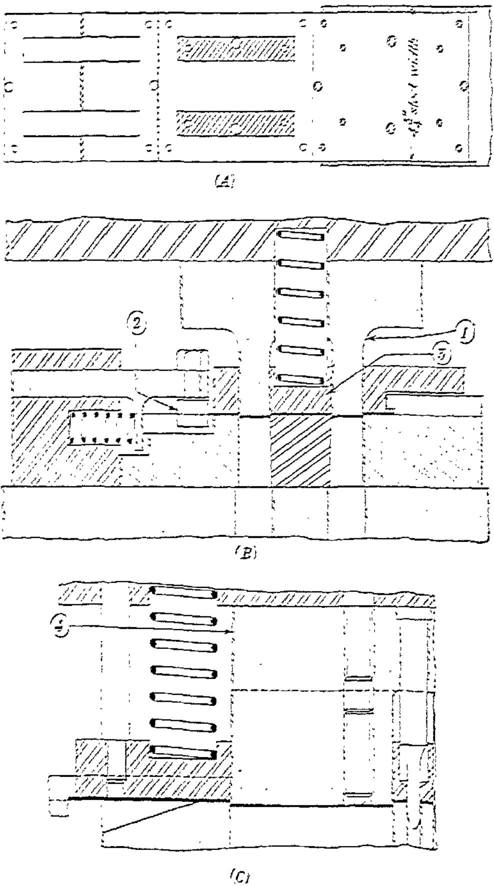
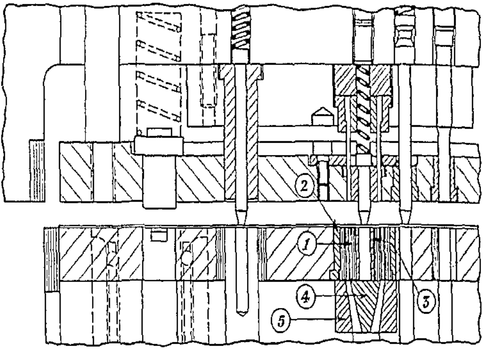


FIG. 15-51. Progressive die for E and I laminations: (A) strip development; (B) blanking station for I laminations; (C) blanking station for E laminations. (Berk Corp.)



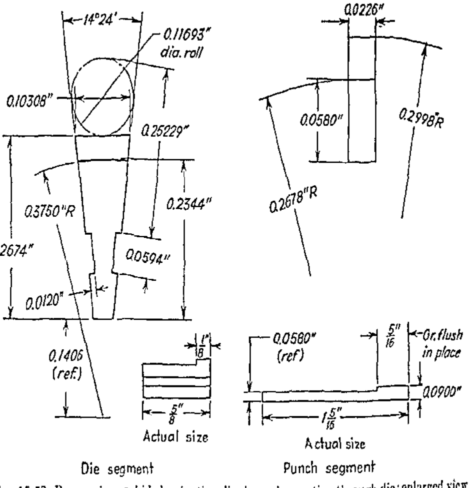


FIG. 15-52. Progressive carbide lamination die shown is a section through die; enlarged view of die segment; and enlarged view of punch. (*Eglinton Carbide Products, Inc.*)

Die for Armature and Field Laminations. A progressive die with carbide cutting elements for producing armature and field laminations of 0.031-in.-thick stock is shown in Fig. 15-53. The carbide die sections are of such length that they extend

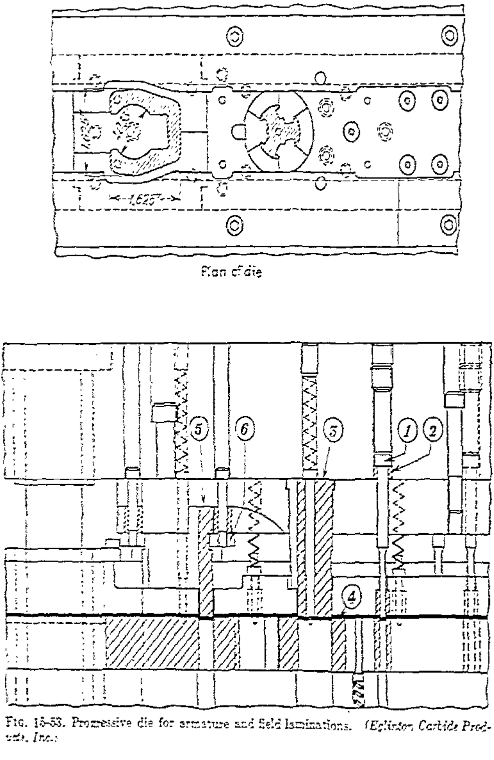


FIG. 15-53. Progressive die for armature and field laminations. (Eclipse Carbide Products, Inc.)

through the die block, which serves only as a locator. The small piercing punches (D1) have sleeves (D2) under their heads to compensate for grinding and are guided by bushings inserted in the stripper.

The carbide blanking punch (D3) for the armature lamination is retained in the punch plate with a shoulder and prevented from turning by pins bearing endwise against two opposite flat surfaces of the punch. The opposite ends of these pins bear against dowels. A spring-loaded shedder pin breaks the oil seal and prevents the

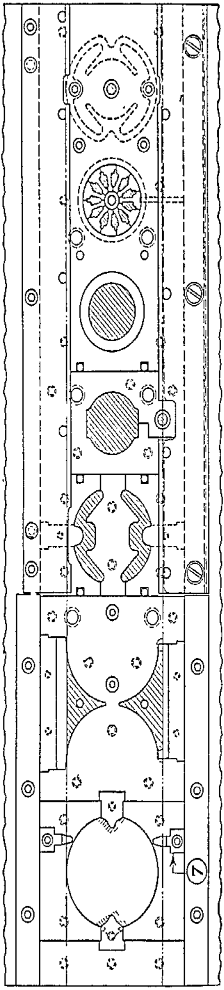


FIG. 15-54A. Strip development for rotor and stator laminations. (*Eglinton Carbide Products, Inc.*)

blank from sticking to the end of the punch. The die (D4) is made of six carefully ground sections fitted to the die block and keyed to prevent rotation.

The blanking punch (D5) for the field is made in two sections and held in the punch plate by two retaining strips (D6). The punch is squared by flats ground to fit into a longitudinal slot in the punch plate. The blanking die is made of three carefully ground carbide sections fitted into a recess in the die shoe.

Carbide-tipped scrap cutters cut the scrap stock into short lengths. Four antifriction guide posts and bushings are used to maintain accuracy over long production runs of this die.

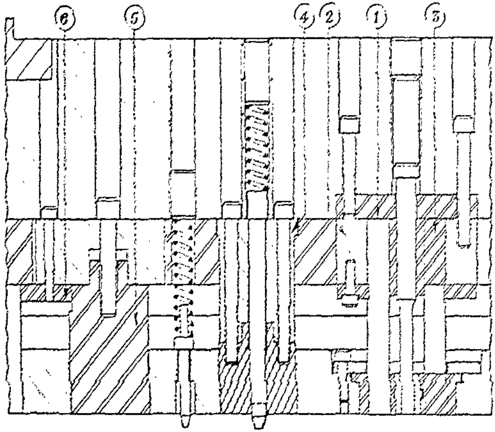


Fig. 15-54B. Section through upper shoe of lamination die, showing punch construction.

Carbide Die for Fabricating Motor Laminations. Strip development for a fragile stator and rotor lamination is shown in Fig. 15-54A. The first station pierces five small holes, two of which are used as piloting holes, one as the shaft hole for the rotor, and the other two as assembly holes for the stator. Stations 2 and 3 produce the rotor lamination which drops through the die at station 3. The remaining stations produce the stator lamination. The carbide die buttons and segments for the first three stations are contained in a plate which is recessed into the die shoe. The recess extends the full length of the shoe and the die segments for the remaining stations are also fitted into it. View B is a section through the upper die or punch-holder assembly. All the punches are guided by the spring-loaded stripper plate. The punches (D1) for the rotor winding slots are held in position by a retaining ring and spider (D2 and D3). The rotor blanking punch (D4) has a carbide tip attached to a tool-steel shank by screws. The screw threads in the tip were tapped by an electric-arc process. The center of the two-piece punch has been bored to hold a spring-loaded pilot. The solid carbide punch (D5) has a pilot which has been fitted into the punch plate and retained by one screw at the center. When tapping a punch of this type it is advisable to relieve the threads a little deeper than the height of the pilot so that the load can be distributed over the shoulder. The key (D6) bears on flats ground on the punches for the two adjoining stations to prevent punch rotation.

The finger (*D7*) is an egg-shaped strip flipper, designed to lift the strip high enough so that it does not catch in the die cavity.

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SECTION 16

COMPOUND AND COMBINATION DIES*

The terms "compound" and "combination" have frequently been interchangeably used to define any one-station die, the elements of which are designed around a common center line (usually vertical), and in which two or more operations are completed during a single press stroke. The dies described in this section are classified as follows:

1. *Compound Dies.* Press tools in which only cutting operations are done, usually blanking and piercing

2. *Combination Dies.* Press tools in which a cutting operation (usually blanking) is combined with a shaping or deforming operation (bending, forming, drawing, coining, etc.)

COMPOUND DIES

A common characteristic of compound-die design is the inverted construction, with the blanking die on the upper die shoe and the blanking punch on the lower die shoe. This construction commonly calls for the pierced slugs to pass through the lower die shoe.

Blank-and-pierce Dies. Compound dies are particularly useful for producing pierced blanks to close dimensional and flatness tolerances. Generally the sheet material is lifted off the blanking punch by a spring-actuated stripper, which may be provided with guides to feed the material and a stop to position the material for the next stroke. The blank tends to remain in the die, from which it is removed by a spring stripper or by a positive knockout. A positive knockout is most satisfactory when blanking relatively hard or heavy materials that tend to remain flat without the use of a holddown or pressure pad. A combination spring-actuated blankholder and knockout is used for blanking thin and springy materials when flatness and accuracy are required. It also is used when the press has no positive-knockout attachment, or when the physical size of the blank is too large to eject properly. Ejection of the blank from the die by spring or positive knockouts makes angular die clearance unnecessary, assuring constant blank size through the entire life of the die.

A typical example of a compound (blanking and piercing) die is shown in Fig. 16-1. During the cutting cycle, the stock is held flat between the faces of the stock stripper and the blanking die. The blanking die makes contact with the stock slightly before the piercing punch, which pierces a hole in the center of the piece after it is blanked out of the strip. As the piece is blanked out, the strip is carried below the cutting edge of the blanking punch (Fig. 16-1*B*) and afterward is brought back slightly above the punch level by the lower stripper.

A compound die for blanking and piercing a clutch disk is shown in Fig. 16-2*A*. The clutch disk (Fig. 16-2*B*) is made of 0.072-in. half-hard cold-rolled sheet steel. The blank is produced from a 10-in.-wide strip and a 6½-in.-diameter hole is pierced in the center. Subsequent operations in other dies pierce 12 small holes in the disk and bend up the ears on the five tongues. In this two-section compound die, the blank is cut from the strip and forced downward into the die by the punch.

* Reviewed by E. C. Clifford, Superintendent, Eagleside Tool & Mfg. Co.

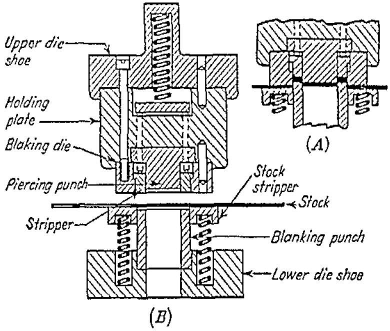


FIG. 16-1. Typical compound blank-and-pierce die.[1,*]

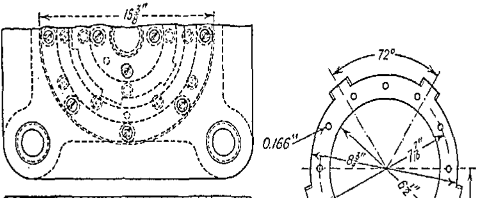


FIG. 16-2. (A) Compound die that blanks out clutch disk and pierces center hole in one operation. (B) Finished clutch disk. (*L. L. Locke.*)

The piercing punch (*D*1)† is a solid block and fits a counterbore in the die shoe. The blanking die (*D*2) also is fitted in a counterbore in the die shoe. A pressure pad (*D*3), located between the die sections, is supported and operated by four pressure pins. Two stripper plates are operated in connection with the punch, one (*D*4) being located on the outside of the outer cutting edge, and the other (*D*5) on the inside of the inner cutting edge. Helical springs furnish stripping pressure for the plates. The construction of this compound tool is substantially the reverse of that shown in Fig. 16-1 because the blanking die and piercing punch are supported by the lower die shoe.

* Superior numbers relate to References at the end of this section.

† *D* indicates detail number on drawing.

A compound die for making a pierced blank for a washer is shown in Fig. 16-3. One press stroke punches the center hole and blanks the piece from 0.015-in. cold-rolled-steel strip. The piercing punch is attached to the upper die shoe, and the blanking punch is attached to the lower die shoe. The piercing punch contacts the material slightly ahead of the blanking die. The part is stripped from both the blanking die and piercing punch by a positive knockout. A spring-loaded shedder pin prevents the part from adhering to the face of the knockout. The blanked strip is lifted off the blanking punch by a spring-loaded pressure pad.

In the blanking and piercing die (Fig. 16-4) the blanking die is made in three pieces whose cutting edges combine to form the outside shape of the part. The part is blanked from 0.050-in. cold-rolled-steel strip. A blanking punch mounted on the lower die shoe mates with the sectionalized blanking die mounted on the upper shoe. Piercing punches mounted in the upper shoe pierce two small holes in the part as it is

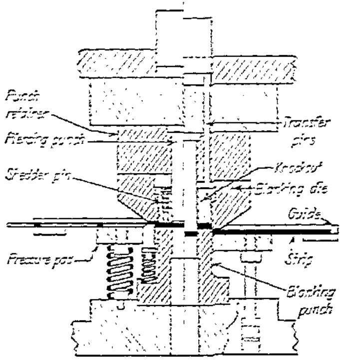


Fig. 16-3. Blank-and-pierce die for a washer. (Cousino Metal Products Co.)

being blanked from the strip. A stripper plate removes the work from the blanking punch, and a shedder pin strips the blank from the small punches.

Three washers and a slug are produced at a single stroke of the press by the die shown in Fig. 16-5. Three concentric punches are attached to the upper shoe, and two concentric sleeve dies are attached to a special combination die block and lower shoe. Two concentric ejector sleeves fit between the punches and two concentric strippers for the blanking dies, one between the dies and one outside the outer die. The outermost of the three upper punches functions as a blanking die, cutting on its ID only. It is seated firmly in a groove in the punch holder and held in place with a screw-on ring. The intermediate blanking punch and the solid center piercing punch are integral and are screwed to the bottom of the punch holder. The ejector sleeve and knockout assembly slide freely between the punches, and gravity holds the ejectors down when the die is open. The knockout ejects the two washers when the press ram reaches the top of its stroke. The spring is intended to balance the weight of the ejector knockout so that the washers will not drop out accidentally.

The strippers, which hold the stock and remove both the pierced stock and the intermediate washer, are actuated by a die cushion through pressure pins. The solid slug falls through the center die. All punch and die edges are sharp except the OD of

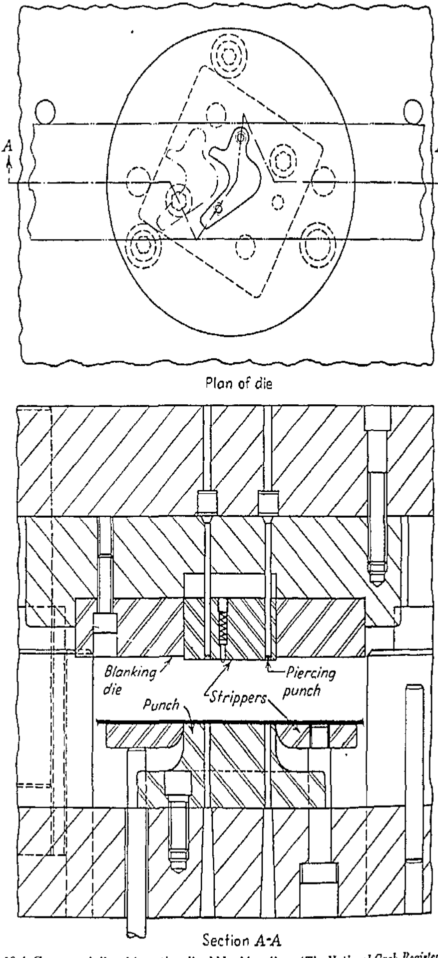


FIG. 16-4. Compound die with sectionalized blanking die. (*The National Cash Register Co.*)

the outside punch. This die cuts cardboard washers from $\frac{1}{16}$- and $\frac{1}{8}$-in. stock but also could cut thin metal. A progressive die could be used to make these washers and automatically sort them.

Blank, Pierce, and Notch Die. In the compound die shown in Fig. 16-6, for producing gray fiber spool heads, the $\frac{3}{32}$-in. sheet fiber stock is fed by hand and is located by a finger stop. This is an inverted die with the blanking punch mounted on the lower shoe. To simplify machining the contour of the cavity in the blanking die (*D*1), the projections into the cavity to cut the notches on the periphery of the blank are inserts in the die. These inserts (*D*2) are keyhole-shaped, the circular portion having a tapped hole to use in securing it to the die plate. The knockout (*D*3) is made in two pieces to facilitate the construction of slots to guide the four slender piercing

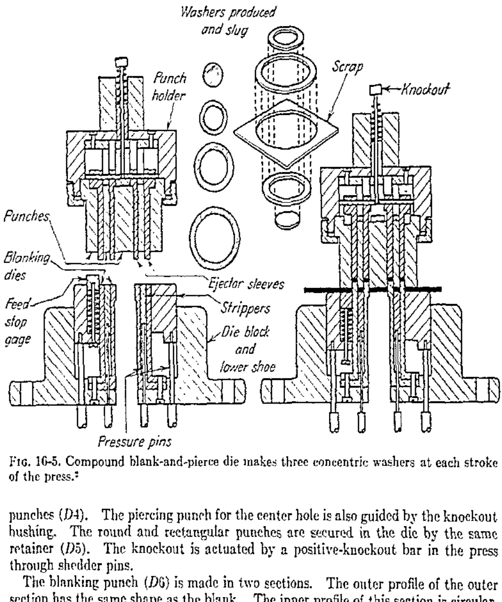


FIG. 16-5. Compound blank-and-pierce die makes three concentric washers at each stroke of the press.[2]

punches (*D*4). The piercing punch for the center hole is also guided by the knockout bushing. The round and rectangular punches are secured in the die by the same retainer (*D*5). The knockout is actuated by a positive-knockout bar in the press through shedder pins.

The blanking punch (*D*6) is made in two sections. The outer profile of the outer section has the same shape as the blank. The inner profile of this section is circular, with notches or keyways the size of the small perforations. The inner section is circular, with flats to serve as the inner edge of the die for the piercing punches. A spring stripper contains the stock guides and strips the blanking punch.

Trim-and-pierce Dies. Most drawn shells must be trimmed. If the trimming is to be performed in a regular single-action press instead of a special flat-edge trimming press, and if other cutting operations are required after the draw, it usually is economical to combine these with the trimming operation. Often shells must be pierced, and the trimming and piercing are readily performed by a compound trim-and-pierce die, two examples of which are shown in Fig. 16-7. A die that pierces holes in a shell

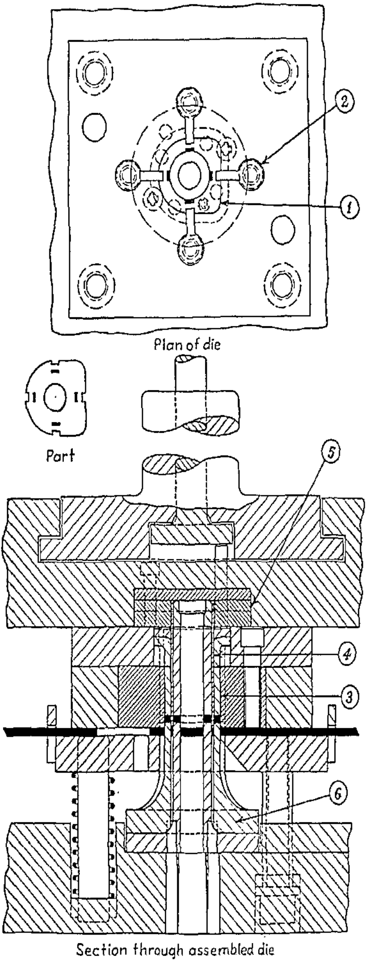


Fig. 16-6. Compound die for blanking, piercing, and notching fiber spool head. (*Harig Mfg. Corp.*)

flange at the same time that the edge is trimmed is shown in Fig. 16-7*A*. After trimming, in case the shell is carried up by the upper die, it is stripped from the die and the punches by a knockout. An inverted die for trimming and piercing shallow shells is shown in Fig. 16-7*B*. Punches pierce holes in the flange, and a center punch pierces a hole in the shell bottom. An indirect knockout must be used because of the centrally located punch. Bushings in the knockout support the long slender punches that pierce the flange holes. The central punch is shorter and does not need support. Oversize parts would tend to stick in these dies, and means of ejection should be provided.

The scrap material beneath the trim die and around the punch can be slit by a chisel-point scrap cutter for easier removal.

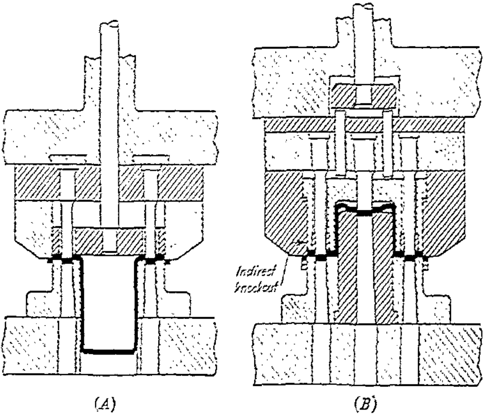
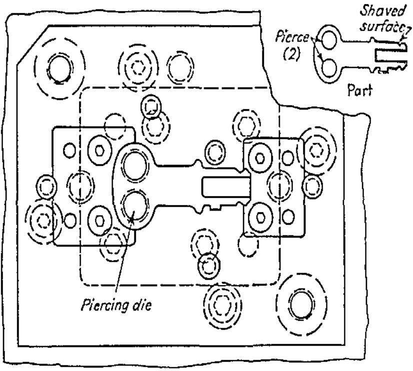


FIG. 16-7. Compound trimming and piercing dies: (*A*) for piercing holes in flange and trimming flange of deep shell; (*B*) for piercing holes in flange and bottom and trimming flange of shallow shell.[1]

Shave-and-pierce Dies. A compound shave-and-pierce die (Fig. 16-8) shaves around the slot and teeth and pierces two holes in a key. A knockout is provided to prevent the part from remaining in the shaving die and a stripper plate strips the part from the shaving punch. A shedder pin prevents the part from adhering to the knockout.

In a compound die for shaving and piercing a signal stop yoke arm (Fig. 16-9), the shaving die (*D1*) is made up of three sections whose cutting edges combine to form the outline of the part. The shaving die and piercing punch is attached to the upper shoe and the shaving punch (*D2*), in which is incorporated the piercing die, is attached to the lower shoe. A knockout containing an oil-seal breaker pin is provided to eject the part from the shaving die and piercing punch. A stripper plate is provided to free the shavings from the shaving punch. This part was previously blanked and pierced in the compound die shown in Fig. 16-4.



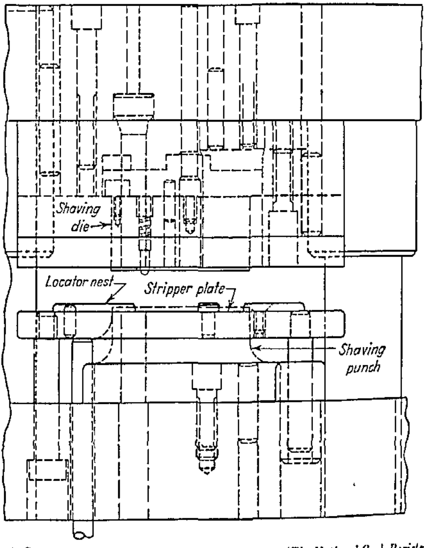


FIG. 16-8. Compound die for shaving and piercing a key. (*The National Cash Register Co.*)

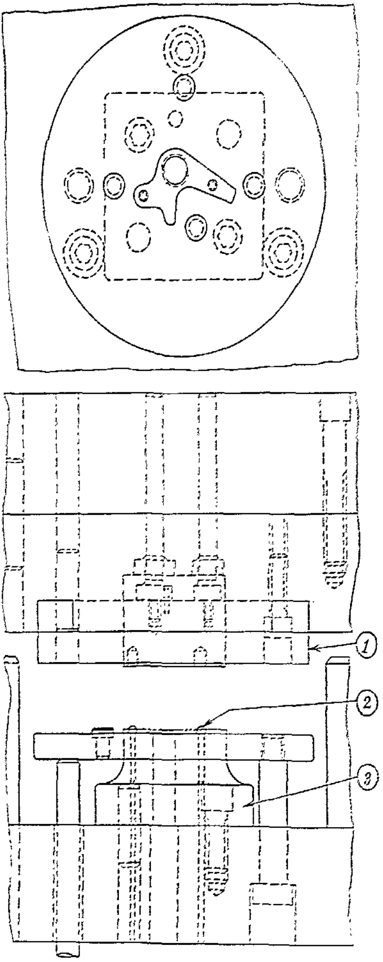


FIG. 16-9. Compound die for shaving and piercing a signal stop yoke arm. *(The National Cash Register Co.)*

roach, Cutoff, and Pierce Die. A broach, pierce, and cutoff die (Fig. 16-10) is used roduce a notched bar from cold-rolled-steel stock $^3\!/_{16}$ in. thick and ½ in. wide, es $^3\!/_{16}$ in. in diameter are located near each end of the part, and there are three ches along one edge. The notches are 0.125 in. wide by 0.032 in. deep and must e square edges all around with a good finish. A groove machined in the stripper e accommodates the stock and guides it through the die. Base blocks support the k during the broaching operation and also act as guides for the three broaches. A ch attached to the upper shoe cuts off the stock to length. A clearance hole in the ch blocks and cutoff punch permits removal of the broach-adjustment shaft when airs are needed on the broach assembly.

When the die is in operation, the broaches engage the work almost immediately at start of the press downstroke. When the broaches have completed two-thirds of r stroke, the cutoff punch contacts the stock and cuts it to length. The part is held securely in place by the broaches, locating the part accurately, so that the cing punches, coming into contact with the work immediately after it is cut off, ce the two holes in correct relation to the broached notches. After the press has npleted its cycle, the stock is hand-fed against the outboard stop.

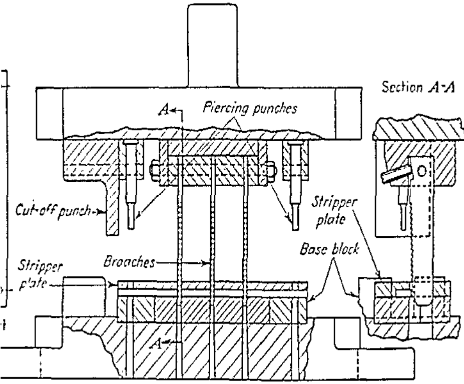


FIG. 16-10. Compound broach, cutoff, and pierce die.[4]

COMBINATION DIES

The range of types of combination dies is much greater than in the case of compound . Two or more operations such as forming, drawing, extruding, and embossing be combined with each other or with the various cutting operations such as king, piercing, trimming, broaching, and cutoff. Much of the success of such depends on the provisions for stripping and ejecting finished parts.

utoff-and-form Dies. The die illustrated in Fig. 16-11 was designed to form s from hot-rolled low-carbon sheet steel which are used as clamps in the assembly wire product. A design requirement is that the sides contact each other at the ned center section with a specified pressure.

Two punches are attached to the upper shoe, one for cutting off the strip and one forming the clip. Strip stock is fed through a grooved guide block until it con- s a stop. As the ram descends, the strip is cut to length just before it is contacted by the forming punch. A pilot pin in the forming punch enters a prepierced hole in the piece to locate it accurately. The two forming blocks pivot around pins within openings in a die block with a U-shaped depression. The U-forming die is free to slide vertically, but it is restrained by a spring until the forming punch descends.

After the workpiece has been cut to length, the forming punch bends it between the upper inside corners of the forming blocks. This temporary bend is removed as the work is forced into the U-shaped groove in the center of the die block. This die block is restrained from sliding downward by a spring until the center of the workpiece is forced to the bottom of the groove. Continued descent of the press ram forces the die block downward until the lower ends of the forming blocks contact the bottom of the base. This causes the forming blocks to pivot toward each other, forcing the workpiece into a rectangular opening in the forming punch, as seen in Fig. 16-11*B*.

On the upward stroke of the press, the forming blocks return to their original positions. This permits the formed clip to be carried upward until it is removed from the punch by the stripper. A blast of air then blows the clip clear of the die. Speed of operation for this die is 200 strokes per minute.

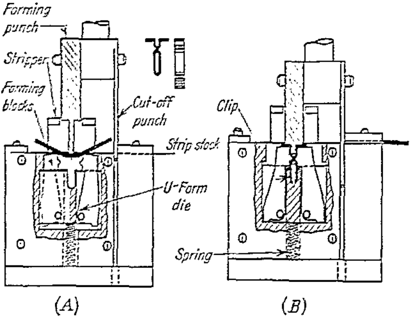


FIG. 16-11. Die for cutting off and forming spring clip: (*A*) relative positions of die members at beginning of operation; (*B*) positions of die members at completion of forming operation.

The combination die shown in Fig. 16-12 forms six bends in one press stroke to produce a spacer clip from SAE 1020 strip steel, No. 4 temper, $\frac{1}{16}$ in. thick and $\frac{1}{4}$ in. wide. Average production is 5,000 pieces per hour, with the punch press operating at 150 strokes per minute. The clips are used as spacers on tubular framework and are spot-welded to the tubes at assembly.

In operation, stock is fed through a die block and guided by pins to a stop. As the press ram begins to descend, a cutoff punch enters the die block and shears the strip. Springs under pressure from the descending ram force a forming block to mate with a forming die and form the center depression in the clip. As the ram continues to descend, slight excess material is cut off by a sharp corner on one edge of the forming block, which shears the piece against the die block. At this stage, the lower ends of the forming block form right-angle bends near the ends of the piece over the corners of two sliding blocks (Fig. 16-13*C*). As the ram continues its descent, these two blocks slide to the rear to provide clearance so that the inward projections of the forming block can bend the piece over the edges of the forming die and thus complete the part (Fig. 16-13*D*).

The sliding blocks are operated by a bell-crank lever. The longer arm of the bell-crank lever is attached to the blocks by means of a pin. The shorter arm of the bell

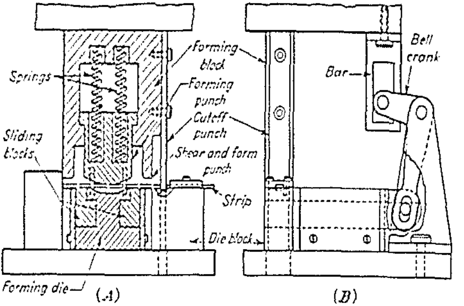


FIG. 16-12. Combination cutoff and forming die for spacer clip: (A and B) die with parts shown in position for beginning of operation.

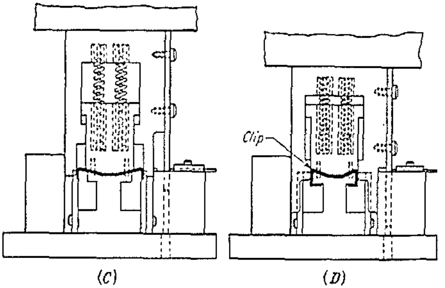


FIG. 16-13. Die of Fig. 16-12: (C) partial stroke, four bends completed; (D) end of stroke, sliding blocks withdrawn, all bends completed.

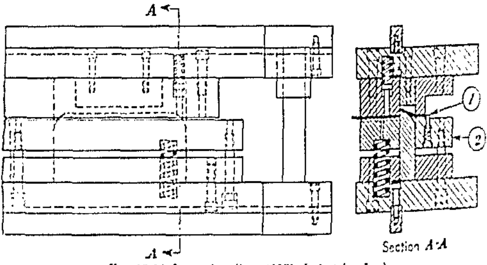
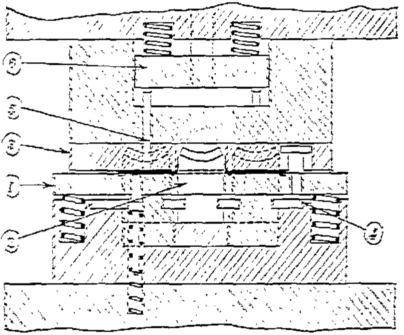
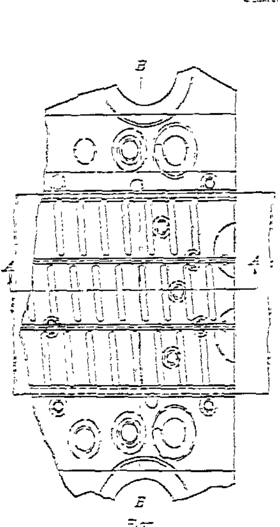


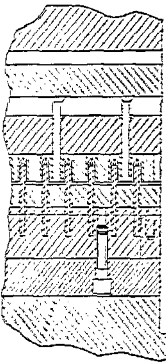
FIG. 16-14. Louvering die. (Mills Industries, Inc.)



Section B-B



Plan



Section A-A

FIG. 16-15. Lance-and-form die for radiator fin. (Hardy Mfg. Corp.)

crank is attached to a pin that passes through a slot in a bar bolted to the ram. As the ram descends, the bell crank remains stationary until the upper end of the slot contacts the pin. Further descent of the ram causes the bell crank to pivot about its fulcrum and withdraw the sliding blocks from underneath the forming block. As the ram ascends, the bell-crank lever is not pivoted until the lower end of the slot in the bar comes in contact with the pin. At this point, the forming block and punch have been entirely withdrawn, thus allowing the sliding blocks to advance to their original position and eject the finished part.

The combination die shown in Fig. 16-14 is for lancing and forming louvers in a side panel of a cabinet. This die was designed for use in a press brake. Two louvers 6 in. long are formed at each press stroke. The spacing of the louvers is controlled by two pins (*D*1) in the spring pressure pad (*D*2). The sheet is held by the spring pressure pad and the upper die (*D*3) while being lanced and formed.

Die to Produce a Radiator Fin. Two longitudinal beads and three rows of flanged slots are formed at one stroke of the press in the die shown in Fig. 16-15. There are 57 slots spaced at 0.373 in. in each of the three rows. The stock used to make this radiator fin is 0.004-in.-thick by 2.760-in.-wide copper strip. On the downstroke, the stripper plate (*D*1) is depressed, carrying the stock over the shear-form punches (*D*2). The concave-shaped punch lances the stock and extrudes it upward into the die (*D*3). The punches are 0.086 in. wide by 0.766 in. long and held in the die by the keys (*D*4). Shedder pins (*D*5) actuated by the spring pad (*D*6) eject the radiator fin from the die. Four guide pins assure proper alignment of the upper and lower sections during the operation.

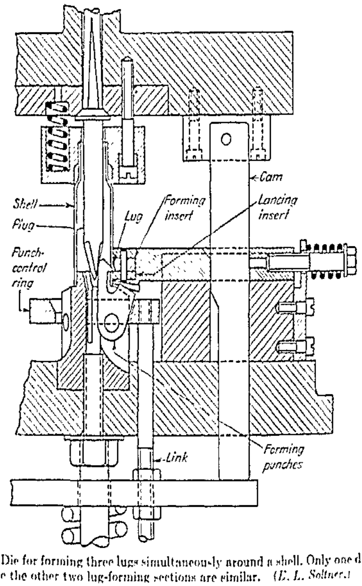


FIG. 16-16. Die for forming three lugs simultaneously around a shell. Only one die section is shown, since the other two lug-forming sections are similar. (*E. L. Soltner.*)

Lance-and-form Die. In designing dies for simultaneously forming lugs equally spaced around the outside of a shell, the forming members must be the receding type to allow the shell to be removed from the die after the lugs are formed. An example of this type of die is illustrated in Fig. 16-16. Three lugs are formed equidistant around a circular shell. To form the lugs, the shell is centered on the pilot end of the holder. As the ram descends, the cam forces a slide radially inward, bringing two die inserts (one a shearing member for lancing and the other a forming member that forms the lug) into position against the shell. At the same time, the upper end of the shell is centered by a spring pad. Upon continued descent of the ram, the pointed end of the actuating plug forces three pivoted punches radially outward and into the walls of the shell. Thus the punches lance and form the lugs in the inserts.

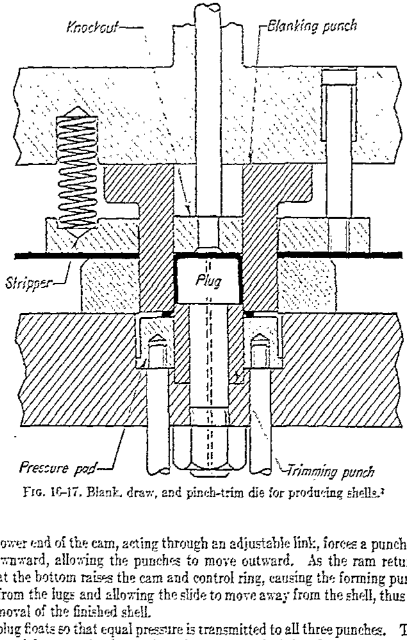


FIG. 16-17. Blank, draw, and pinch-trim die for producing shells.[1]

The lower end of the cam, acting through an adjustable link, forces a punch-control ring downward, allowing the punches to move outward. As the ram returns, the spring at the bottom raises the cam and control ring, causing the forming punches to recede from the lugs and allowing the slide to move away from the shell, thus permitting removal of the finished shell.

The plug floats so that equal pressure is transmitted to all three punches. The plug is prevented from turning by a triangular section, which is a free fit in a hole in the plate which is secured to the punch block. Plug thrust is taken by a spherical shoulder, which normally is held against its seat by a coil spring.

Blank, Draw, and Pinch-trim Die. High production is achieved in the die shown in Fig. 16-17 by combining blanking from a strip with drawing and trimming operations. A blanking punch blanks and draws the shell over the plug, and the shell is then pinch-trimmed by a punch in the lower member. A knockout ejects the shell at the top of the stroke, and a spring stripper removes the strip from the blanking punch.

The pressure pad supplies pressure for drawing and strips the scrap ring from the trimming punch.

Blank, Draw, Form, and Pierce Die. A spice-box cover which is part of a two-piece cover assembly is made on the combination die shown in Fig. 16-18. Material for both the cover and "slide" which is used to close the openings in the cover is 80-lb tin plate 0.010 in. thick Both parts are produced on 28-ton double-action inclinable presses equipped with air-blast aid ejection Metal strips are fed into the dies by automatic vacuum-feed attachments. Speed of operation (for the cover) is 135 strokes per minute

At each stroke of the press the stock is fed in, blanked, drawn, and formed, characters *stamped, spoon entry hole pierced, slug returned to the blank, and the finished* cover ejected. Near the bottom of the stroke, the guides for the slide are formed, and the spoon entry hole is pierced and stamped with the letters "Punch In." The rubber

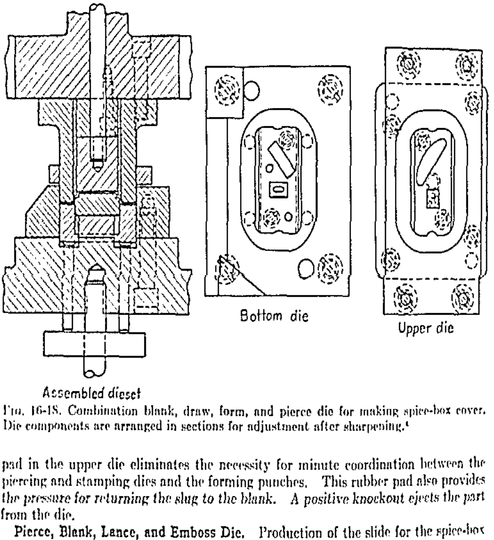


FIG. 16-18. Combination blank, draw, form, and pierce die for making spice-box cover. Die components are arranged in sections for adjustment after sharpening.[4]

pad in the upper die eliminates the necessity for minute coordination between the piercing and stamping dies and the forming punches. This rubber pad also provides *the pressure for returning the slug to the blank. A positive knockout ejects the part* from the die.

Pierce, Blank, Lance, and Emboss Die. Production of the slide for the spice-box cover (die shown in Fig. 16-18) is at the rate of 150 strokes per minute (four pieces per stroke) on the die shown in Fig. 16-19. This die also is sectional, and the four units are arranged to distribute pressure evenly over the die face. It is ejected by a positive knockout.

On the finished cover assembly, after the slide has been assembled to the cover plate, movement of the slide is performed by hooking a small U-shaped projection with a spoon or fingernail. The lancing punch used to form this projection is sharp on the *sides but has rounded ends. Thus it slits the two sides and draws out the projection* without breaking the ends.

The die completes the piece in six virtually simultaneous steps: feed in, pierce small holes, blank slide, *lance projection, emboss, eject.* The holes are pierced with 0.076-

in.-diameter, 1⅝-in.-long high-speed-steel punches held in place with socket-head setscrews.

Cutoff, Form, and Curl Die. A valve for an air-control device is completed by combining three operations in one die (Fig. 16-20). Two of the operations (cutoff and form) are performed during the downstroke and the third operation (curling) performed during the upstroke. Steel 0.018 in. thick is used, and the parts range in length from 5 to 14 in.

As the punch plate descends, the material is held in place by the pressure pad. A cutoff punch shears the stock against the cutoff die as the ram continues downward. At a predetermined point, the punch plate contacts four pins in the bottom die, which compresses the die cushion, counteracting the upward pressure of the forming and curling dies. Forming punches force the metal down to the necessary depth, where half curls are produced by bottoming of the forming and curling dies.

As the forming punches rise with the upstroke of the press, the pressure pad continues to hold the part while the two curling dies are forced up by the die cushion, curling the two edges into the finished diameter.

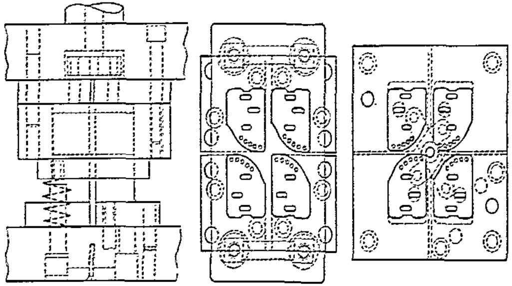


FIG. 16-19. Die for producing slide, which is assembled to spice-box cover.[6]

Combination Blank, Form, and Pierce Die. The die shown in Fig. 16-21 blanks, forms, and pierces the pronged collet in one press stroke. This die is designed for use on a double-action press. The blank is cut by the punch (*D1*) and die (*D2*) on the outer press slide. On the inner slide, the spring-loaded drawing punch (*D3*) forms the blank into a shallow cup. Continued descent of the inner slide causes the draw punch to act as a blankholder, while the nail-point-shaped punch (*D4*) pierces the cup and forces the four prongs into the ring (*D5*). The ejector (*D6*) is actuated by the die cushion and lifts the part up to be blown out through the opening in the blanking die.

Cutoff, Form, and Pierce Die. Figure 16-22 shows a punch and die used to cut off, form, and pierce the part illustrated. In operation, strip stock is fed through the die until it contacts the end stop. After the press is tripped, the ram descends and a pressure pad comes down onto the strip stock to hold it securely. After the stock is cut to length, the swing punch contacts the material, carrying and forming it to suit the form in the die. Since the swing punch is free to swing on its center, it follows the die contour as it forms the bend in the part. Die construction is such that the left-hand angle-form operation is completed at the same time as the right-hand radius forming. Just prior to completion of the form operations, the punches pierce the two small holes in the part.

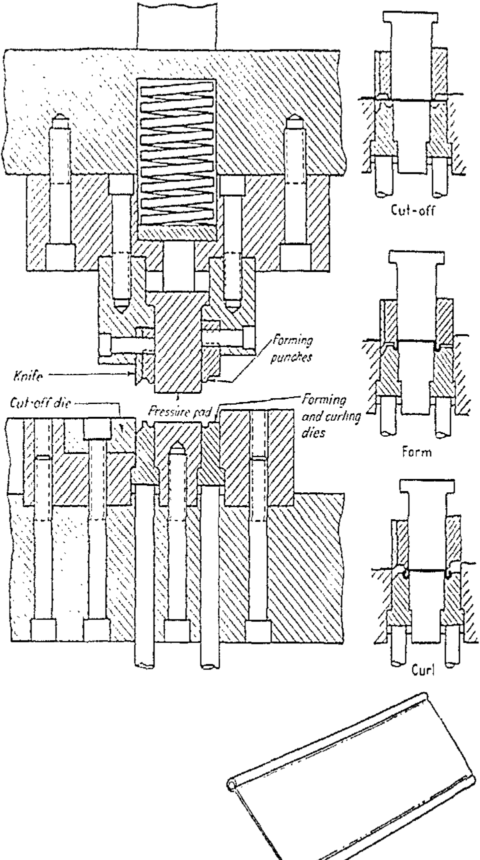


FIG. 16-20. Combination die for cutting, forming, and curling operations on a valve for air-control device.[7]

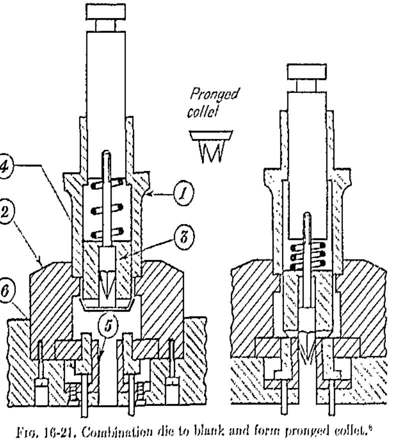


FIG. 16-21. Combination die to blank and form pronged collet.[a]

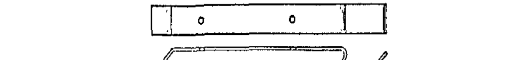


FIG. 16-22. Combination die used to cut off, form, and pierce a part in one operation.[a]

Blank, Draw, Form, Trim, and Pierce Die. A die that combines the five operations of blanking, drawing, forming, trimming, and piercing a ferrule is shown in Fig. 16-23. At the left of the vertical center line, the various parts of the tool are shown as they appear at the top of the press stroke; while the right-hand portion of the drawing shows relative positions of the parts at the bottom of the stroke. The ferrule is made of 0.020-in.-thick cold-rolled steel, and the work is done in a single-action press.

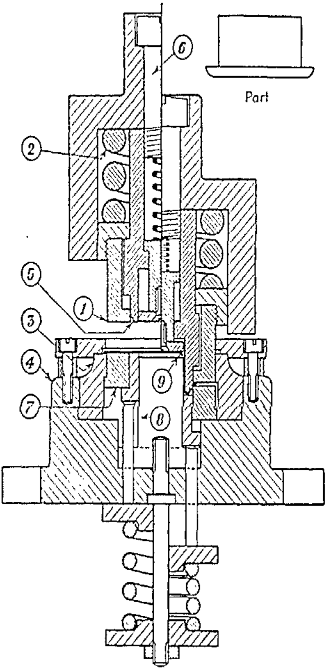


FIG. 16-23. Combination die to blank, draw, form, trim, and pierce a ferrule. Drawing shows relative positions of die components at both ends of stroke.[19]

The blanking punch (*D*1) is screwed into a ring, above which is heavy coil spring (*D*2), so designed as to deliver ample pressure upon the punch to blank out the stock yet to allow it to recede as the press continues its downward movement. Blanking die *D*3 has about $\frac{1}{16}$-in. shear, which reduces cutting pressure required by about 50 per cent.

The blanking die is held in place by a stripper, which is secured to the die shoe (*D*4) by screws. The combined drawing die and trimming punch (*D*5) is secured to the punch holder by a large screw (*D*6) passing through the shank of the holder. Drawing ring D7 inside the blanking die is made in two pieces and rests on plungers, by which the support is transferred to a washer above another heavy coil spring below the press bed. Drawing punch D8 sets in a recess in the die shoe and is held down by a shouldered stud upon which the lower spring mechanism is assembled.

In operation, the strip of material is fed through the die from the right. As the ram descends, a blank is cut and gripped between the punch face and drawing ring in the die. As downward movement continues, the blank is drawn over punch D8 by

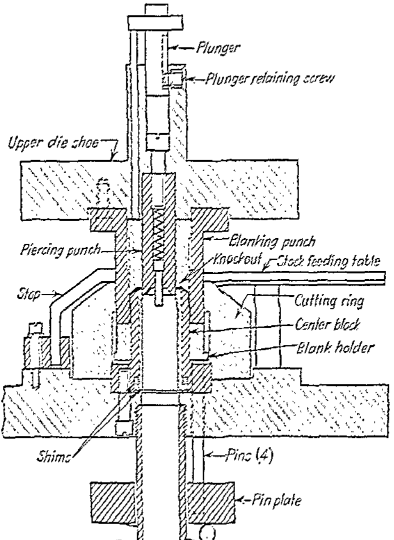


FIG. 16-24. Die combining center piercing with blanking and drawing of thin stock. The stock is blanked and drawn to shape before the center punch cuts to avoid distortion of the hole.[31]

die D5. After the blanking punch motion is stopped, the turning motion of the drawing tool forms the flange of the ferrule.

As the downward movement nears the end of the stroke, the grip of the tools prevents further drawing of the stock, and the center of the shell is pierced out by the sharp upper corners (D9) of the drawing post. On the upstroke of the press, the ferrule is ejected by the drawing ring and is carried out of the tools by the next advance of the stock.

Blank-and-draw Die (Thin Stock). Dies for stock under 0.020 in. thick differ from thick-metal dies in such construction details as clearance, die hardness, and various features of die design. Figure 16-24 illustrates a die for center piercing, combined with blanking and drawing. On such a die, the piercing punch should not cut until the stamping has been drawn to its full depth. This is especially true when the pierced hole in the bottom of the part is relatively large, and the blankholder consequently does not grip a sufficient area of stock to prevent enlargement of the hole. The center piercing punch on this die has a spring-loaded shedder pin to ensure ejection of the slug.

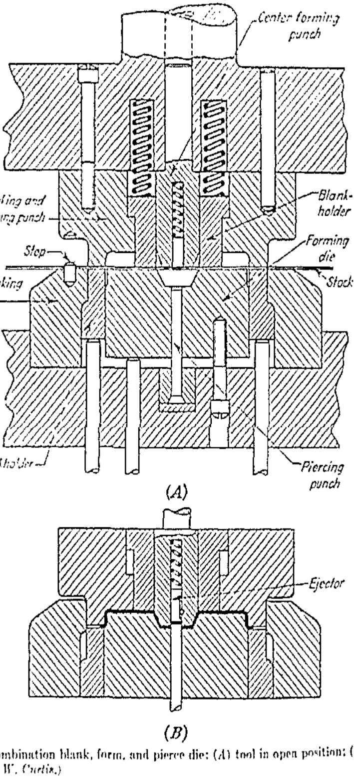


FIG. 16-25. Combination blank, form, and pierce die: (A) tool in open position; (B) closed position. (F. W. Curtis.)

The bushing, which is the center blanking die, should be provided with shims which may be removed and built up under the bushing to raise it when it is shortened by sharpening. The bushing is given a ½° taper and hardened. The center piercing punch, however, is semihard and forced through the bushing to avoid clearance and ensure a clean cut of thin metal.

Blank, Form, and Pierce Die. A combination blanking, forming, and piercing die (Fig. 16-25) produces a circular flanged part from No. 29 gage tin plate. The punch blanks the stock to size as it passes through the die. To avoid wrinkling during the forming process, the stock is held by the upper blankholder against the blanking die and the lower blankholder against the forming punch.

The forming die is held in position by an auxiliary die cushion in the position shown in Fig. 16-25*A*, until the work is completely formed. Then, as the ram travels downward, the forming die is forced down, allowing the piercing punch (which is held stationary in the die shoe) to pierce a $^{5}/_{16}$-in. hole in the part. When the punch is raised, the ejector removes the slug from the die. The work itself is ejected by action of the pressure ring against the flange.

Pierce, Serrate, Countersink, and Blank Die. Figure 16-26 shows a cross section of the punch-and-die assembly to produce the part illustrated. This part is made in extremely large quantities and must be held to fairly close tolerances. It has two pierced holes which must be countersunk to allow riveting of two studs. (Refer to Sec. 2 for permissible tolerances on stampings.)

The center hole on the part must be serrated to prevent a hub from turning under radial load after it is staked into location. Because the hub staking is a secondary operation, it is required that the serrate indentations around the edge of the hole be consistently and accurately located.

Since the parts are not carried through the die but are forced back out after blanking is complete, walls of the die hole are straight, not tapered as is conventional for clearance. A knockout rod assures positive action of the ejector. A stripper plate carries the stock up and off of the punch.

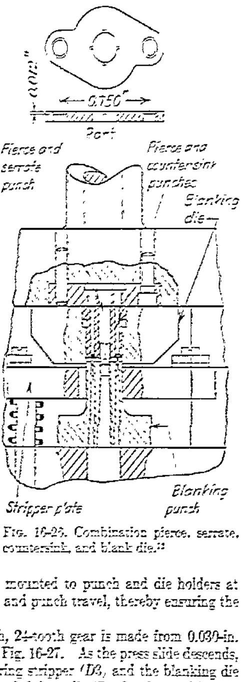


FIG. 16-26. Combination pierce, serrate, countersink, and blank die.[22]

Punches must be very accurate, so that the 0.012-in. depth to be countersunk can be attained in both holes. Stop blocks are mounted to punch and die holders at opposite corners to limit the ram downstroke and punch travel, thereby ensuring the desired depth.

Blank, Draw, and Pierce Die. A 60-pitch, 24-tooth gear is made from 0.030-in. nickel silver on the combination die shown in Fig. 16-27. As the press slide descends, the strip is held between the faces of the spring stripper (*D3*) and the blanking die (*D4*) while the cup is drawn into the spring-loaded draw die (*D5*) by the combination perforating die and draw punch (*D2*). As the press slide continues downward, the center hole is pierced, the OD is blanked by *D1* and *D4*, and the bottom of the cup is flattened between *D2* and *D9*. The pierced slug falls through the hole in the perforating die.

On the upstroke, *D5* strips the part from the blanking die and forces it back into the strip, from which it is easily removed when desired. A round-nosed pin (*D7*), which fits the center hole in the work, positions the strip for the next stroke.

Shear-and-form Die. Figure 16-28 illustrates a die that shears and forms five blades on a ventilating fan from a precut blank. The shearing punches (*D1*), which have shear ground on them, cut the blades to shape, then form a 90° bend on the heel end of each blade. These punches are individual and mounted on the lower shoe. Shedder pins actuated by the positive knockout remove the part from the die and a stripper plate removes the part from the punches.

Pierce-and-form Die. Center pierce and tab-forming operations are performed on a ball-bearing retainer by the combination die illustrated in Fig. 16-29. This is a

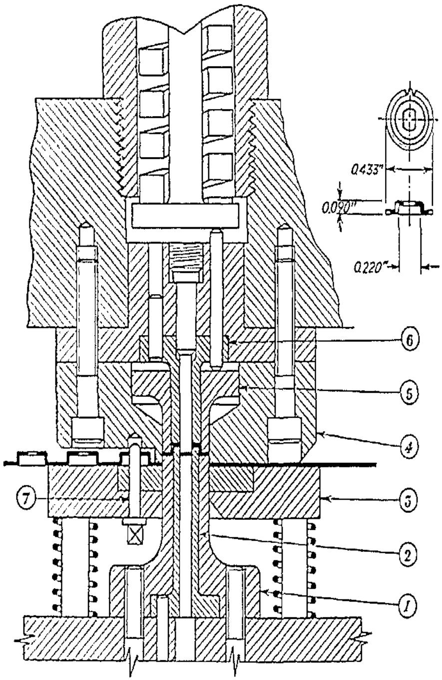


FIG. 16-27. Combination blank, draw, and pierce die for making nickel-silver gear. (*H. L. Barth.*)

secondary operation, and the preformed part is located by a portion of a ball-shaped locator (*D1*). The taps are formed between the forming punch (*D2*) and forming die (*D3*). The forming punch is supported by the die cushion and moves downward to allow the retainer to be pierced by the punch (*D4*) and die (*D5*). The positive knockout (*D6*) ejects the scrap from the die and actuates the shedder pins (*D7*) to remove the retainer from the form die. The spring stripper (*D8*) lifts the part from the forming and piercing punches.

Redraw, Pinch-trim, and Pierce Die. The redrawing, pinch-trimming, and piercing of an oval-shaped can are shown in the combination die in Fig. 16-30. The blankholder is supported by the die cushion and returns with the closing of the die to reduce the can to size. Near the end of the press stroke, the open end is pinch-trimmed to height and the bottom is pierced by two punches. A positive knockout removes the shell from the die, and a slight expansion of the open end of the shell enables the blankholder to lift it from draw punch. Air holes are provided to eliminate a vacuum or back pressure in the die.

Pierce, Blank, and Emboss Die. A combination die (Fig. 16-31) blanks a gear to shape and pierces holes in the blank, and embosses welding projections on the surface of the gear blank. An embossing punch projecting upward from the blanking punch forms a projection by forcing metal into a hole in the knockout. A second punch, in the hole in the knockout, *forms a flat top on the* projection. A shedder pin is used to break the oil seal between the face of the stripper and finished part.

Combination Die for 12-gage Steel Shell. The combination die in Fig. 16-32 blanks, draws, pinch-trims, pierces, and embosses a symmetrical shell of 12-gage (0.1046-in.) cold-rolled deep-draw-quality steel. The blanking die has shear ground in it to reduce shock and blanking load of the press. After the bottom is pierced, eight radial indentations are embossed in the bottom of the shell. The pinch-trim operation on this gage stock left a chamfer around inside the open end of the shell, which was desirable in this case, since it is chamfered more in a later operation. Ejection from the punch is accomplished by the air cushion and from the die by a positive knockout. If the part is not immediately removed from the punch, the cooling of the part will shrink it enough to freeze to the punch. The success of the operation is largely dependent upon the proper clearance between the pinch-trim ring and the draw ring. Clearance, per side, should be 10 per cent of stock thickness, so that the metal will pinch to the point of fracture and then tear clearly, leaving a pinched-off scrap ring that will overlap the shell periphery and lift it from the punch on the return stroke. A mirror finish on the draw radius of the draw ring and a speed of the 150-ton hydraulic press suitable to the drawing compound used are prime factors in the operation.

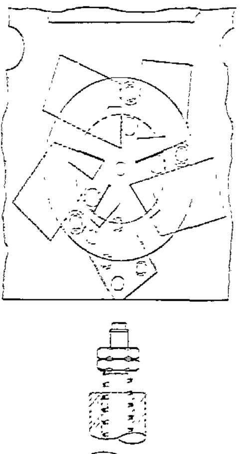


FIG. 16-28. Combination shear and forming die for five-blade fan made from 0.015-in. steel. *(Heric Mfg. Corp.)*

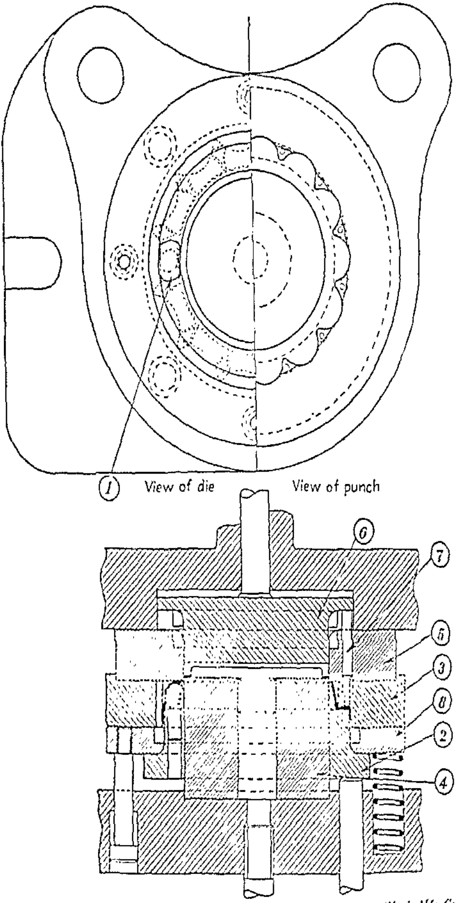
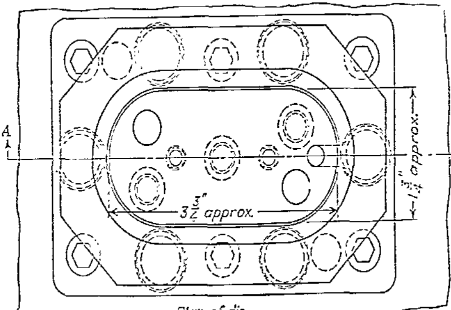
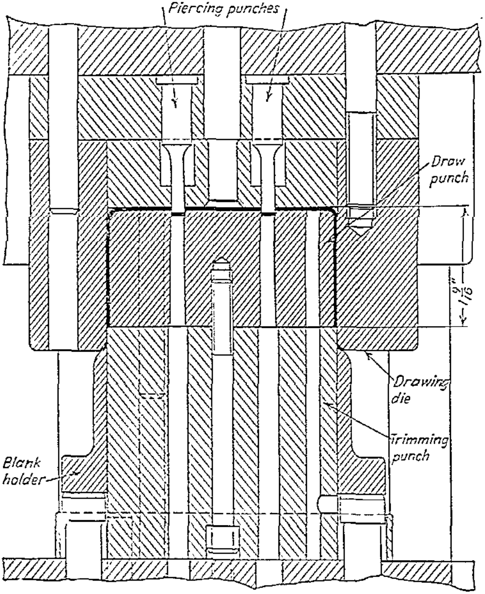


FIG. 16-29. Combination pierce-and-form die for ball-bearing retainer. (Harig Mfg. Corp.)



Plan of die



Section A-A

Fig. 16-30. Combination die to redraw, pinch-trim, and pierce two holes in steel cover. (*White-Rodgers Electric Co.*)

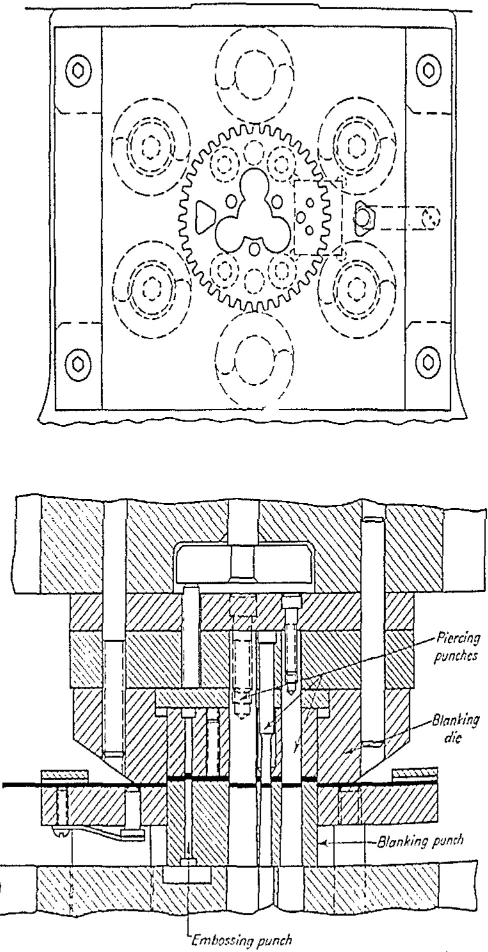


FIG. 16-31. Combination die for blanking and piercing gear and extruding projections on the surface. (*Barth Corp.*)

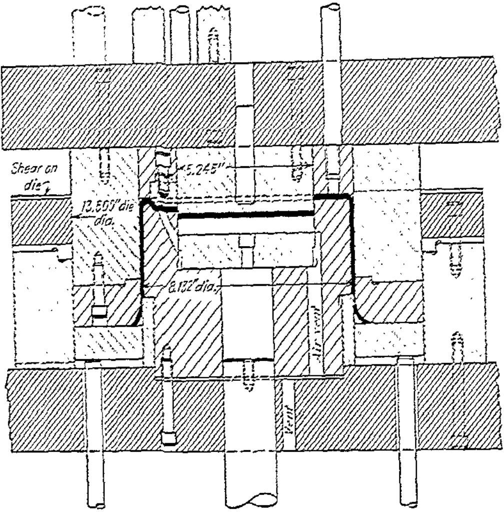


FIG. 16-32. Combination die produces symmetrical shell of 12-gage (0.1046-in.) stock. (*Davey Products, Inc.*)

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SECTION 17

MISCELLANEOUS DIES*

BULGING DIES

The design of various products requires that the lower portion of some parts be expanded to a size larger than the top; this expansion may be either symmetrical or nonsymmetrical. This type of work cannot be accomplished by a conventional drawing operation and must therefore be done in a separate operation. To facilitate the removal of the parts from the die after bulging, the die elements must be split, sectional, or of a fluid type. The fluid portion of the punch may be water or oil, pumped into the shell under sufficient pressure to expand it. Rubber, heavy grease, or tallow

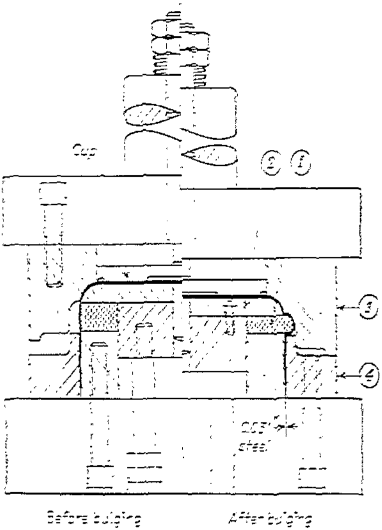


FIG. 17-1. Bulging die for cooking-utensil cover. (Hoyle Mfg. Corp.)

* Reviewed by A. L. Redmond, Sales Manager, Die Department, Richard Brothers Division of Allied Products Corp.

are also used as the bulging medium. Bulging punches of segmental design normally leave slight flats on the finished part which might be objectionable.

A bulging operation is limited by the amount of cold working the workpiece material will withstand before fracturing. Annealing the metal between cold-working operations increases the amount of cold working the material will withstand.

Bulging Die for Pot Cover. The die in Fig. 17-1 forms a bead around a 0.031-in.-thick steel shell. The finished part is a cover for a cooking utensil; since the cover fits inside the utensil, the bead acts as a shoulder to hold the cover in place.

A ring of rubber (*D1*)* is used as the bulging medium in this die. The plate *D2*, machined to fit the inside contour of the drawn shell, forces the rubber to be displaced

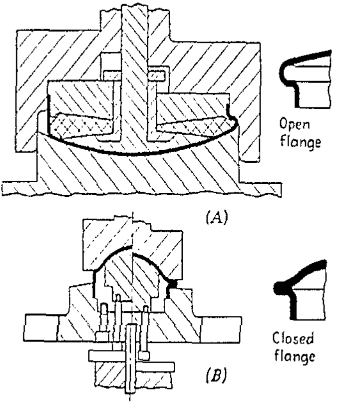


FIG. 17-2. Dies for expanding flanges on cover shapes: (*A*) open-flange tool; (*B*) closed-flange tool.[1] †

outwardly. The size and location of the bulge are determined by the location and contour of the recess formed by the two rings (*D3* and *D4*).

Other examples of dies for expanding cover shapes are shown in Fig. 17-2. View *A* shows a die for producing a bead similar to the example in Fig. 17-1. The open edge of the shell is forced down to assist the rubber in bulging the metal. View *B* shows a die for producing a closed flange around the cover. The operation is based on controlling the failure of a band of skirt metal, which is made to collapse outward and is then flattened. In this type of tool, the metal in the upper part of the cover and the lower part of the skirt is more or less confined. To make a uniform flange, the collapse should take place along a plane parallel to the open edge of the shell and about in the center of the band. A small groove is sometimes rolled in the skirt to control the location of the collapsing band.

Die to Bulge a Rectangular Cover. The bulging of a bead in a rectangular-shaped cover is illustrated in the die shown in Fig. 17-3. In this die the straight sides are bulged by confining the upper and lower parts, but the corners are formed by sliding wedges (*D1*), which are beveled on one end and formed to the contour of the bulged corner on the other end. A beveled edge on the stationary heel plate (*D2*) forces the

* *D* indicates detail number on drawing.

† Superior numbers relate to References at the end of this section.

sliding wedge outward as the die closes. The sliding wedges are contained in a spring-loaded blankholder, and the stationary heel plate is mounted on the lower shoe.

Die for Bulging a Brass Tube. Short lengths of tubing can also be bulged by using rubber as a bulging medium. The die in Fig. 17-4 uses this principle. The tube is slipped over the locating plug *D1* and, as the die closes, the rubber *D2* bulges the metal into the recess formed by the two rings *D3* and *D4*. The locating plug can be elevated to eject the part from the lower ring.

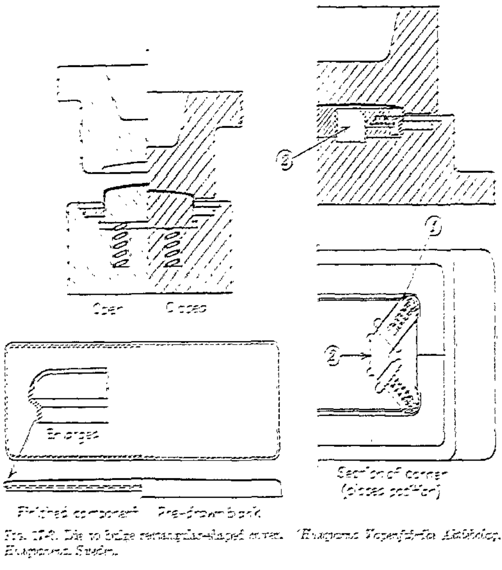


FIG. 17-3. Die to bulge rectangular-shaped cover. (*Husqvarna Vapenfabriks Aktiebolag, Husqvarna, Sweden.*)

Beading an Automotive Distributor Insert. The distributor insert which receives the spark-plug wire, shown in Fig. 17-5, is extruded and beaded in one operation. The slug of copper or aluminum is placed in the die and, as it closes, the punch forces the metal to be extruded as shown at *A*. Further closing of the die starts the bead to be formed as at *B*; view *C* shows the bead finished. Since the part is both extruded and beaded in this die, the cavity that forms the bead must be in the punch holder.

Bulging Die for Double-action Press. The bulging of a shell in a die designed for use in a double-action press is shown in Fig. 17-6. The contour of the cavity is machined in two blocks, the upper half being fastened to the blankholder slide and the lower half to the press bed. The bulging tool is attached to the inner slide. In operation the drawn shell is placed in the lower half of the die cavity and the blankholder slide is lowered. As the inner slide moves the punch down into the shell, its bottom face comes in contact with the bottom of the shell in the cavity. Further downward movement compresses the rubber, which moves outwardly to form the metal into the shape of the cavity. When the punch moves up, the rubber pad returns to its original shape and permits withdrawal from the shell.

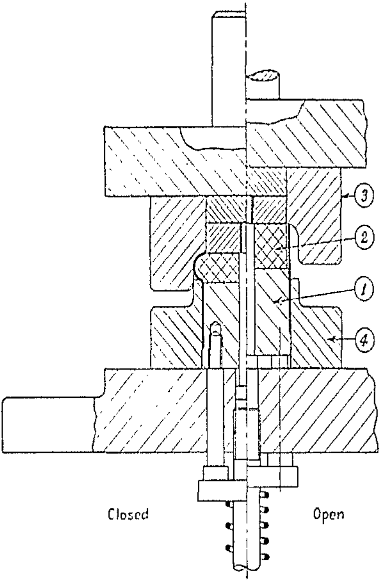


FIG. 17-4. Bulging die for brass tubing. (*Harig Mfg. Corp.*)

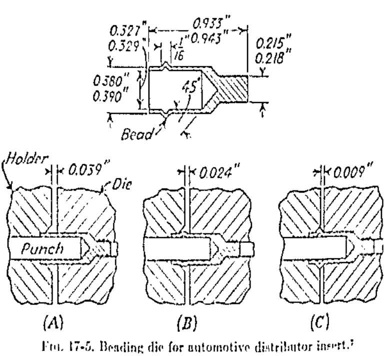


FIG. 17-5. Beading die for automotive distributor insert.[7]

Bulging a Drawn Shell. The die illustrated in Fig. 17-7 is for bulging the bottom of a textile-machinery part. The drawn shell for this operation is produced in three conventional drawing operations. Before being placed in this die, the shell is partially filled with a measured amount of melted tallow which is allowed to solidify. The amount of tallow must be carefully measured, because too little would result in an incompletely formed shell, and too much might cause serious damage to the tools.

The tallow-filled shell is placed upside down on the locating plug (1), and the split-die-cavity block (2) is placed in the clamping ring (3). The sleeve (4) surrounding the punch (5) is spring-loaded to hold the split-die block in place and, as the punch descends, the part is bulged into the cavity provided. The tallow supports the shell while it is changing shape. The ejector pins extending to the die cushion lift the die-cavity blocks from the clamp ring at the end of the operation.

Straight-sided shells which are to be bulged at the bottom, similar to the one in Fig. 17-6, do not require the split die to permit their removal from the die. Such parts can be formed in a fixed die block, and the die cushion is utilized to eject the finished part from the die.

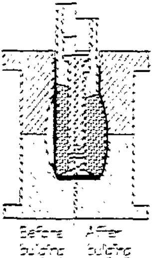


FIG. 17-6. Die for bulging shell on a double-action press.[?]

Bulging with a Liquid. A shell may be expanded by placing it within a die cavity and partially filling with a fluid. A punch closely fitted to the mouth of the shell is inserted and its downward travel displaces the incompressible fluid. With the shell

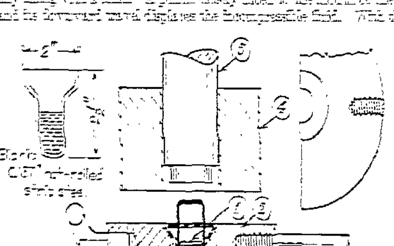


FIG. 17-7. Bulging a drawn shell in a die using tallow as a bulging medium. (F. W. Curtis.)

resting upon the bottom of the die, the pressure set up by the ram is transmitted to the fluid; in following the path of least resistance it expands the shell within the die walls. Success of the operation depends upon the thickness and annealed condition of the shell material. When using split-die-cavity blocks not encased in a clamping ring, the hinge and latching device must be quick and easy to operate and hold tight enough that the internal pressure will not force the halves apart and mark the shell. The punch should fit closely within the neck of the shell and enter at least half its diameter before expansion begins.

Bulging Die with Interchangeable Cavities. The die shown in Fig. 17-8 has interchangeable parts to accommodate two different shells. The predrawn shell is placed

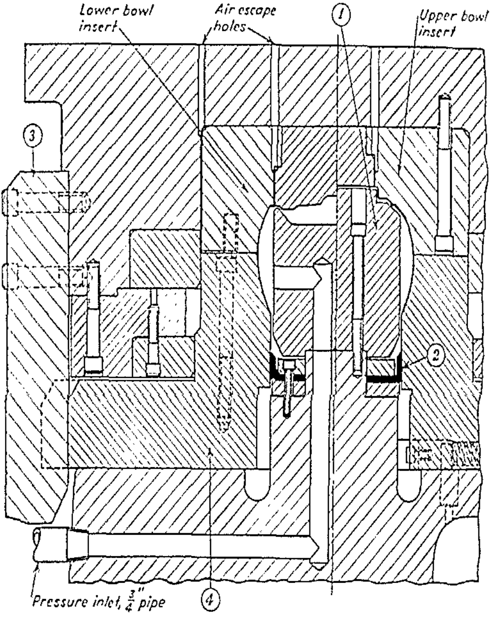


FIG. 17-8. Hydrostatic die with interchangeable parts for bulging the upper and lower bowls of a coffee maker. (*Knapp-Monarch Co.*)

in an inverted position over the locating plug (*D*1) and the leather cup (*D*2). As the ram descends, surfaces of the cam (*D*3) on the upper die engage segments *D*4 on the lower die, moving these segments radially in around the work and sealing the mouth of the drawn shell. The segments are moved outward by springs to permit loading and unloading of the die. After the die is closed, the fluid is pumped into the shell to expand it to the shape of the cavity. Air vents are provided in the die cavity to allow the air to escape during the bulging operation. Any air trapped in the die cavity outside of the shell may collapse the shell when the internal pressure is released. In order to position each predrawn shell properly, the locating plug in the lower die is interchangeable as well as the die cavity of the upper die.

This die performs the bulging operation on the coffee maker shown in Figs. 14-18, 14-19, and 14-20. The left side of the illustration shows the locating plug and upper die cavity for the lower bowl; the right side shows the die parts in place for the upper bowl.

Bulging by Hydraulically Expanded Rubber Die. The bulging of a shell may be done by hydraulically expanding a rubber bladder. A preformed shell can be placed in a cavity, the rubber bladder being then inserted, locked in place, and expanded by pumping fluid into it. The die cavity and locking arrangement should be carefully designed to withstand the pressure to which they are subjected.

Molded-rubber Expanding Die. The die shown in Fig. 17-9 is used to form the flutes on light reflectors. A molded-rubber form is contained in the upper die cavity and is used to expand the shell inwardly against the accurately machined punch. The

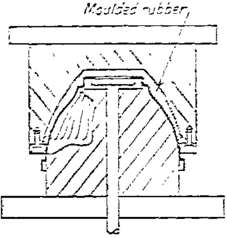


FIG. 17-9. Molded rubber expanding die for lighting reflector. *(General Electric Co.)*

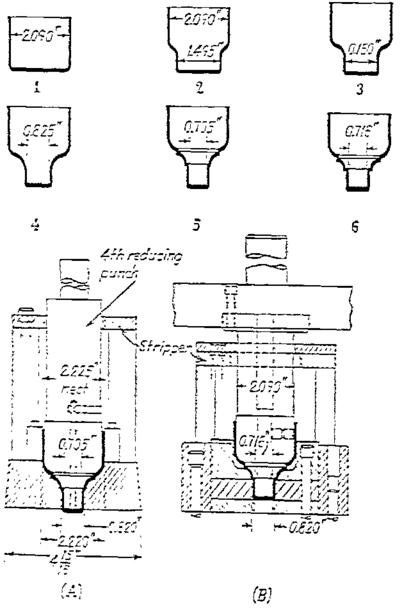


FIG. 17-10. Series of reducing dies for a tubular doorknob shank.[4]

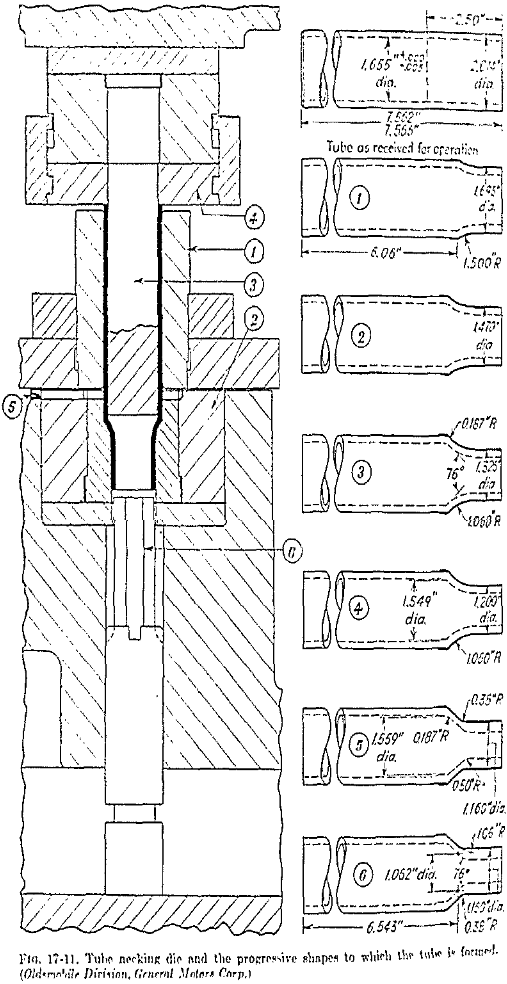


FIG. 17-11. Tube necking die and the progressive shapes to which the tube is formed. (*Oldsmobile Division, General Motors Corp.*)

flutes which are machined in the punch are formed in the reflectors as the pressure is applied by closing the die halves together.

REDUCING AND NECKING DIES

These dies are commonly used for operations subsequent to drawing-die operations. Shells are placed in these dies to reduce the cross-sectional dimensions for part of their length. The reducing operation may be performed on either the open or closed end. Reducing is often referred to as work performed on the closed end of the shell, and necking as work performed on the open end.

Reducing Die for Doorknobs. The development of the part, and a die for reducing the shank end of a doorknob from a drawn cup, are shown in Fig. 17-10. The dies for the reducing operations 2, 3, 4, and 5 are designed to be placed in a universal die shoe for mounting into a press. The first operation uses a combination blank-and-draw die to produce the cup for the doorknob. Dies progressively reduce the shank to size in three steps. Decorative and functional steps are embossed, in addition to reducing the shank to its final diameter, in the die shown in view *A*. The shank is ironed to a uniform thickness and the steps embossed in the previous die are sharpened by coining by the die shown in view *B*. Following operations on this part include piercing the bottom and closing in the top to a semispherical shape.

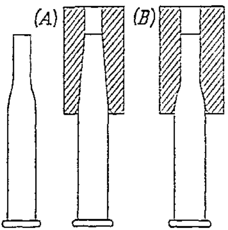


Fig. 17-12. Necking dies for cartridge cases: (*A*) first operation, form taper; (*B*) second operation, complete neck shape.[4]

Die for Necking Steel Tubing. The necking of SAE 4140 steel tubing is illustrated in Fig. 17-11. Before being placed in the die for forming, the tubes are cut to 7.564 in. length, centerless ground to 2.014 in. diameter, and bored to 1.650 in. diameter for a distance of 2.50 in. The section of the die shown is one station of a nine-station indexing die. The die has one unloading, two loading, and six working stations.

In operation the tube is placed in the nest (*D*1) at one of the loading stations and the indexing plate moves the part through each successive die. The tube is forced into the die (*D*2), containing a carbide insert for the cavity, by the punch (*D*3) and the face plate (*D*4). Lubricating oil is injected into each die by the tube (*D*5). After the forming operation, the parts are lifted out of the die cavity by the ejector rod (*D*6) operated by a lifter plate which is fastened to the press ram. In the unloading station, the tube is pushed down through the die shoe and slide, out the front of the press, passing to a conveyor which takes the parts to a degreaser to prepare them for subsequent operations.

Necking Dies for Cartridge Cases. Dies similar to those shown in Fig. 17-12 are often used to taper and reshape a neck on the end of a cartridge case. A plain taper is formed as at *A* by the first die; the neck is completed by the second die as at view *B*.

IRONING

Ironing is a method of redrawing a tubular shell to reduce the wall thickness and assure a smooth uniform wall surface.

There are two purposes for ironing the side walls of a shell. One is to counteract or correct the natural thickening of the wall. This may be accomplished in the final redrawing operation by making the clearance per side between the punch and die equal to the original stock thickness. The second purpose for ironing a shell is to reduce its wall thickness considerably. This is done by making the clearance per side between the punch and die less than the thickness of the shell wall so that the metal is thinned and the length of the shell is increased as it is pulled through the die by the punch (Fig. 17-13). Unless the material being ironed is especially ductile, reductions in steel should be limited to 10 to 12 per cent of the thickness of the shell wall in one operation. For the most ductile "-0" (annealed) aluminum alloys, as much as 40 per cent reductions can be made in a single ironing operation. For less ductile alloys, the percentage of reduction in thickness per operation must be reduced in proportion to the ductility. It is often advisable to anneal the cup between operations, thereby securing larger permissible reductions. The bottom of the shell is not affected by ironing operations, and retains the original metal thickness.

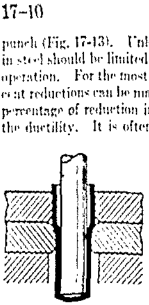


Fig. 17-13. Ironing operation partially completed.[4]

The ironing of a shell is applied on a large scale in the production of steel and brass cartridge cases.

An ironing operation is usually made without the use of a blankholder, since the reductions in diameter are nil with the punch fitted closely to the ID of the part. The contour of *the die used for ironing determines to a great* extent the amount of draw force required for the operation. Most used are bellmouthed dies with an included angle of 10 to 45°.

The force needed to iron a shell increases as the entrance angle of the die is decreased, thus increasing the length of contact of the metal with the die. The length of the straight or working face in the die slightly increases the force, in proportion to its length. The force P for ironing may be approximated by

$$P = \pi dis \tag{1}$$

where d = mean working diameter, in.
i = reduction of wall thickness due to ironing, in.
s = yield point of the metal, psi

Some authorities recommend increasing the value of P by about 20 per cent to compensate for friction between the workpiece and the die.

The original drawn height H of a shell to be finished by ironing may be approximated by the equation

$$H = \frac{ht}{T} \tag{2}$$

where t = ironed thickness, in.
T = original thickness of metal, in.
h = ironed height, in.

Figure 17-14 may be used to approximate the pressure required for ironing. A *20 per cent allowance for friction is included in addition to the work of ironing.* This figure is empirical and presupposes well-polished dies and suitable lubrication. If a reduction operation accompanies the ironing, then the drawing pressure should be added to the value determined by this chart or Eq. (1). The nomograph is used as follows:

Given: A 4-in.-OD steel shell of 50,000 psi compressive resistance is to be ironed with a displacement of 0.010 in. of its thickness.

Solution: 1. Connect point 4 on d scale to point 0.010 on i scale with a line (line 1).

2. At its intersection with the middle (unmarked) scale draw a line to 50,000 on the S scale.

3. The projection of this line (line 2) intersects the P scale at 3.8 tons, the required ironing pressure.

The punch for ironing may be either straight or tapered. A tapered punch produces a shell with a wall thinner at the top than at the bottom, and with straight, smooth outside walls. The punch-nose radius may be as small as one-half the stock thickness. When the operation is principally wall reduction, the punch should be slightly smaller than the ID of the shell to allow for easy insertion of the shell and yet prevent confinement of the lubricant.

The reduction in wall thickness obtainable by ironing is about 60 per cent for annealed 70-30 brass. For hard-drawn brass and annealed copper, the reduction is about 55 per cent; for low-carbon steel, up to 50 per cent; and up to 40 per cent for hard-drawn carbon steel. Higher reductions can be obtained by ironing than by drawing only, because the part is shrunk on the punch, and the punch therefore carries part of the load.

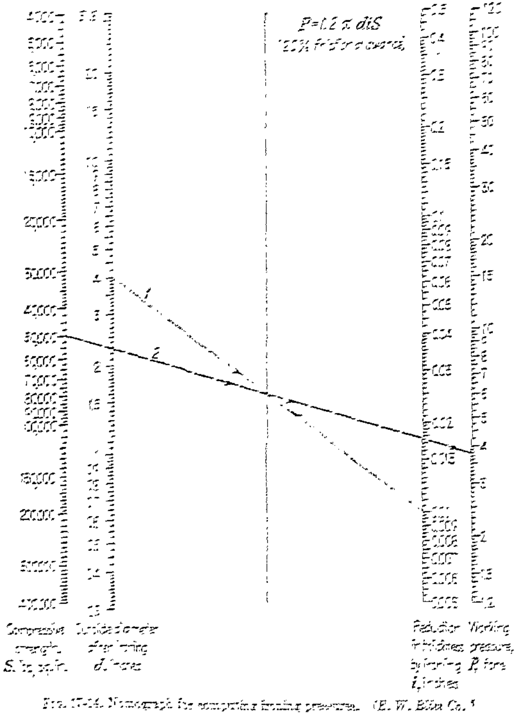


FIG. 17-14. Nomograph for computing ironing pressures. (E. W. Bliss Co.)

Greater reductions are possible by using two-step dies, Fig. 17-15, rather than single dies, except when the two dies are spaced so close together that their working faces conform to that of a single die. This spacing depends upon the outer diameter and the wall thickness of the shell. If the shell-wall thickness is 4 per cent of the diameter, a distance between the bearing surfaces of the dies equal to 1¼ times the shell diameter permits a reduction in the second die of 50 per cent of the reduction in the first die. Should the die spacing be increased to twice the shell diameter, the second reduction can be 75 per cent of the first reduction. With a shell diameter ten times the wall thickness, and die spacings of $1\frac{1}{2}$ and 3 times the workpiece diameter, a second reduction of 50 and 75 per cent, respectively, of the first reduction is possible.

If a very long, thin part must be made by ironing, the shell is first drawn and redrawn in the conventional manner, without intentionally reducing the wall thickness, until the diameter is sufficiently small to permit heavy reduction in wall thickness in combination with minimum reductions in diameter.

A die to reshape and iron the side walls of the cup in Fig. 14-10 is shown in Fig. 17-16. This die has an entrance angle of 45° per side with a radius blending it into the straight or bearing surface in the die cavity. The bearing surface is $\frac{1}{4}$ in. wide, and the remainder of the die is relieved with a $\frac{1}{2}$° angle per side. The part is pushed through the die and is stripped from the punch by three equally spaced spring-loaded stripping fingers. The punch and die are polished smooth and free from all grind marks, eliminating tiny pockets on the punch surface in the areas contacted by the part.

Fig. 17-15. A typical two-step ironing die.[5]

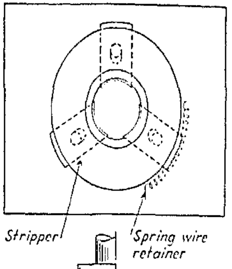


Fig. 17-16. Die to iron wall of cup to thickness. (*Coinex, Inc.*)

LOW-PRODUCTION DIES

The need to produce short-run stampings of irregularly shaped blanks at a low tool cost, and to maintain uniformity and accuracy of the parts, requires that tools be designed and made by methods not applicable in making first-class tools.

This type of tooling is required when:

1. Parts cannot be produced economically by any other method than by a punch and die.
2. Parts may require engineering-design changes which might render the tooling obsolete.
3. Inexpensive tooling will permit immediate production.

The materials used for low-production dies are not so durable as those used in more permanent and longer-lived dies. Kirksite, backed up with steel plates, may be used for both the punch and the die for blanking soft metals such as aluminum up to 0.072 in. thick. Strips of rubber cemented around the punch and in the die cutout are used to strip the punch and die. Carbon steel with a hardened edge produced by flame hardening or carburization can also be used as a punch with a Kirksite die. Somewhat more durable tools may be made by using ground gage stock.

Floating-punch Die. An inexpensive method of diemaking produces the punch and the die from the same piece of tool steel. A die of this construction is shown in Fig. 17-17 with the punch (*D1*), punch-positioning plate (*D2*), spacers (*D3*), and die plate (*D4*). This die is used in a press equipped with a die set having hardened and ground steel faces and sturdy leader pins and bushings. The minimum shut height of this die set is determined by the thickness of the floating-punch die.

In operation, the stock is fed into the die; the punch is located in the positioning plate and on top of the strip, and the die is then slid in between the two surfaces of the hardened and ground faces of the die set. After tripping the press, the die is slid out of the die set, allowing the punch and blank to fall out.

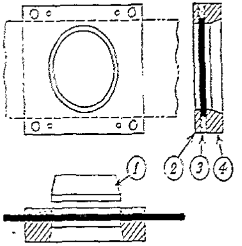


Fig. 17-17. Floating-punch die using the Continental method. (*The DoAll Co.*)

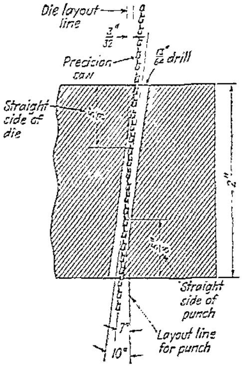


Fig. 17-18. Method of sawing punch-and-die block from same piece of steel.[5]

The method of making the punch and die from one piece of tool steel is illustrated in Fig. 17-18. The outline of the finished part is laid out on both sides of the plate. The outline is then sawed out by tilting the blade at such an angle that it cuts on the inside of the layout on the top side and outside the layout on the lower side. The die block and punch are then finished by filing to the outline perpendicular to their respective faces. The cold-rolled-steel punch-positioning plate is fastened to the die block with spacers between to provide a tunnel stock guide. Data pertinent to proper dimensioning for this method of diemaking are listed in Table 17-1.

Plate-type Blanking Die. A blanking-die arrangement in which the punch and die are attached to relatively thin plates that can be readily attached to a universal die set is shown in Fig. 17-19. Dowel pins permanently pressed into the die shoes position the mounting plates in which coordinating holes are drilled and reamed. Pieces of rubber or cork may be cemented around the punch and in the die cavity to function as strippers, and stock guides and stops are permanently fastened to the mounting plate to be fastened to the lower shoe.

The production rate on this type of die is higher than on the floating-punch type which must be repositioned after each press stroke.

A plate-type blanking die with the die set permanently attached to the press is shown in Fig. 17-20. In this die a positive-knockout arrangement strips the stock strip from the punch, and ejection pins operated by a die cushion remove the blank from the die.

The lower shoe (*D1*) has been drilled in a multiple pattern and is equipped with

TABLE 17-1. DIMENSIONAL DATA FOR DIEMAKING TECHNIQUE SHOWN IN FIG. 17-18

Die thickness, in.	Angle of saw starting hole, deg	Angle for saw cut, deg	Distance from die layout line to center of saw kerf, in.	Distance from die layout line to center of starting hole, in.	Diameter of drill, in.	Width of starting saw, in.	Amount of straight sides on punch and die, in.
1/2	21	18	5/64	3/32	1/8	3/32	1/16
3/4	18	15	3/32	1/8	1/8	3/32	3/32
1	14	11	3/32	1/8	9/64	1/8	3/8
1 1/4	12	9	3/32	1/8	9/64	1/8	15/32
1 1/2	11	8	7/64	9/64	9/64	1/8	9/16
2	10	7	1/8	3/16	13/64	3/16	13/16
3	9	6	5/32	1/4	17/64	1/4	1 1/4
4	8	6	7/32	9/32	17/64	1/4	1 3/4
5	7	6	1/4	5/16	17/64	1/4	2 1/4
6	6	5	1/4	5/16	17/64	1/4	2 1/2

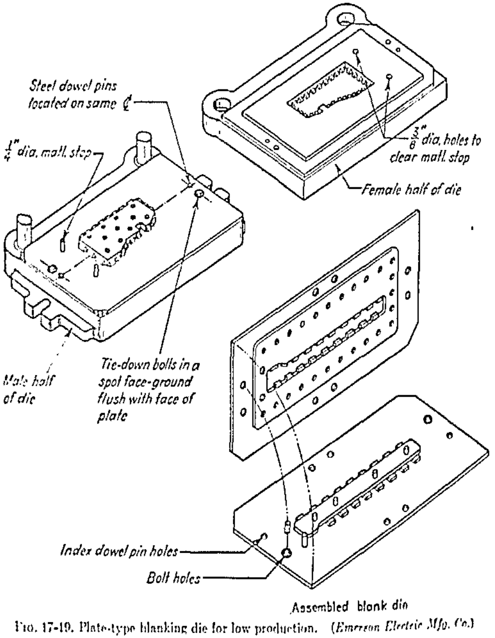


FIG. 17-19. Plate-type blanking die for low production. (*Emerson Electric Mfg. Co.*)

permanent ejection pins (D2). The lower platen (D3) has been drilled with the same pattern and the shorter ejection pins (D4) are inserted as required by the die. The die plate (D5) is held in place with the eccentric pins (D6) contained in the support blocks (D7). Holes are tapped in the lower platen so that the support blocks may be placed in locations to suit the width of the various die plates.

The punch (D8) is fastened to a slide (D9) which is dovetailed into the upper shoe (D10). The slide is drilled with a multiple pattern of holes which receive cap screws

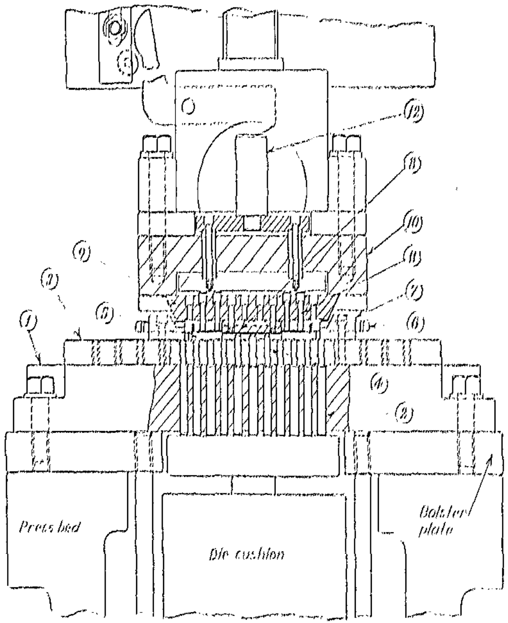


FIG. 17-20. Cross-section view of assembly of punch-press holder with plate-type punch and die in blanking position. (General Electric Co.)

to retain the punch and shedder pins (D11) to strip the punch. These pins are actuated by a positive-knockout assembly (D12).

The first cost of this die is more than the one previously described, but it does not require a separate mounting plate for each additional punch and die made.

An arrangement similar to this for piercing holes in parts is described in Sec. 5.

Punch and Die to Round Off Plate Corners. An inexpensive punch and die for rounding off the corners of plates is shown in Fig. 17-21. To make this die, ground flat stock was drilled and reamed for the required radius. Then a 90° notch was bandsawed into the plate. The back side of the plate was milled or shaped down to about half the original thickness so as to leave shoulders to position the work and so that the point of the work would rest back of the notch. A punch of the same diameter as the hole originally drilled in the plate pushed the stock down and trimmed off the corner.

Low-cost Piercing Dies. The economical piercing of holes in a small quantity of parts is accomplished by using a nesting templet to position a part. The end of the punch is placed in the hole of the templet and the press is tripped, piercing the hole.

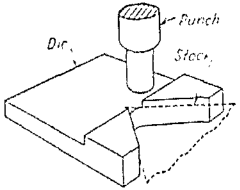


FIG. 17-21. Punch and die to round off corners of plates.[2]

If holes of various sizes are required in a part, readily interchangeable punches and dies are used, or special machines are available with the units mounted in turrets which are easily indexed into position.

Punching units which can be conveniently mounted to templets, or mounted on special die sets with T slots and positioned from templets, are described in Sec. 18. Punching units for press brakes are also shown.

The cost of building blanking-and-piercing dies may be reduced by using a low-melting-point metal alloy as a punch retainer rather than jig-boring and jig-grinding the punch-holder plate. Using this construction, the die plate is jig-bored and ground, then used to position the punches in the punch-holder plate in which the holes have been bored oversize.

General-purpose Cutoff Die. The cutoff die shown in Fig. 17-22 may be used in shops where production does not justify the purchase of a shearing machine. The die is designed to utilize the four cutting edges on each cutoff blade before being removed

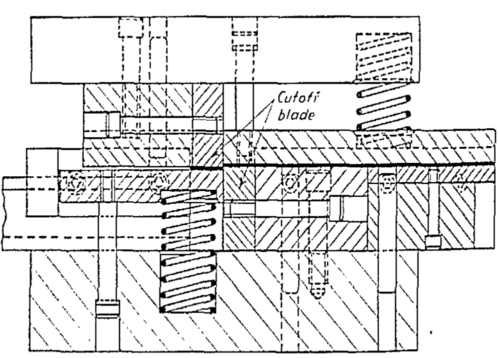


FIG. 17-22. Shear-type cutoff die for use in a punch press. (*Darcy Products Co., Inc.*)

for resharpening. To sharpen the die it is necessary to grind the face of the blades only and, on replacing in the die, to add shims to compensate for the stock ground off. These shims may be placed behind one or both of the blades. Shims can also be used to adjust the clearance for shearing thick or thin materials. Spring-loaded pressure pads under each blade grip the stock and assure a cleanly cut blank. An easily adjusted stop is provided for gaging the length of blanks. This die is mounted in a four-post die set to maintain the desired clearance between the two blades.

Low-cost Forming Die. The making of a low-cost punch and die for an irregular-shaped part is shown in Fig. 17-23. The punch is machined or cast to shape, depending upon the tolerances. *From the finished punch a die is produced by pouring a* zinc-base or bronze alloy around the punch contour. Clearance between the punch and die is secured by utilizing a hydraulic press and thinner stock gradually formed to shape under pressure, with stock of gradually increased thickness being used until the correct stock thickness is attained. *A small amount of hand fitting may be required* before the die is ready for production. To complete the die, the punch is assembled to a mounting plate and a spring-loaded pressure pad surrounding the punch.

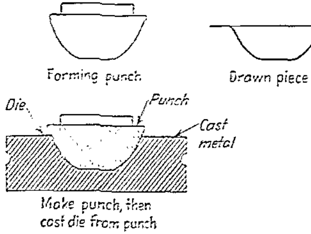


FIG. 17-23. Low-cost forming die for an irregular shape.

Knurling on a Punch Press. The knurling of all or part of a pin may be done on a punch press with the die shown in Fig. 17-24, where the die is shown partially closed. As the punch descends, the piece is rolled between the knurl dies and finally drops through the die shoe. Two spring-loaded pins permit the feeding of only one part at a time. For best results, this die should be operated in an inclined press.

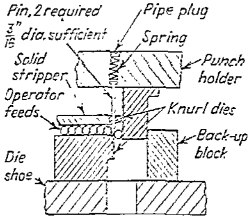


FIG. 17-24. Die for knurling pins on a punch press.[1]

Plastic Dies for Low Production. Experimental and low-production stampings can be produced at low cost by using lightweight, easily made plastic dies. These dies can be used to draw or form practically all grades of sheet steel and aluminum from which sheet-metal parts are fabricated.

The basic design of a plastic draw die is the same as for a conventional draw die; the punch, die, and blankholder or binder ring mount in the press in the same manner as conventional dies. The draw die shown in Fig. 17-25 has a metal container to support the plastic components. The metal containers can be made of cast iron, steel weldments, or cast Kirksite. The working faces are solid cast plastic or are built up of layers of plastic-impregnated glass cloth. The working surface is backed up by a plastic core or other filler material.

The cross section of a flanging die with plastic working faces is shown in Fig. 17-26. The locating member (*D1*) of the die has a cast epoxy surface with a polyester core on a steel base plate. The flanging punch (*D2*) uses a cast-iron base for the cast epoxy surface. The steel backing is required, because the present plastics have a compressive strength of approximately 11,000 psi and an approximate tensile strength of 5,000 psi.

Dies of this type can be built by using a conventional die model with a developed binder line to make a plaster splash mold for the punch. The die model does not need

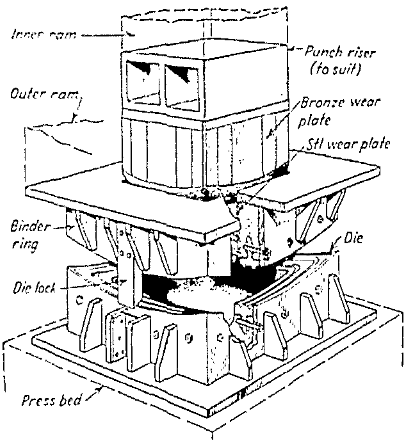


FIG. 17-25. Draw die with plastic working surfaces for low-production parts.[13]

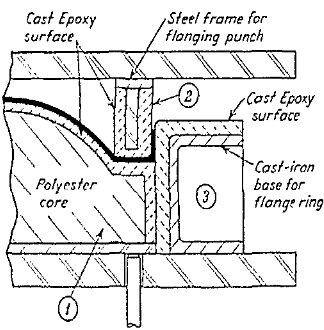


FIG. 17-26. Cross section of a flanging die with plastic working surfaces. (*Kish Industries.*)

to be compensated for shrinkage; the plastic material shrinks an insignificant amount in most cases. A plaster model of the binder ring is developed to the draw line on the die model. Draw beads, if considered necessary, may be worked into the face of the model so that they may be cast into the binder ring from the plaster splash mold. The edge of the draw beads should be about 1¼ in. from the die cavity to prevent the edge from breaking away during the operation. Steel and bronze wear plates should be fastened to the punch and binder ring to prevent wear on the plastic surfaces.

The finished binder ring and punch are assembled to use as the model for the die cavity. The surfaces of the punch and binder ring are built up, equal to stock thickness, by using either patternmaker's wax or a spray-paint build-up. From this model, a plaster mold for the die is made, from which the die itself is finally cast. The curing of the material in the plastic die depends upon the plastic itself. Some plastics are self-curing; others require heating in an oven at a controlled temperature for a period of time.

The die construction in Fig. 17-27 illustrates the use of a zinc alloy container which was cast to the rough outline of the product and with flanges for attaching to the press.

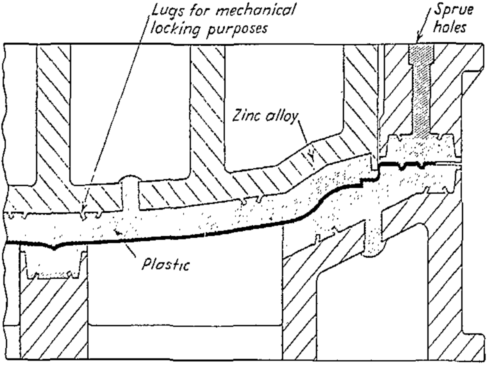


FIG. 17-27. Typical cross section of a plastic-faced die on a zinc alloy base. (*Richard Brothers Division, Allied Products Corp.*)

Because of its nonshrinking characteristics, the thickness of the plastic does not need to be held constant. The simplicity of the shape of the finished part allows the use of a partially-open-die construction where the punch and die mate only at the areas of severe forming. Holes were drilled at angles in the sand mold for the zinc alloy casting to provide lugs to anchor the plastic face. The binder-ring faces and beads are made of plastic in this die. An alternate type of die construction may use a more uniform thickness of plastic and the zinc alloy for the beads and binder-ring surfaces. Cast iron may be used in place of the zinc alloy where the foundry facilities are available.

STRETCH FORMING

The basic stretch-forming process consists of gripping a metal sheet, an extruded shape, or a brake or roll-formed section at each end with a pair of jaws, then stretching or wrapping it over a die of the desired contour.

The design of stretch dies need not include spring-back allowance. The reason why no spring-back occurs after forming is illustrated in Fig. 17-28. The upper part of the diagram shows the effect of bending a sheet of metal. This cross section shows that the fibers in the upper portion are stretched, while the fibers in the lower portion are compressed. The lower part of the diagram represents a sheet formed by a stretch die. All the fibers have been stretched beyond the yield point and put in tension. The neutral axis, or the pivot point about which spring-back occurs, has been moved out of the plane of the metal so that all the locked-in forces are in the same direction.

Parts may not be stretch-formed to shapes that have a reentrant curvature. The shape must be so designed that a string, pulled by the jaws across the block, will follow the block from end to end without leaving the surface.

The typical shapes to which shapes may be readily formed are shown in Fig. 17-29. As indicated by the arrows, the direction of stretch should be at right angles to the radii of curvature.

In most cases, stretching work-hardens the material to a higher strength uniformly throughout the part. This work hardening is done with a minimum reduction of stock thickness and does not exist on the surface of the sheet only, as is found in many roll-formed parts.

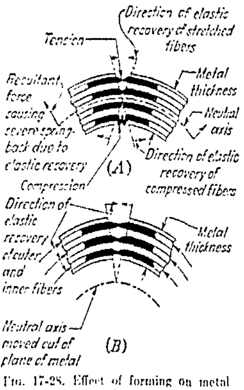


FIG. 17-28. Effect of forming on metal fibers: (A) by bending; (B) by stretch forming.[11] (*Reynolds Metals Co.*)

The primary cause of part failure is tearing at the point of maximum metal elongation. A sheet with a large curvature will usually fail by tearing between the jaw and form block. A sharp curvature causes failure at the crown or about halfway between the jaws. The point of failure in saddle-back-shaped parts is at the edge of the sheets where the maximum stretch is located. Smooth or polished *edges on sheets will permit greater elongation of the* parts than when the sheet has sheared edges.

The blank sheets should be of uniform width in order to distribute the stresses uniformly throughout the sheet. Cutouts and holes required in the finished part must be made after forming, to prevent distortion of the holes and to avoid rupturing at the cross-sectional area of least strength. Because of the severity of forming, blanks with imperfections will not stretch-form successfully; fracture will occur before the operation is completed.

Wrinkling or puckering of the sheet rarely occurs, except in the case of double-curvature parts, because stretch forming holds the sheet under tension during the operation. Stretch forming requires an extra length of material between the die and jaw to minimize the stress in the sheet caused by changing from a curve to a straight

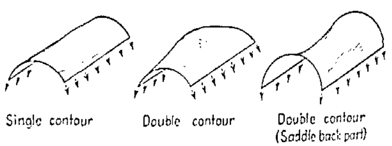


FIG. 17-29. Typical shapes to which sheets may be readily stretch-formed.[18]

line. Saddleback parts have a tendency to slide toward the center of the die and thereby cause wrinkles running lengthwise between the jaws. Increasing the sheet *width and extending it over the edges of the die helps to prevent the sheet from* sliding. Increasing the stock thickness or using a material or alloy of greater tensile strength may decrease wrinkling.

STRETCH-FORM MACHINES

There are three basic types of stretch-forming machines (Fig. 17-30).

1. *Moving-ram type.* These machines are of two designs: (1) moving die, and (2) moving jaw.

The moving-die machine has stationary jaws, trunnion-mounted, to grip the stock while the die, mounted on a ram, is pushed into the sheet. The moving-jaw machine has a stationary die, the jaws being on trunnion-mounted hydraulic cylinders to stretch the sheet over the die.

2. *Rotary-table type.* This machine has the die fastened to a rotary table. One end of the material is gripped in a jaw on the table; the other end is gripped in a jaw on the machine framework. As the die is rotated, the part is stretched and wrapped to the die contour.

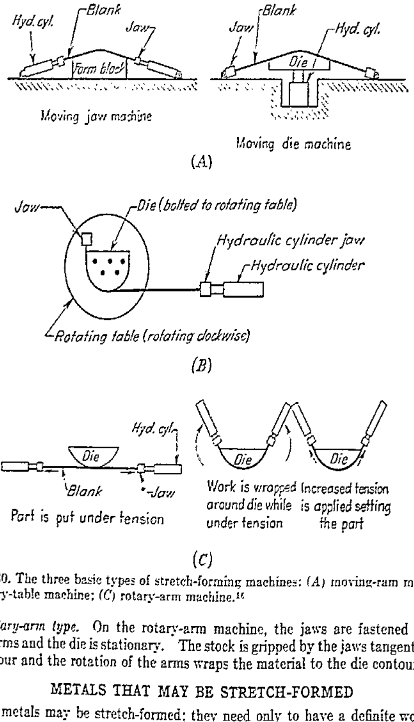


FIG. 17-30. The three basic types of stretch-forming machines: (*A*) moving-ram machine; (*B*) rotary-table machine; (*C*) rotary-arm machine.[16]

3. *Rotary-arm type.* On the rotary-arm machine, the jaws are fastened to the rotary arms and the die is stationary. The stock is gripped by the jaws tangent to the die contour and the rotation of the arms wraps the material to the die contour.

METALS THAT MAY BE STRETCH-FORMED

Most metals may be stretch-formed; they need only to have a definite workable range between the yield point and the ultimate strength of the material.

Steel. The low-carbon steels (SAE 1010, 1020) are readily formed and will give excellent results. The austenitic stainless steels give excellent results in the annealed state, the forming becoming increasingly difficult as the hardness of the material increases. Full-hard stainless steel is nearly impossible to form except under ideal conditions.

Aluminum. These materials are widely used for stretch forming, and most of the alloys are readily formed. Forming is done cold and may be accomplished by using heat-treated stock in many cases. When this is possible, the subsequent heat treatment, distortion, and restretch may be eliminated. The 75ST aluminum alloy is *difficult to form; 75SO is readily formed.*

Magnesium. Magnesium should be formed at a temperature of approximately 400°F in heated dies. Because magnesium has higher physical properties when cold than when heated, the jaws which grip the material should be cold, since this helps to prevent part breakage at the jaws.

STRETCH-DIE MATERIALS

The dies may be made of various materials, depending upon the production requirements. Common materials used are cast iron, wood, zinc alloys, Masonite, cloth-based phenolic resin-bonded materials, and cast plastic. If the dies overhang the machine platen, sufficient strength must be built into them to prevent distortion under the heavy stretching load. If a die block is allowed to deflect to a considerable extent during the stretching operation, the sheet will be formed to the shape of the deflected block.

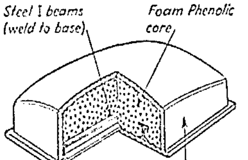


FIG. 17-31. Cross section of a typical plastic stretch-form die.[17]

The type of workpiece material, its annealed condition, and its thickness have great influence on the selection of material from which the forming blocks are to be made. The thickness of the material, together with the basic material specification, determines the load which will be exerted upon the form block during the stretching operation.

Stretch dies made of well-seasoned wood are satisfactory for a limited production. White pine, straight-grained birch, and mahogany have been used with excellent results. Where there are sharp edges or shapes to be formed that result in points of very high pressure, the wood will wear excessively. At these points it is good practice to use zinc alloy, cast iron, or plastic inserts. Wooden dies should be a minimum of 4 in. thick; on very large dies it may be necessary to reinforce the block with a subbase made of structural-steel members.

The zinc-based alloys will give longer service than wood, provided there are no points of extreme pressure. The inherently greasy nature of these alloys is most desirable since it makes necessary only limited lubrication of the die surface. If dies become obsolete, this material may be reclaimed and reused. Patterns must be made for zinc-based alloys, and special foundry practice exercised to produce the castings. Depending somewhat upon the surface finish of the pattern and models, these castings must be finished and polished by hand. The dies must be well supported to prevent any possible distortion in use.

Gray cast iron is good from the standpoint of inherent strength of the die blocks themselves. Because of the relatively high strength of cast iron, the die blocks may be cored out underneath the solid top to conserve weight. Considerable labor might be required to finish the working surface of a cast-iron die, but the long die life would justify the cost.

Plastic dies are lightweight and present virtually no problems in casting, because no shrinkage allowance is necessary. This material gives good results from the standpoint of wear resistance, workability, and stability of contour regardless of changes in temperature and humidity. The glasslike surface that may be obtained eliminates practically all the galling or other die marks that frequently appear on the parts made with metal stretch dies. The die in Fig. 17-31 is a typical cross section of a plastic stretch die with a foam phenolic core and a solid phenolic working surface. The die has a steel backing plate with I beams welded to it for rigidity. Unless the plastic form blocks are supported throughout their underside by a rigid structure, the lower edges will tend to chip off. The use of expanded metal lath in the compressive flange of the block has an excellent retarding action on the chipping induced by the load of operation on the lower surface of the block. It is also advantageous to strengthen plastic die blocks by placing reinforcing bars on the tension side, and to rely on the compressive strength of the material to carry the bending load on the opposite side of the block.

Masonite should be used only for the more simple shapes, with no hammer work on the sheet while it is being stretched, as Masonite tends to disintegrate under impact on its edge grain.

FORMING EXTRUSIONS AND ROLLED SHAPES

In forming extrusions and roll or brake-formed sections, distortion and spring-back are minimized by initial stretching of the part.

Steel and Masonite are the most widely used die materials for stretch-forming such sections. Laminated dies are normally used, and the design will vary according to the section to be formed. A cross section of a typical laminated die for forming a Z-shaped section is shown in Fig. 17-32. The die plate (*D1*) is made to the contour of the finished part. The spacer plate (*D2*) provides clearance between the die plate and pressure plate (*D3*) to allow the work to form without distortion and still prevent binding. This plate varies in thickness, allowing a clearance of 0.002 in. for thin parts and several thousandths of an inch for thicker sections. The flexible section (*D4*) prevents the collapsing of the lower leg while forming. It is made of a variety of materials, depending upon the part to be formed and the severity of the finished contour. Materials commonly used are wood, Masonite, steel segments, Kirksite, and other low-melting-point alloys. Rigidity is given to the die by the base plate (*D5*). Removable accessories such as drill jigs and scribe blocks to locate cutouts and end of part can be fastened to the die.

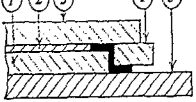


Fig. 17-32. Cross section of a typical stretch-form die for a Z-shaped section.

EYELET-MACHINE TOOLS*

The conventional eyelet machine has independently actuated plungers permitting flexibility in setting the stroke and shut height of each station. There are two methods of stroke control. The smaller machines are cam-driven; the heavier machines are driven by an eccentric crank mechanism.

The eyelet machine was originally designed to make small metal eyelets for shoes. With the development of large machines, metal up to 0.060 in. thick and shells 3 in. deep can be fabricated.

The eyelet machine combines such operations as blanking, drawing, piercing, trimming and forming, light coining, and even thread rolling and side piercing.

The principal advantages of an eyelet machine over a progressive die lie in the economical tooling and the speed with which it can be produced. Less material waste is involved, because each shell is carried free after the rough blank is cut from the coil stock. There is no material loss due to the necessity of the transfer ribbons associated with progressive-die operations. The cost of a complete set of eyelet-machine tools would be approximately half the cost of a progressive die required to produce the same part.

The only disadvantage is that eyelet machines operate somewhat more slowly than a progressive die. Normal output in medium-sized eyelet machines is approximately 5,000 pieces per hour. If speed-control units are installed on the machine, the output can be increased to 7,500 per hour.

Long-run jobs, and especially runs on stainless-steel shells, can be completed with a

* Reviewed by C. Stephens, Chief Engineer, Brighton Division, Advance Stamping Co.

minimum of down time by using carbide inserts in the draw and redraw stations. In some cases sintered carbide is used for piercing and trimming also.

Eyelet machines range from 6 to 11 individual stations. Normal setup time for an eight-station job would be approximately 6 hr. New jobs require considerably more setup time because carrying fingers must be fitted to each individual station, and the draw radius on dies must be developed to eliminate wrinkles and die marks.

Some parts made on screw machines can, with slight modifications, be made on eyelet machines (Fig. 17-33).

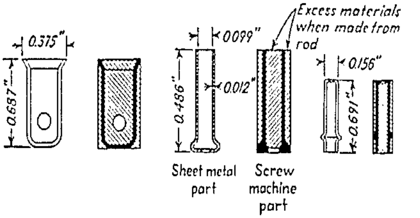


FIG. 17-33. Typical screw-machine parts and a similar part produced on the eyelet machine.

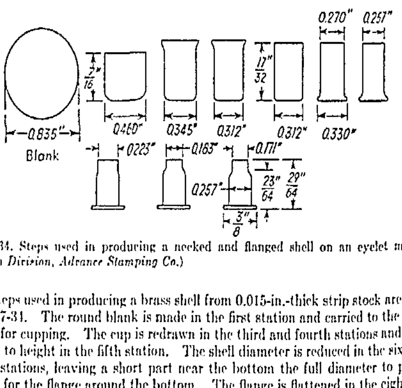


FIG. 17-34. Steps used in producing a necked and flanged shell on an eyelet machine. (*Brighton Division, Advance Stamping Co.*)

The steps used in producing a brass shell from 0.015-in.-thick strip stock are shown in Fig. 17-34. The round blank is made in the first station and carried to the second position for cupping. The cup is redrawn in the third and fourth stations and pinch-trimmed to height in the fifth station. The shell diameter is reduced in the sixth and seventh stations, leaving a short part near the bottom the full diameter to provide material for the flange around the bottom. The flange is flattened in the eighth station and the necking of the top is started. Further reduction of the neck diameter is done in station 9, and the part is finished to diameter in station 10.

A small brass part and the tools used to produce the parts are shown in Fig. 17-35. The operations include blank, draw, flange, coin, and pierce. The first operation blanks a 1.223-in.-diameter blank from a brass strip 0.020 in. thick and 1⁹⁄₃₂ in. wide. The blanking punch (*D*1) places the blank into the carrier pad (*D*2) to be transferred to the second station where it is cupped. The hold-down (*D*3) in the second station grips the blank while it is drawn by the punch (*D*4) into the carbide die (*D*5). Station 3 squares the top edge in preparation for pinch trimming in station 4. The pinch-trim punch (*D*5) has a replaceable hardened-steel tip held in place by the pilot (*D*6). The die at this station has a carbide insert. Stations 2, 3, and 4 have an ejector to lift the part to the level of the transfer fingers so that it can be moved to the next station. The operations in stations 5 and 6 are performed at the level of transfer and do not require ejectors.

At station 5, the part is held in the forming die (D7), while the sleeve (D8), actuated

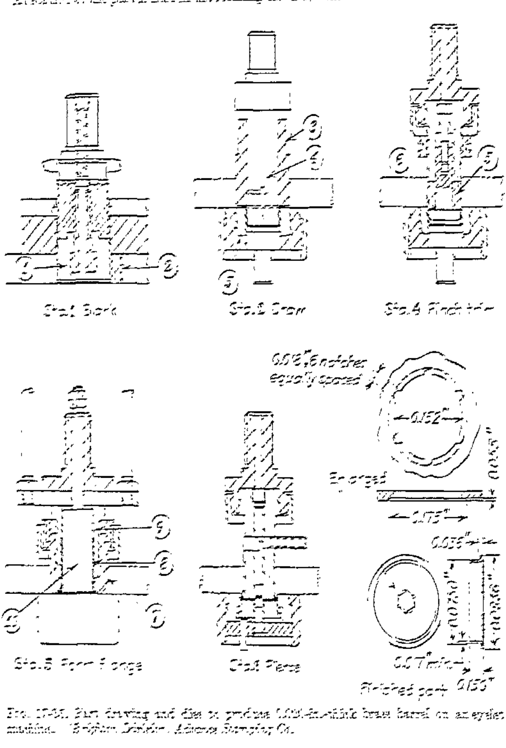


FIG. 17-33. Part drawing and dies to produce 0.005-in.-thick brass barrel on an eyelet machine. (*Brighton Division, Advance Stamping Co.*)

by the sleeve retainer (D9), forms the flange. The punch (D11) guides the inside of the part and holds the bottom flat.

The part is sized in station 4, and an area in the bottom is coined 0.0035 in. deep and 0.175 in. in diameter in station 3. The hole is pierced in the bottom of the cup at station 6.

The part shown in Fig. 17-34 is a guide made on an eyelet machine of 0.042-in.-thick cold-rolled-steel strip stock. The strip is automatically fed into the first station where the blank is made. It is then carried to station 2 where the 0.125-in. radius is formed on each of the legs which are to form the sides of the part. The legs are formed upward in station 3 into a cylindrical shape. Station 4 restrikes the bottom of the guide to form a 1/64-in. inside radius, and a 0.161-in.-diameter hole is pierced in the bottom. *In station 5 the small legs are bent downward and the cylindrical body is resized.*

Forming an Aluminum Guide. The 0.020-in.-thick aluminum guide shown in Fig. 17-37, view *A*, is made in eight stations on an eyelet machine. The 0.980-in.-diameter blank is produced in the first station from 1 1/32-in.-wide strip stock. The first forming operation on the recess is performed in the second station by the tools shown in view *B*. The drawn recess appears to have tapered walls because of a 1/32-in. draw radius and a 3/64-in. punch-nose radius. The flange has a 20° taper for a diameter of about 3/4 in.,

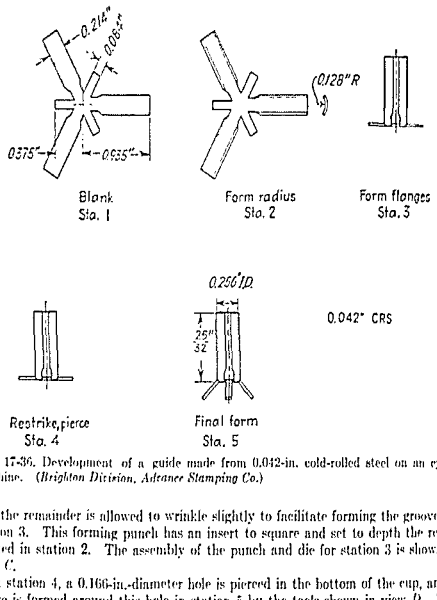


FIG. 17-36. Development of a guide made from 0.042-in. cold-rolled steel on an eyelet machine. (*Brighton Division, Advance Stamping Co.*)

and the remainder is allowed to wrinkle slightly to facilitate forming the grooves in station 3. This forming punch has an insert to square and set to depth the recess started in station 2. The assembly of the punch and die for station 3 is shown in view *C*.

At station 4, a 0.166-in.-diameter hole is pierced in the bottom of the cup, and a flange is formed around this hole in station 5 by the tools shown in view *D*. The trimming of the periphery is accomplished in station 6, and the forming of the tabs is done in station 7. In station 8, the grooves are restruck, while the lower edge of the flanged hole is coined to height and to the 45° bevel.

Tools for Multiple-slide Presses. With these machines, and properly designed tools and dies, parts can be produced that would present considerable difficulty on standard-type presses. Barrel, box, elliptical, and intricate shapes, whether notched, pierced, formed, or drawn, can be fabricated since there are two separate and distinct positions on the machine at which work is done in completing a finished part.

A typical part and the operations required to produce it on a multiple-slide press are shown in Fig. 17-38.

The part is cylindrical, with notched ends, two circumferential beads, and two

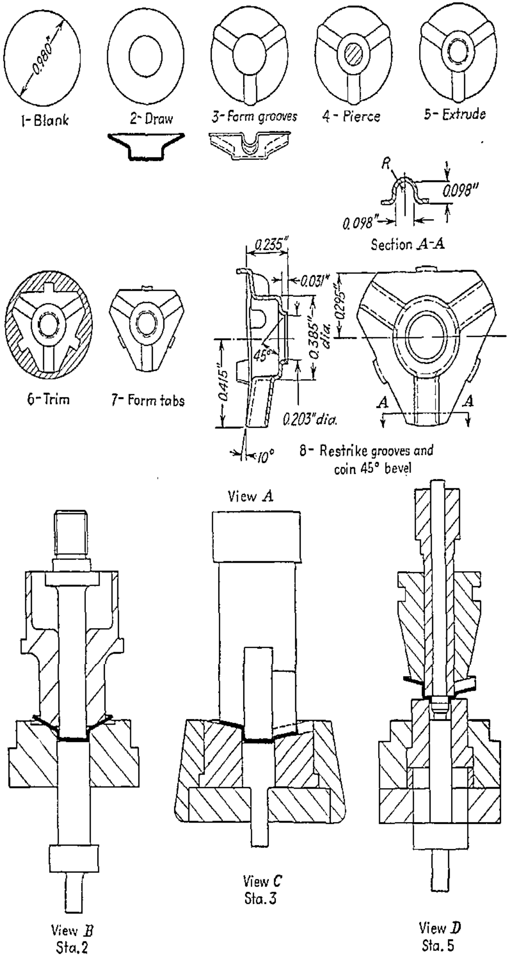


FIG. 17-37. Eyelet machine fabrication of an aluminum part: view *A*, part development; views *B*, *C*, *D* die details. (*Brighton Division, Advance Stamping Co.*)

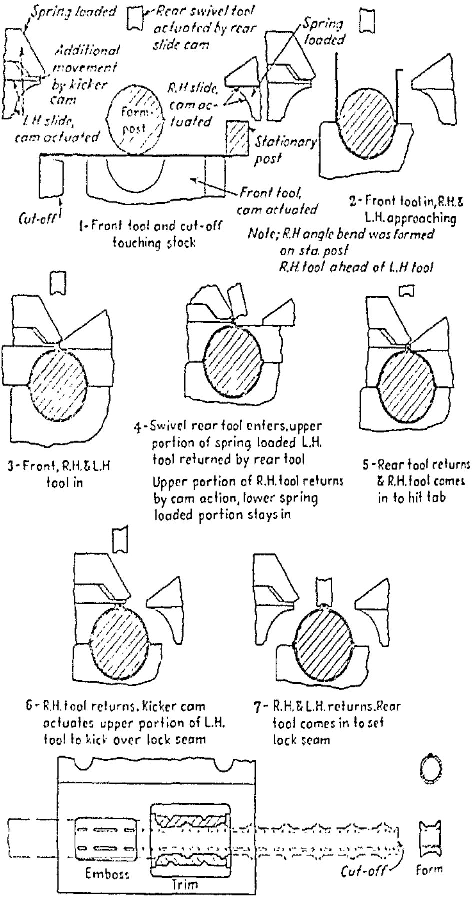


FIG. 17-38. Forming a part with a lock seam with tooling on a multiple-slide press. (*U.S. Tool Co., Inc.*)

longitudinal beads. The part is held in the cylindrical shape with a lock seam produced by the tools in the press.

The complex radio-tube plates (Fig. 17-39) are quickly notched and formed on the multiple-slide machines. Tab shapes and locations are produced accurately in the notching die which precedes forming the plate. The sectional construction of the punch facilitates grinding the tab forms to close tolerances, and an extra long quide pin and bushing are in constant engagement to maintain close alignment. After

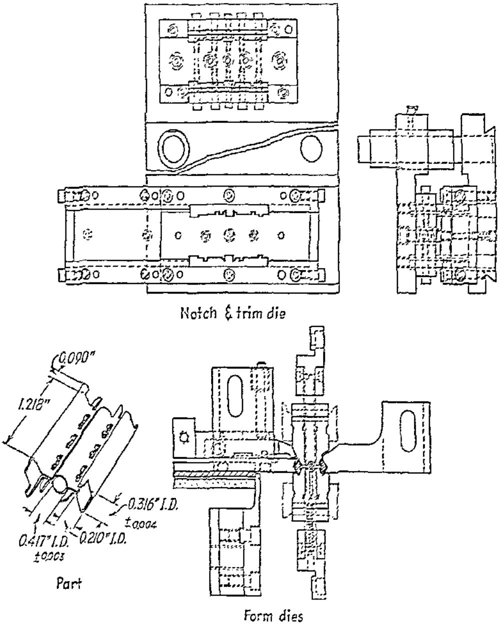


Fig. 17-39. Tools for producing radio-tube plates on a multiple-slide press.[19]

locating the notched section of the strip on the forming arbor, a cutoff blade parts the strip; then closely timed slides operate to form the part and lock it together with stakes engaged in cutouts.

ASSEMBLING DIES*

Assembling dies fasten parts together by either of two methods: (1) fastening them together by means of a third part, such as a rivet, which is plastically deformed by the die, the parts being subjected to little or no deformation; (2) joining them by plastically deforming mating areas in either or both parts in operations of staking, folding, crimping, curling, seaming, or press-fitting. Conventional rivets may have one end

* Reviewed by A. J. Pangburn, Manager, Tool Engineering, Department 541, International Business Machines Corp.

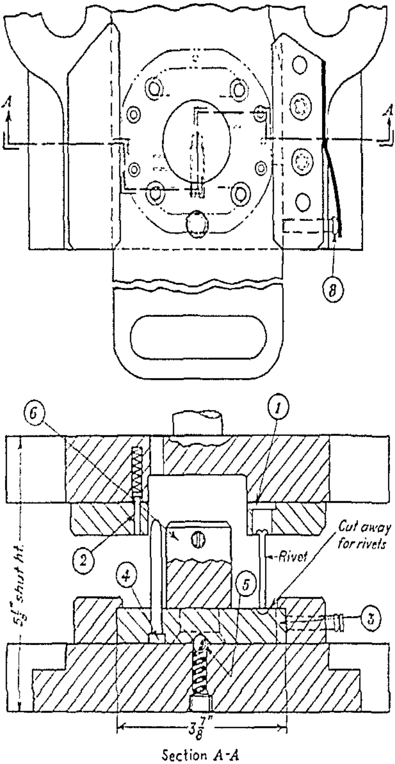


Fig. 17-40. Multiple riveting die. (*Harig Mfg. Corp.*)

upset in a die to fasten parts together; or pins, rods, bushings, or projections of the part itself may be used instead of a rivet.

RIVETING DIES

Ram-coin dimpling is an assembly operation involving a type of riveting; pertinent data are found in Sec. 8 [Figs. 8-5, 8-6 and Eq. (8)].

Riveting Die. A riveting-die design (Fig. 17-40) incorporates a slide (*D3*) which is pulled out by the operator for loading stator laminations. Four pilots (*D4*) and a post (*D6*) enter pilot holes and the armature hole, respectively, as the laminations are stacked on them and on four copper rivets. Outward slide movement is limited by a

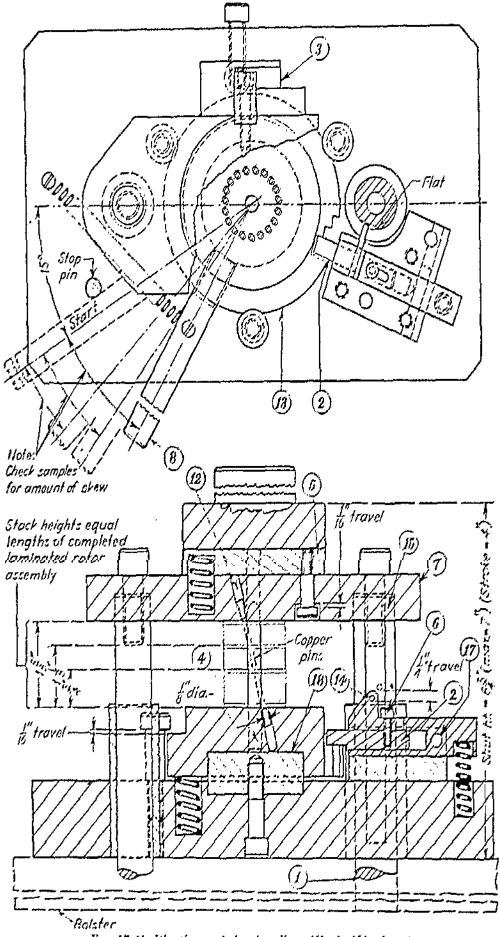


FIG. 17-41. Riveting and skewing die. (Harig Mfg. Corp.)

spring-loaded stop pin (*D8*); inward movement and positioning of the slide are controlled by a spring-loaded detent ball (*D5*). Four riveting punches (*D1*) upset the copper rivets to a rivet length of 1⅝ in. A shedder pin (*D2*) is mounted in the punch retainer plate between each pair of riveting punches.

Riveting and Skewing Die. Motor rotor laminations are stacked on a center pilot (Fig. 17-41, *D4*) and 19 copper pins are inserted vertically in holes circularly spaced in the laminations to project into undercut holes similarly spaced in an upper floating punch plate (*D7*) and in a lower rotating punch plate (*D18*). The holes contain 19 upper and 19 lower riveting punches (*D12*) which bear lightly against the ends of the

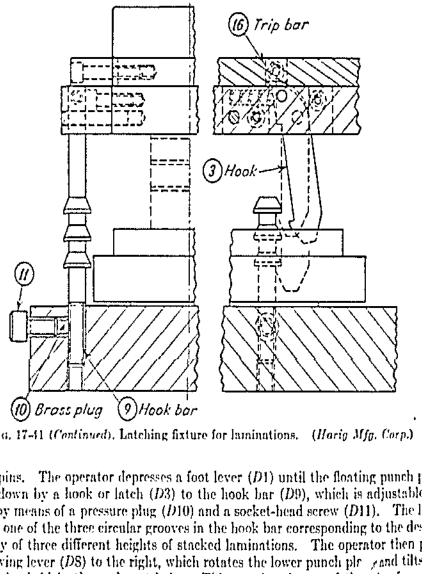


Fig. 17-41 (*Continued*). Latching fixture for laminations. (*Harig Mfg. Corp.*)

copper pins. The operator depresses a foot lever (*D1*) until the floating punch plate is held down by a hook or latch (*D3*) to the hook bar (*D9*), which is adjustable for height by means of a pressure plug (*D10*) and a socket-head screw (*D11*). The latch engages one of the three circular grooves in the hook bar corresponding to the desired assembly of three different heights of stacked laminations. The operator then pulls the skewing lever (*D8*) to the right, which rotates the lower punch pl[illegible] and tilts the copper pins held in the undercut holes. This angular change of t[illegible] pins from the vertical corresponds to a setting of an automatic indexing stop ([illegible]). Its position, selected by an adjustment of a screw (*D6*), determines the amo[illegible] skew in a stack of laminations. Three notches in the indexing ring (*D13*) eng[illegible] the indexing stop corresponding to three lengths of rotor assemblies and contro[illegible] amount of skew desired in a completed assembly. The press is tripped after t[illegible] skewing operation, allowing 38 riveting punches to travel $\frac{1}{16}$ in. and upset both en[illegible] of the copper pins to complete the assembly of a rotor. On the downstroke a trip bar (*D16*) is depressed to release the hook bar from its latching position. The indexing stop, pivoting on its pin (*D17*), is raised above the indexing ring during the last ¼ in. of the upstroke by a pickup pin (*D14*) contacting the edge of a flat on a post (*D15*). Upward movement of the stop allows the spring-loaded skewing lever to return to its starting position against its stop pin.

Riveting Magneto Laminations. A stack of laminations is placed between stationary and movable nest plates (Fig. 17-42, *D7*, *D4*); the latter is swung to the right by the operator's handle (*D6*) to align and clamp the stack as the toe of the handle bears against a clamping post (*D8*). Three riveting punches (*D1*) held in a punch holder (*D2*) upset three rivets as the stack is compressed by an insert (*D3*) shaped to contour of the laminations. On the upstroke the handle is swung to the left, and a knockout (*D5*) is actuated through the linkage shown and returned by a spring (*D9*).

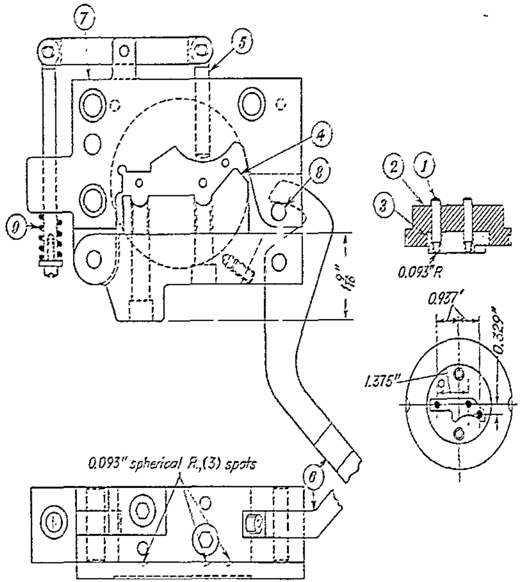


FIG. 17-42. Riveting magneto laminations. *(Fairbanks, Morse & Co.)*

Staking Dies. The hub of a gear (Fig. 17-43*A*, *D1*), splined in a previous operation, is fastened to a wheel (*D2*) by a staking punch (*D3*). The four splines (*D4*), forced outward and against the washer by the four chisel edges of the staking punch, provide rigidity in the assembly. In view *B*, a stripping fork (not shown) prevents the staking assembly from sticking to the punch (*D1*) and its pilot (*D2*). The punch forces metal from the hub into the chamfer in the plate. In view *C*, two segmented staking rings (*D1*) inwardly force metal of a wheel (*D3*) against the serrated portion of a shaft (*D2*).

A 1/16-in.-diameter ball is staked into a 1/8-in.-diameter shaft as shown in view *D*. The amount of taper on the punch provides enough metal displacement to hold the ball securely.

Staking-punch Design. Data for the design of four-bladed punches for staking hubs, tubes, and similar parts are given in Fig. 17-44.

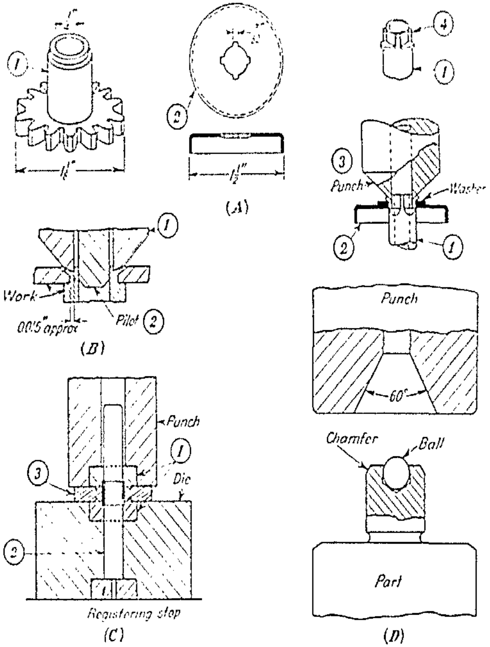
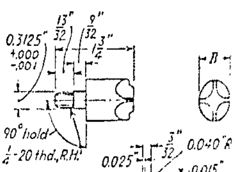


FIG. 17-43. Staking operations: (A, B) staking outwardly (F. W. Curtis); (C) staking inwardly[11]; (D) staking a ball.[12]



No	A	B
1	0495	3/4
2	0307	"
3	0432	"
4	0370	"
5	05575	7/8
6	0605	"
7	0588	"

FIG. 17-44. Staking-punch design. (National Cash Register Co.)

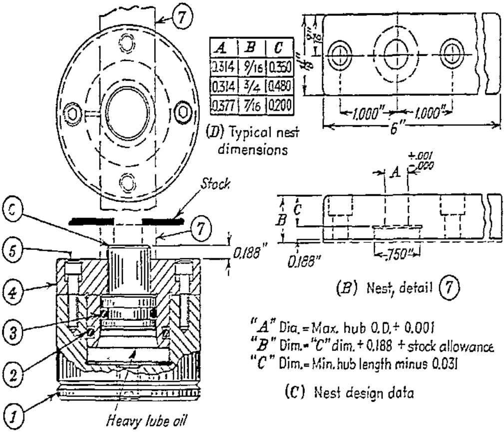


FIG. 17-45. Hydraulic compensating staking die; (A) assembly; (B) nest, detail 7; (C) nest design data; (D) typical nest dimensions. (*National Cash Register Co.*)

Hydraulic Compensating Staking Die. A nest (Fig. 17-45, *D*7) positions aluminum hubs which are staked into holes in aluminum sheet stock. The hub is placed tenon side up in the nest which is bolted to the die top (*D*4) by cap screws (*D*5). Enough oil is contained in the well to maintain the 0.188-in. dimension between the die top and the cylinder (*D*6) as shown. O rings (*D*2, *D*3) seal the oil in the well in the base (*D*1). A Denison 1-ton hydraulic press forces the hub and cylinder down. Oil pressure forces the top up to clamp the stock between it and a rubber pressure pad on the ram. Further pressure compresses the rubber pad to allow the staking punch to enter the hole in the stock and stake it to the hub. This design compensates for hub-length

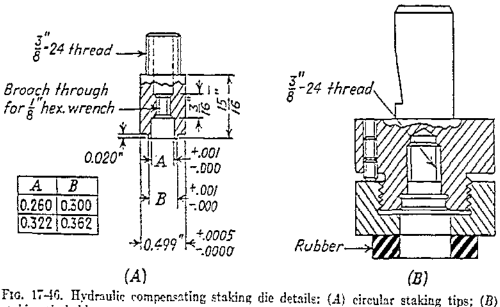


FIG. 17-46. Hydraulic compensating staking die details: (*A*) circular staking tips; (*B*) staking-tip holder.

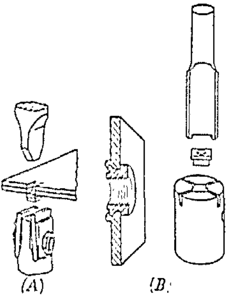


FIG. 17-47. Commercial assembling dies: (A) Metalace type (*Crockett Engineering Co.*); (B) clinch-nut type (*Richard Brothers Division, Allied Products Corp.*).

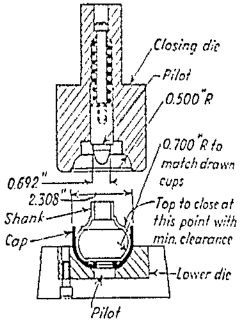


FIG. 17-48. Folding over doorknob parts.[1]

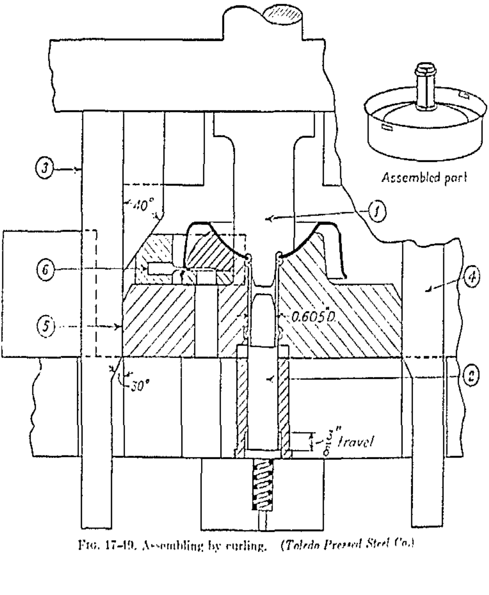


FIG. 17-49. Assembling by curling. (*Toledo Pressed Steel Co.*)

variations by always allowing the stock to lie flat during the staking operation. The die assembly is placed in an adapter which can be permanently fixed to the press bed or attached to a sliding fixture for loading and unloading out from underneath the punch. Staking tips (Fig. 17-46, view A) are screwed into a holder (view B). The holder is mounted in an adapter (not shown) which is screwed in the ram of the press.

Commercial Assembling Die Sets. A design for fastening sheet-metal sheets together (Fig. 17-47A) incorporates a die which expands slightly under the impact of the lance-form punch. At B, a nut which does the piercing is held magnetically to the bottom of the punch and is staked to the workpiece. Interchangeable ball-lock

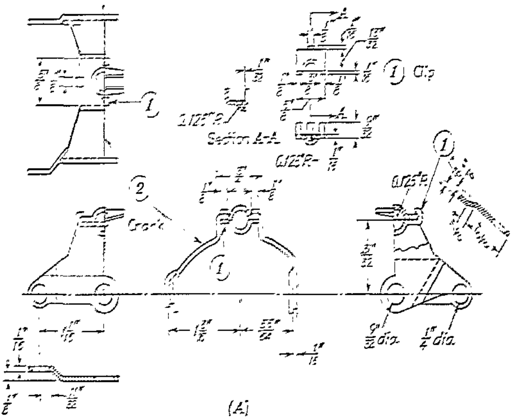


Fig. 17-50A. Parts assembled in die of Fig. 17-50.

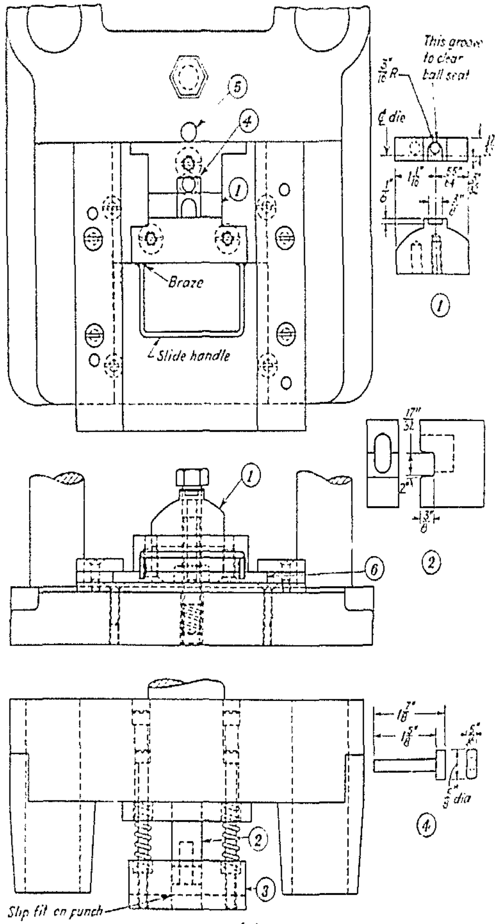
punches and die buttons for staking various sizes and shapes of shouldered nuts are available.

FOLD-OVER AND CRIMPING DIES

A die for assembling a doorknob part is shown in Fig. 17-48; the cap is folded over and around the inner knob (or shank) so that it will not slip when a torque of 50 in.-lb is applied. The closing or upper die incorporates a spring-loaded pilot for centrally locating the shank; another pilot in the lower die locates the cap. Stock is quarter-hard 0.050-in.-thick brass. The forming of the shank is described earlier in this section.

Assembling by Curling. A split beaded cylinder is placed on a spring-loaded pilot (Fig. 17-49, D2) and one end is curled over the edge of a hole in a shallow cup. There are no wrinkles in the curled flange in the cylinder since it was previously fabricated with a longitudinal split. Sliding nests (D5), actuated by cams (D3, D4), slide inwardly to position and hold the cylinder during the curling operation. This die can be classified as a combination die, since horizontal punches (D6), actuated by 40° cam surfaces, cut narrow slots in the cup's rim.

Assembling by Folding Over. Three tabs of a metal clip (Fig. 17-50A, D1) are folded over to assemble it to a small bell crank (D2). A form block (Fig. 17-50, D1) mounted on a manually operated slide (D6) also functions as a nest. A spring-loaded stop pin (D4) disappears as the punch (D2) descends to bend the tabs over the crank's



(B)

FIG. 17-50. Assembling by folding over. (*Century Electric Co.*)

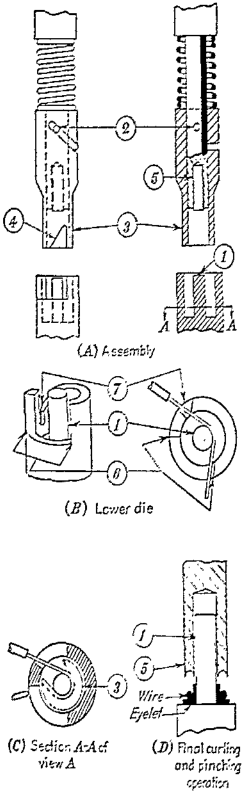


FIG. 17-51. Die for wire-to-eyelet assembly: (A) assembly; (B) lower die; (C) section A-A of view A; (D) final curling and pinching operation.[11]

edges. Inward travel of the slide is limited by a stop pin D5. A spring stripper (D3) also functions as a pressure pad to hold the parts in alignment.

Die for Wire-to-eyelet Assembly. A metal eyelet or grommet is placed around the central post of the lower die (Fig. 17-51, D1), and the bared end of an electrical wire is placed in the front notch (D6), bent around the post and down in the bottom of the rear notch (D7) as shown in view B. A notch (D4) in the revolving sleeve (D3) straddles the wire on the downstroke, wraps it around the post, and cuts it off as shown in view C. The clockwise revolution of the sleeve is actuated by ram pressure on the

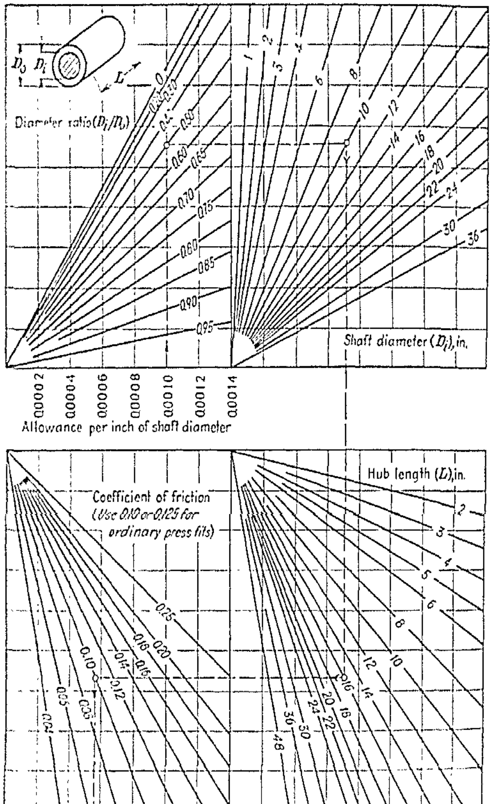


FIG. 17-52. Press-fit force chart.[14]

pin (*D2*) in its helical groove. A curling punch (*D5*) within the sleeve curls the grommet over and pinches it tightly on the wire as shown in view *D*.

Press Fitting. Press-fit assemblies generally involve the design of relatively simple locating and holding fixtures adapted to a given press. A factor in the choice of a press is the press-fit force needed. Calculation of press-fit forces is somewhat cumbersome; the chart (Fig. 17-52) permits their quick determination.

Example: Find the force required to fit a 10-in.-diameter steel shaft to a hub (OD of 20 in.) 16 in. long with an allowance of 0.001 in. per in.

1. Find ratio of shaft to hub diameter, or $^{10}/_{20} = 0.50$.
2. Project vertically upward on 0.0010 ordinate to intersection of 0.50 curve.
3. Project horizontally from this point to 10-in. shaft-diameter curve.
4. Project vertically downward to intersect with 16-in. hub-length curve.
5. Project horizontally from this point to 0.10-in. coefficient-of-friction curve.
6. Project vertically downward to abscissa of press-fit force to find force of 280 tons.

When a hub bore is uneven or the shafting is rough, use values for the coefficient of friction of 0.18 to 0.25. To prevent overloading of the press, the chart may be entered at the press capacity and the process reversed to find the other variables.

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SECTION 18

DIE SETS AND COMPONENTS*

A punch-and-die set is an assembly consisting of an upper member or shoe, a lower member or shoe, and guide or leader pins for holding the members in alignment.

TWO-POST, BACK-POST, AND DIAGONAL-POST SETS

Two-post commercial die sets are available in many styles and sizes. The sizes, dimensions, and tolerances for back-post and round-series diagonal-post die sets listed in Tables 18-1 to 18-7, inclusive, are excerpted or adapted from American Standard ASA B5.25-1950, "Punch and Die Sets."

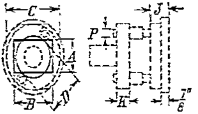


TABLE 18-1. DIMENSIONS OF ROUND DIAGONAL-POST DIE SETS

Die area: Rectangular area, A	Die area: Rectangular area, B	Die area: Diam. D	Die holder diam. C	Thickness: Die holder J	Thickness: Punch holder K	Min guide-post diam. P
1¾	3½	2¾	5	1¾	1¼	½
2¼	4½	3½	6	1¾	1¼	⅝
2¾	5¾	4	7	2	1½	¾
3½	7	5¼	9	2	1½	1
4½	9	7	11	2	1½	1¼

All dimensions are given in inches.

Material: This standard does not specify the material for the punch holder or die holder. They are generally made from cast iron, semisteel, or steel plate and should be free from dirt, slag, and detrimental blowholes and be sufficiently thick to permit machining of outer scale to provide uniform structure as to the finish of the surface on which the punches and dies are mounted. The material should be of sufficient hardness to stand up on service and have good machining qualities.

Note: A and B dimensions may be plus or minus ½ in. during a 5-year transition period so that suppliers may use present patterns.

* Reviewed by R. J. Fischer, President, Detroit Die Set Corp.

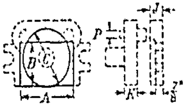
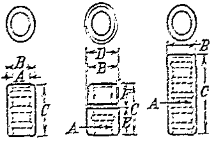


TABLE 15-2. DIMENSIONS OF BACK-POST DIE SETS

Die area			Thickness				Min guide-post diam.
			Die holder J		Punch holder K		
Right to left A	Front to back B	Diam. C	From	To	From	To	P
3	3	3	1	1¼	1	...	¾
4	4	4	1⅜	1¾	1¼	...	1
4	6		1½	2¾	1¼	2¼	1
5	4		1⅜	1¾	1¼	...	1
5	5	5	1½	2	1¼	1¾	1
5	8		1½	3	1¼	2¼	1
6	3		1½	2	1¼	1¾	1
6	4	5	1½	2¼	1¼	2¼	1
6	6	6½	1½	2½	1¼	2¼	1
6	9		1½	3¼	1¼	2¼	1¼
7	5	5¾	1½	3	1¼	2¼	1
7	7	7½	1½	2½	1¼	2¼	1
7	10		1⅝	3¼	1⅜	2¼	1¼
8	4		1½	2½	1¼	2¼	1
8	6	7	1½	3	1¼	2¼	1
8	8	8½	1½	2½	1¼	2¼	1
9	12		1¾	3½	1½	2¼	1½
10	5		1½	2½	1¼	1¾	1¼
10	7		1¾	2¾	1⅜	2¼	1¼
10	10	10	1⅝	2¾	1⅜	2¼	1¼
10	14		1⅞	3¾	1⅝	2¾	1½
11	9	10	1¾	3½	1½	2¼	1¼
12	4		1¾	2¼	1½	2	1¼
12	6		1½	2½	1½	2	1¼
12	12	12½	1¾	3½	1¾	2¼	1½
12	16	.	2	3¾	1¾	2¾	1½
14	8	.	1¾	3¼	1⅝	2¾	1½
14	10	11½	1¾	3¼	1⅝	2¾	1½
14	14	14	1¾	3¼	1⅝	2¼	1½
15	5	..	1½	2½	1½	2	1½
15	9		1½	2½	1½	2	1½
18	8		1½	2½	1½	2	1½
18	10		1½	2½	1½	2¼	1½
18	11	15	2	3	1¾	2¼	1½
18	16	17	2	3	1¾	2¾	1½
20	5		1¾	2½	1½	2	1½
22	9		1¾	2½	1½	2¾	1½
22	12		2	3	1½	2	1½
25	7		1¾	3	1½	2¼	1½
25	11		1¾	3	1½	2¾	1½

All dimensions are given in inches.
Material and tolerances: same as for Table 18-1.



Type 1 regular Type 2 shoulder Type 3 long

TABLE 18-3. REGULAR-SERIES STEEL GUIDE-POST BUSHINGS

Size	Type	ID A Max	ID A Min	OD B Nominal	OD B Max	OD B Min	Overall length C	Shoulder Length E	Shoulder Diam. D	Shoulder End to shoulder F
½	1	0.5001	0.4999	...	0.8142	0.8138	1¾			
	3	0.5001	0.4999	...	0.8142	0.8138	3			
⅝	1	0.6251	0.6249	...	1.0017	1.0013	1¾			
	3	0.6251	0.6249	...	1.0017	1.0013	3			
¾	1	0.7501	0.7499	...	1.1272	1.1268	1¾			
	2	0.7501	0.7499	...	1.1272	1.1268	2¼	.....	1 5/16	
	3	0.7501	0.7499	...	1.1272	1.1268	3			
⅞	1	0.8751	0.8749	1⅜	1.3772	1.3768	1¾			
	2	0.8751	0.8749	1⅜	1.3772	1.3768	2¼	1.266	1 7/16	1.234
		0.8751	0.8749	1⅜	1.3772	1.3768	2½	1.516	1 7/16	0.984
	3	0.8751	0.8749	1⅜	1.3772	1.3768	3			
1	1	1.0001	0.9999	1½	1.5022	1.5018	1¾			
	2	1.0001	0.9999	1½	1.5022	1.5018	2¼	1.266	1 11/16	1.234
	3	1.0001	0.9999	1½	1.5022	1.5018	3			
1⅛	1	1.1251	1.1249	1⅝	1.6272	1.6268	2			
	2	1.1251	1.1249	1⅝	1.6272	1.6268	2¼	1.391	1 13/16	1.259
		1.1251	1.1249	1⅝	1.6272	1.6268	2½	1.266	1 13/16	1.234
	3	1.1251	1.1249	1⅝	1.6272	1.6268	3			
1¼	1	1.2501	1.2499	1¾	1.7522	1.7518	2			
	2	1.2501	1.2499	1¾	1.7522	1.7518	3	1.516	1 15/16	1.484
		1.2501	1.2499	1¾	1.7522	1.7518	2¾	1.391	1 15/16	1.359
	3	1.2501	1.2499	1¾	1.7522	1.7518	3			
1½	1	1.5001	1.4999	2	2.0027	2.0023	2			
	2	1.5001	1.4999	2	2.0027	2.0023	3	1.516	2 3/16	1.484
	3	1.5001	1.4999	2	2.0027	2.0023	3			
1¾	3	1.7501	1.7499	2¼	2.2529	2.2525	3			
	2	1.7501	1.7499	2¼	2.2529	2.2525	3 15/32	1½	2½	1 21/32
2	3	2.0023	2.0020	2½	2.5032	2.5028	3			
	2	2.0025	2.0020	2½	2.5032	2.5028	3 15/32	1½	3¼	1 21/32
2½	3	2.5028	2.5025	3	3.0035	3.0031	3			
	2	2.5029	2.5025	3	3.0035	3.0031	3 15/32	2	3½	1 21/32
3	2	3.0030	3.0025	3⅝	3.6289	3.6285	3 21/32	2	4½	1 21/32

All dimensions are given in inches.

General: The ID and OD shall be ground or lapped to the dimensions shown in the table. Generally bushings up to 1¾ ID are lapped and all outside diameters and the larger inside diameters are ground.

Material: This standard does not specify material for guide-post bushings. They are generally made from 52100 steel or equivalent, heat-treated Rockwell C62 to 65.

Note: Oil grooves may be omitted if provided in the guide posts.

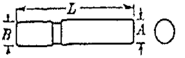


TABLE 18-4. DIMENSIONS OF GUIDE POSTS—REGULAR SERIES

Nominal diam.	Diam. Ground, B		Diam. Lapped, A		Length L (inclusive)
	Max	Min	Max	Min	
½	0.5017	0.5012	0.5002	0.5000	4 - 4½
⅝	0.6267	0.6262	0.6252	0.6250	4 - 4½
¾	0.7520	0.7515	0.7502	0.7500	4 - 5
⅞	0.8770	0.8765	0.8752	0.8750	4 - 8
1	1.0020	1.0015	1.0002	1.0000	4 - 9
1⅛	1.1270	1.1265	1.1252	1.1250	4 - 9
1¼	1.2525	1.2520	1.2502	1.2500	4½-12
1½	1.5025	1.5020	1.5002	1.5000	4½-12
1¾	1.7525	1.7520	1.7502	1.7500	6 -14
2	2.0025	2.0020	2.0003	2.0000	6 -20
2½	2.5030	2.5025	2.5003	2.5000	8 -20
3	3.0030	3.0025	3.0003	3.0000	8 -20

All dimensions are given in inches.

Material: This standard does not specify the material for guide posts. They are generally made from X1314 steel or equivalent, heat-treated Rockwell C62 to 65.

Note: Longer lengths of guide posts than those tabulated in this standard are available. Oil groove in the guide post may be optional with the supplier.

TABLE 18-5. DIMENSIONS OF REMOVABLE PUNCH-HOLDER SHANKS

Diam. of shank A	Length of shank B	Length of screw thread C
1½	2⅞	1¾-3½ incl.
1 9/16	2⅞	1¾-3½ incl.
2	2⅞	1¾-3½ incl.
2½	2⅞	1¾-3½ incl.
3	2⅞	1¾-3½ incl.

All dimensions are given in inches.

Material: This standard does not specify material for removable punch-holder shanks. They are generally made from 1112 steel or equivalent.

Tolerance on shank diameter +0.000, −0.002 in.

Tolerances on fractional dimensions are ±0.010 in. unless otherwise specified.

Screw threads shall be American Standard fine-thread series; 1½-12 NF-2, 1¾-12 NF-2, or 1⅞-12 NF-2 shall be optional for 2, 2½, and 3 diameter shanks.

All burrs shall be removed.

TABLE 18-4. SHANK DIAMETERS AND LENGTHS

Back-post and round diagonal-post die sets

Diam	1½	1¾*	2	2½*†	3†
Length	2⅛	2¼	2⅝	2⅞	2⅞

* Not a preferred shank diameter.

† Back-post die sets only.

All dimensions are given in inches.

Allowable tolerance on diameter shall be −0.000, −0.002 in. Allowable tolerance on length shall be ±0.010 in.

Lengths shown are standard but shorter shanks will be furnished when specified.

Steel shanks screwed in place (to be locked by user) will be furnished instead of integrally cast shanks when specified. For threading and detail dimensions see Table 18-6.

Back-post die sets may be obtained without the shank.

TABLE 18-5. TOLERANCES FOR DIE SETS

	6 by 6 in. and under	Over 6 by 6 to 12 by 12 in.	Over 12 by 12 to 20 by 20 in.	Over 20 by 20 in.
Die Holders (Lower Shoes)				
Parallelism, in. per ft, top and bottom faces*	0.001	0.001	0.002	0.0025
Thickness, in.	−1/16–1/32	+1/16–1/32	+1/32–1/16	+1/32–1/16
Punch Holders (Upper Shoes) with Solid Shanks				
Parallelism, in. per ft	0.0015	0.0015	0.0015	
Thickness, in.*	±1/32	±1/32	+1/32–1/16	
Punch Holders (Upper Shoes) without Shanks				
Parallelism, in. per ft*	0.001	0.0015	0.0015	0.002
Thickness, in.	±1/32	±1/32	±1/16	±1/16

Upper or Lower Shoes

Flange thickness: Machined, −1/16–1/32 in.
Not machined on top, ±1/16 in.

Partial Assembly

Guide posts (with upper shoe removed): Must be parallel and perpendicular to bottom surface of lower shoe, within 0.001 in. in 6 in.

Guide Bushings: Must be parallel and perpendicular to top surface of upper shoe, within 0.001 in. in 6 in.

Difference in center distances of guide posts and guide bushings, not to exceed 0.002 in. on any set.

Shank diameter tolerances: −0.000, −0.002 in.

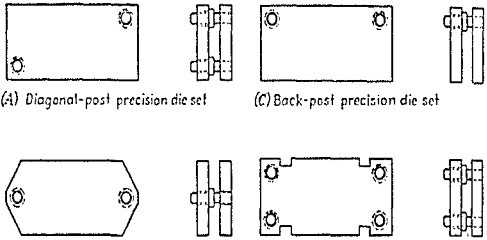
Assembled Sets

Parallelism, in. per ft, top surface of upper shoe and bottom surface of lower shoe	0.002	0.0025	0.0025	0.003

* Tolerance for parallelism applies to die space at contact surfaces.

NONSTANDARDIZED COMMERCIAL DIE SETS

Other typical designs of die sets commercially available, as yet unstandardized, are shown in Fig. 18-1. These are available in an almost infinite number of combinations of post diameters and lengths, shoe thicknesses, and variations in the lettered dimensions.



(A) Diagonal-post precision die set (C) Back-post precision die set

(B) Center-post precision die set (D) Four-post precision die set

Fig. 18-1. Typical commercially available die sets.

Sizes of four commonly used by a large manufacturer are listed in Table 18-8.

TABLE 18-8. DIMENSIONS OF COMMONLY USED FOUR-POST DIE SETS[1]*

Thickness of plates J and K: 1, 1⅛, 1¼, 1⅜, 1½, 1⅝, 1¾, 1⅞, 2, 2¼, 2½, 2¾, 3, 3¼, 3½, 4, 4½, 5, 5½, 6, 6½

O = 1½†			O = 1¾†			O = 2‡			O = 2§					O = 2½‖				
L = 18		20	22	24	26	28	30	35	40	45	50	55	60	65	70	80	90	100
D = 14		16	18	19½	21½	23½	25	30	35	40	45	50	55	60	64	74	84	94
W	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
10	6	6	6	5½	5½	5½	5	5	5	5	5	5	5	5	4	4	4	4
12	8	8	8	7½	7½	7½	7	7	7	7	7	7	7	7	6	6	6	6
14	10	10	10	9½	9½	9½	9	9	9	9	9	9	9	9	8	8	8	8
16	12	12	12	11½	11½	11½	11	11	11	11	11	11	11	11	10	10	10	10
18	14	14	14	13½	13½	13½	13	13	13	13	13	13	13	13	12	12	12	12
20	..	16	16	15½	15½	15½	15	15	15	15	15	15	15	15	14	14	14	14
22		.	18	17½	17½	17½	17	17	17	17	17	17	17	17	16	16	16	16
24				19½	19½	19½	19	19	19	19	19	19	19	19	18	18	18	18
26			.		21½	21½	21	21	21	21	21	21	21	21	20	20	20	20
28				...	..	23½	23	23	23	23	23	23	23	23	22	22	22	22
30							25	25	25	25	25	25	25	25	24	24	24	24
35						.	..	30	30	30	30	30	30	30	29	29	29	29
40					.		..		35	35	35	35	35	35	34	34	34	34
45						.	.			40	40	40	40	40	39	39	39	39
50											45	45	45	45	44	44	44	44
55			.				.					50	50	50	49	49	49	49
60													55	55	54	54	54	54

† No chain slots.
‡ F = 3, E = 5.
§ F = 4, E = 5.
‖ F = 4, E = 6.

(L) Shoe length; (D) shoe width; (W) post centers, right to left; (C) post centers, front to back; (F) width of chain slot; (E) end of shoe to chain slot; (J) lower shoe thickness; (K) upper shoe thickness; (O) guide-post diameter.

* Superior numbers relate to References at the end of this section.

DIE SETS WITH INTERCHANGEABLE ELEMENTS

Die sets incorporating interchangeable piercing punches, button dies, and strippers are commercially available. The die set of Fig. 18-2 incorporates T slots in both upper and lower shoes (*D*1, *D*2),† to which slotted interchangeable retainers (*D*3 and *D*4), for interchangeable punches (*D*5), button dies (*D*6), and stripper units (*D*7), are mounted. A slotted stock gage (*D*8), mounted to correct T slots, provides for the exact positioning of various sizes of blanks or strip.

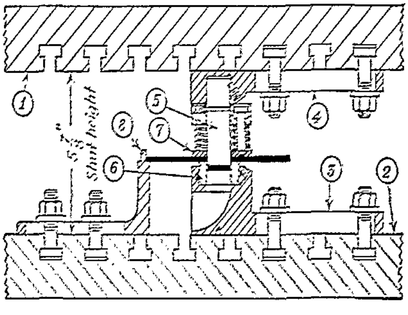


FIG. 18-2. Interchangeable die set.[3]

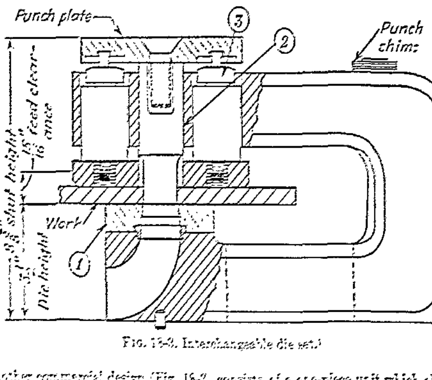


FIG. 18-3. Interchangeable die set.[3]

Another commercial design (Fig. 18-3) consists of a one-piece unit which also may be set up on T-slotted plates in presses or press brakes. Interchangeable punches (*D*2) and dies (*D*1) of various sizes are available. Stripping pressure is provided by cylinders (*D*3) containing oil under pressure.

A cam-actuated side-piercing unit which may be mounted on T-slotted plates in presses or press brakes is manufactured with interchangeable punches and dies of various sizes and shapes.

† *D* indicates detail number on drawing.

Self-contained punching units of various sizes and shapes of commercial design to be bolted to templets on the upper and lower shoes or directly to the shoes are also available.

Interchangeable strippers, punches, and button dies of various sizes and shapes, mounted in magnetic retainers, are incorporated in commercial equipment.

DIE DIMENSIONS

Determining the size of die sets is usually based upon practical experience, actually a matter of "rule of thumb." Some empirical rules[1] state that die plates can be provisionally selected as 0.03, 0.06, or 0.085 in. thick for every ton per square inch of required shear pressure for stocks, respectively, 0.1, 0.2, and 0.3 in. thick. In addition, the data state that the minimum distance between the cutting edge of a die and its outside border, for small dies, should be from 1.5 to 2 times die thickness; for larger dies, from 2 to 3 times die thickness. Such ratios apply to dies having cutting perimeters up to 2 in.; for longer perimeters, die thickness should be multiplied by the applicable factor listed in Table 18-9.

TABLE 18-9. FACTORS FOR CUTTING EDGES EXCEEDING 2 INCHES[1]

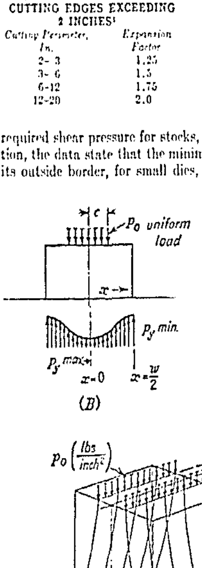
Cutting Perimeter, In.	*Expansion Factor*
2- 3	1.25
3- 6	1.5
6-12	1.75
12-20	2.0

TABLE 18-10. MINIMUM CRITICAL AREA VS. IMPACT PRESSURE[1]

Impact Pressure, Tons	*Cross-sectional Area of a Die between the Cutting Edge and Outside Border of a Die, Sq In.*
20	0.5
50	1.0
75	1.5
100	2.0

Further, the critical cross-sectional area of a die between the cutting edge and outside border of a die must not be less than the values listed in Table 18-10. If the pressures are exceeded, die thickness must be increased accordingly.

These data apply to heat-treated tool-steel dies adequately supported.



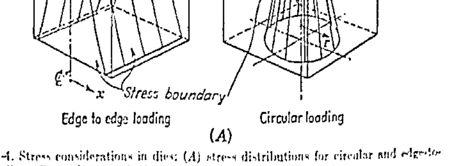


FIG. 18-4. Stress considerations in dies: (A) stress distributions for circular and edge-to-edge loading; (B) maximum and minimum vertical stress components.[2]

Design of Large Die Sets. Recent studies[2] of stress distributions in dies weighing more than 100 tons have been made to determine their optimum thicknesses and width. Nearly all the vertical stress components are contained in the stress boundary diagrammatically shown in Fig. 18-4, at *A*. The stress studies were made for both edge-to-edge and circular loading. For assumed uniformly applied loads at the top of a die, the vertical component P_y at the bottom is a maximum at the center ($x = 0$) and a minimum where $x = w/2$, as shown in Fig. 18-4, at *B*.

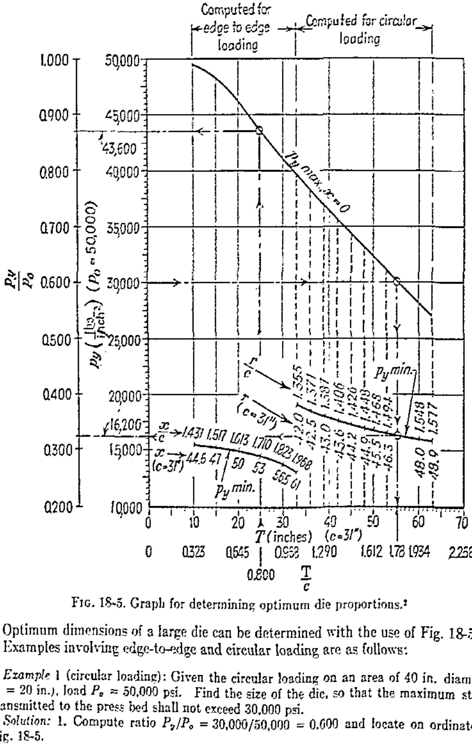


Fig. 18-5. Graph for determining optimum die proportions.[2]

Optimum dimensions of a large die can be determined with the use of Fig. 18-5. Examples involving edge-to-edge and circular loading are as follows:

Example 1 (circular loading): Given the circular loading on an area of 40 in. diameter (c = 20 in.), load P_o = 50,000 psi. Find the size of the die, so that the maximum stress transmitted to the press bed shall not exceed 30,000 psi.

Solution: 1. Compute ratio $P_y/P_o = 30{,}000/50{,}000 = 0.600$ and locate on ordinate in Fig. 18-5.

2. Follow along horizontal line from point $P_y/P_o = 0.600$ to intersect with curve P_y (max).

3. Extend vertical line down to intersect with curve P_y (min). The point of intersection corresponds to a value of $r/c = 1.51$ or $r = 1.51\ c$, $r = 1.51 \times 20 = 30.2$ in., and

$$d = 2r = 60.4 \text{ in.}$$

This is the required diameter or width of the die.

4. To determine the thickness of the die set, extend the vertical line farther to intersect abscissa T/c. This point of intersection corresponds to $T/c = 1.78$ or

$$T = 1.78\,c = 1.78 \times 20 = 35.6 \text{ in.}$$

This is the required thickness of the die.

5. From intersection with curve P_y (min) read horizontally the ordinate value

$$P_y/P_s = 0.324$$

or $P_y = P_y$ (min) $= 0.324 \times P_s = 16{,}200$ psi. This is equal to the minimum stress at the edge of the die being transmitted to the press bed.

Example 2 (edge-to-edge loading): Given the loading on rectangular area of $2c \times L$ as shown in Fig. 18-4, intensity of load $P_s = 50{,}000$ psi. Assume the thickness of die is limited to a value of $T/c = 0.800$ and $c = 31$ in. Required to find the width of the die w, and the maximum stress P_y transmitted to the platen below the die for these conditions.

Solution: 1. Ratio $T/c = 0.800$. Locate this point on abscissa of Fig. 18-5.

2. Extend vertical line from this point upward to intersect curve P_y (min). This point corresponds to a value of $x/c = 1.700$. Hence $x = 1.700\,c$, or $w = 2xc = 3.4\,c = 105.4$ in. This is the required width of the die.

3. Extend vertical line $T/c = 0.800$ farther to intersect curve P_y (max).

4. Read horizontally on ordinate P_y/P_s = value equal to 0.872, or

$$P_y = P_y\,(\text{max}) = 0.872 \times P_s = 43{,}600 \text{ psi.}$$

This is the maximum stress transmitted to the platen for the specified loading condition. The maximum stress is at the center of the die at the plane of contact with the press platen.

PUNCH DIMENSIONING

The determination of punch dimensions has been generally based on practical experience.

When the diameter of a pierced round hole equals stock thickness, the unit compressive stress on the punch is four times the unit shear stress on the cut area of the stock, from the formula

$$\frac{4S_s}{S_c}\frac{t}{d} = 1 \tag{1}$$

where S_c = unit compressive stress on the punch, psi
S_s = unit shear stress on the stock, psi
t = stock thickness, in.
d = diameter of punched hole, in.

The diameters of most holes are greater than stock thickness; a value for the ratio d/t of 1.1 is recommended.[3]

The maximum allowable length of a punch can be calculated from the formula

$$L = \frac{\pi d}{8}\frac{E}{S_s}\frac{d}{t} \tag{2}$$

where d/t = 1.1 or higher
E = modulus of elasticity

This is not to say that holes having diameters less than stock thickness cannot be successfully punched. The punching of such holes can be facilitated by:

1. Punch steels of high compressive strengths
2. Greater than average clearances
3. Optimum punch alignment, finish, and rigidity
4. Shear on punches or dies or both
5. Prevention of stock slippage
6. Optimum stripper design

Design of Small Piercing Punches. Punches made of drill rod are satisfactory for perforating light-gage steel, brass, and aluminum. The punch heads are peened over and backed up by a hardened backing plate and the punches can be guided by stripper plates and held in alignment by quills.

A shoulder punch made of a good grade of tool steel, hardened and ground, is the most efficient type for cutting holes from 3/16 to 1/2 in. diameter in both low- and high-speed die operations.

Recommended dimensions for heavy- and light-duty punches and corresponding punch holders are given in Fig. 18-6 and Table 18-11.

TABLE 18-11. PUNCH DIMENSIONS[9]
For dimension diagram, see Fig. 18-6

Diam. A	Diam. B	Diam. C	Diam. D
Punches for Piercing Metal up to 3/32 Thickness*			
0.375 + 0.005	0.375–0.005	0.2505 + 0.0003	0.031–0.250
0.500 + 0.005	0.500–0.005	0.3755 + 0.0003	0.251–0.375
0.625 + 0.005	0.625–0.005	0.5005 + 0.0003	0.376–0.500
0.750 + 0.005	0.750–0.005	0.6255 + 0.0003	0.501–0.625
0.875 + 0.005	0.875–0.005	0.7505 + 0.0003	0.626–0.875
1.000 + 0.005	1.000–0.005	0.8755 + 0.0003	0.751–0.875
1.125 + 0.005	1.125–0.005	1.0005 + 0.0003	0.876–1.000
Heavy-duty Punches for Piercing Metal over 3/32 Thickness†			
Diam. A	Diam. B	Diam. C	Diam. D
0.437 + 0.005	0.437–0.005	0.2505 + 0.0003	0.094–0.250
0.562 + 0.005	0.562–0.005	0.3755 + 0.0003	0.251–0.375
0.750 + 0.005	0.750–0.005	0.5005 + 0.0003	0.376–0.500
1.000 + 0.005	1.000–0.005	0.7505 + 0.0003	0.501–0.750
1.250 + 0.005	1.250–0.005	1.0005 + 0.0003	0.751–1.000

* E = 3/32 in. min; F = 11/16 in. min; R = 1/32 in. min.
† E = 1/4 in. min; F = 13/16 in. min; R = 1/16 in. min.

Methods of Mounting and Securing Punches. Matrix metal (alloys of low melting temperatures) helps to anchor sectional punches for producing rotor laminations (Fig. 18-7*A*) and also serves as a shock absorber. Setscrews bear against two closely spaced punches at *B*, or against a single punch at *C*, and expedite punch removal. A flat on the punch shoulder, at *D*, bears on a slot in the punch retainer to prevent punch rotation; a pin, or "dutchman," extending through the punch shoulder, at *E*, accomplishes the same purpose. The prevention of punch rotation and the easy replacement of both the punch and the die button are features of the design shown at *F*. The punches and dies, held in their respective retainers by spring-loaded balls, are commercially available for the piercing of round and irregular holes of many sizes.

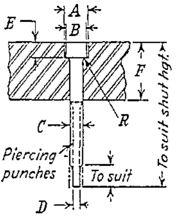


FIG. 18-6. Punch dimensions.[9]

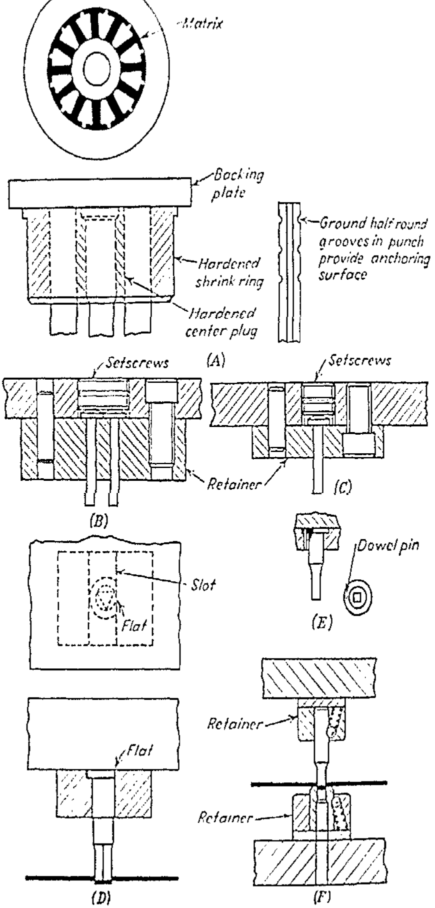


FIG. 18-7. Methods of mounting and securing punches by the use of: (A) a shrink ring (Sterling Tool Co.); (B, C) setscrews;[16] (D) a flat shoulder;[2] (E) dowel pin; (F) ball-lock retainers.[11]

Punch fabrication and sharpening are facilitated by the assembly of punch sections within a ring (Fig. 18-8, A); a hardened button takes the thrust. At B, lifter keys (D1) fit the keyways in the side of the carbide punches (D2) to allow the removal of one punch without disturbing the others.

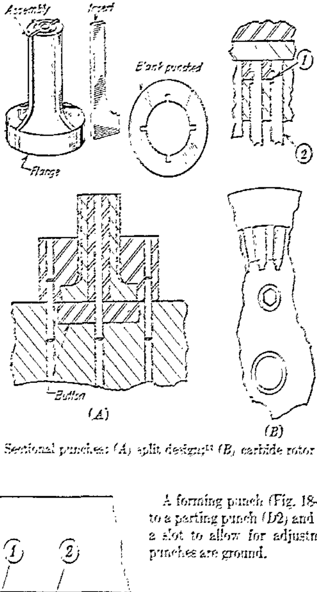
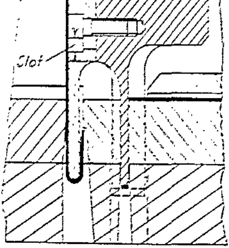


FIG. 18-8. Sectional punches: (A) split design;[13] (B) carbide rotor slotting.[14]

A forming punch (Fig. 18-9, D1) is bolted to a parting punch (D2) and is provided with a slot to allow for adjustment after both punches are ground.



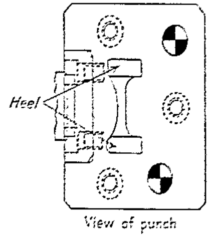


FIG. 18-9. Mounting of a sectional punch for grinding adjustment. (Harig Mfg. Corp.)

Floating or Gag Punches. A cutoff blade (Fig. 18-10, *D*1) is held up in the non-operating position by a spring (*D*2) but functions when a lever (*D*4) is swung clockwise to move a slide (*D*3) inwardly to the operating position shown.

Two slides (Fig. 18-11, *A*) control the operation of two punches; a similar design with a larger number of slides and punches, simple to set up to pierce holes in various combinations of size and location, is adaptable for short runs. A simpler arrangement, at *B*, for punching light stock, incorporates setscrews which are backed off to render the punch inoperative.

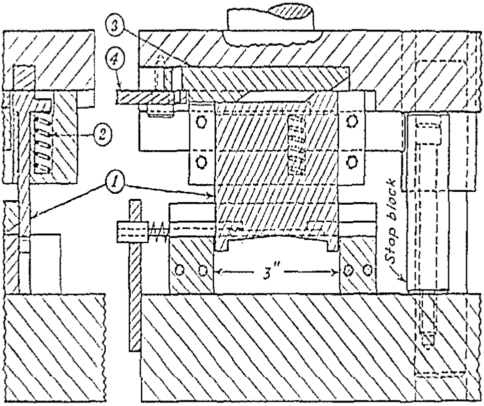


Fig. 18-10. Floating cutoff punch. (*Horig Mfg. Co.*)

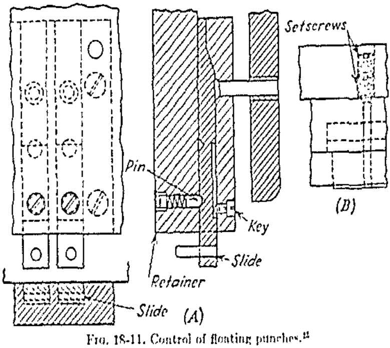


Fig. 18-11. Control of floating punches.[8]

An operator-controlled pneumatic cylinder moves a gag bar having rack teeth along one side to engage the teeth of a rotary-face cam shown in Fig. 18-12, *A*. A punch is mounted in the rotary cam which mates with a fixed-face cam, at *B*. The rotary cam and the punch move ⅜ in. up or down in 80° of rotation when the rotary cam is actuated by the toothed gag bar. Individual punches in several rows can be made operative or nonoperative in succession; it is somewhat convenient if this arrangement is mounted on the lower shoe with the button dies in the upper shoe.

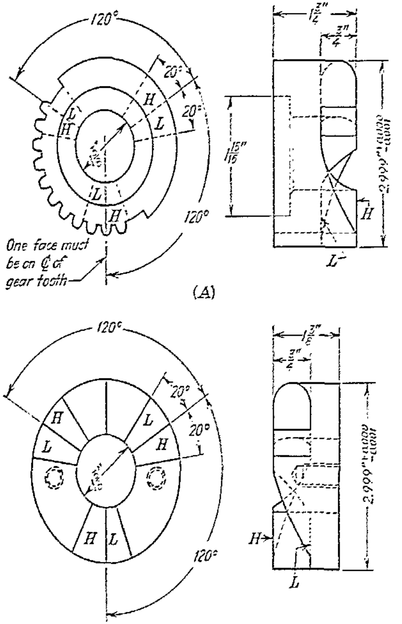


Fig. 18-12. Gag-punch cam design: *H*, *L* designate high and low faces.[11]

Piloted Punches. Removable pilots facilitate the grinding of punches. A spring-loaded pilot, centrally located inside a punch, is suitable for engaging thin stock. If the hole in the stock is irregular in outline, a pin or thin dowel can be pressed through the body of the punch. The pin bears against a flat ground on the pilot, allowing it to move freely in a vertical direction, but preventing it from turning.

Flanging-punch Design. Combination punch design is shown in Fig. 18-13; a punch (*D3*) blanks and draws the outside of the cup. Another punch (*D1*) aids in drawing the cup and in forming the flange around the hole. A stepped punch (*D2*) enters a previously pierced hole (0.0276 in. diameter) to form the flange to a nominal diameter of 0.0571 in. A lower stripper (*D4*) is actuated by springs (not shown) through pins (*D5*).

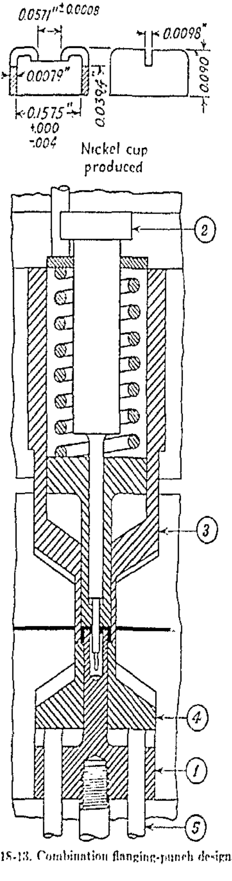


Fig. 18-13. Combination flanging-punch design.[13]

Automotive-body Punches. A lance-and-bend punch commonly used in the automotive industry for producing anchoring tabs in automobile bodies is shown in Fig. 18-14.

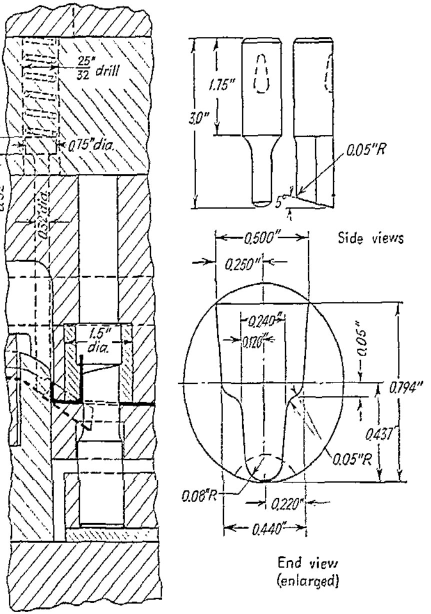


Fig. 18-14. Lance-and-bend punch.[2] *(Ford Motor Co.)*

Punch-and-die Design for Producing Holes for Self-tapping Screws. Punch-and-die button design (press-fit type) for producing holes in mild-steel sheets to be fastened to another sheet with self-tapping screws is shown in Fig. 18-15. These elements are also made in the ball-lock type.

The hole in the lower sheet is punched with a radial slit, and the surrounding metal is formed into a spiral cone conforming to the pitch of the screw thread. Optional hole sizes for a given range of stock thicknesses are listed in Table 18-13. For maximum rigidity, use the smaller hole sizes in combination with the heavier stock thickances. Development of the pierced hole to a specified formed-hole diameter is a function of bottoming pressure and stock thickness. For materials other than mild steel, data probably must be revised.

Pertinent tabular data for the elements shown in Fig. 18-15 are listed in Tables 18-12 to 18-14. The forming punches, piercing punches, and die buttons are made of tool steel, hardened and ground. The forming punches and die buttons are heat-treated to Rockwell C59 to C61; the piercing punches to Rockwell C63 to C64.

The proper selection of screw sizes for various stock thicknesses and hole sizes is listed in Table 18-13.

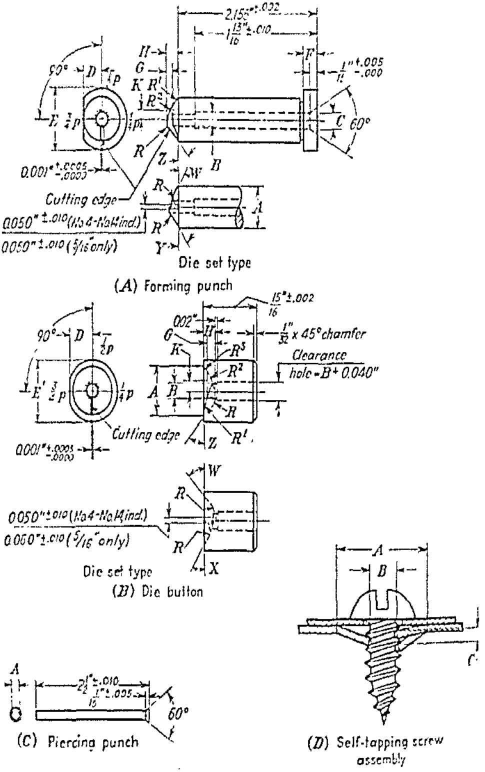


FIG. 18-15. Punch-and-die design for spiral slotted holes.[8] (*General Motors Corp.*)

TABLE 18-12. FORMING-PUNCH AND DIE-BUTTON DATA[a]

Stock-thickness ranges	0.015-0.025	0.016-0.031	0.020-0.044	0.025-0.047	0.037-0.056	0.044-0.062	0.047-0.062
Screw sizes	No. 4-24	No. 6-18	No. 8-15	No. 10-12	No. 12-11	No. 14-10	5/16
Forming Punches (for dimension diagram, see Fig. 18-15, A)							
A, punch OD (retainer)	0.3740-0.3747	0.4000-0.4007	0.4000-0.4007	0.4000-0.4007	0.6240-0.6247	0.6240-0.6247	0.7490-0.7497
A', OD (die set)	0.3751-0.3752	0.5001-0.5002	0.5001-0.5002	0.5001-0.5002	0.6251-0.6252	0.6251-0.6252	0.7501-0.7502
B, small hole diam.	0.061-0.063	0.080-0.084	0.093-0.090	0.090-0.096	0.120-0.126	0.100-0.103	0.185-0.182
C, large hole diam.	0.073-0.070	0.091-0.087	0.108-0.104	0.108-0.104	0.140-0.136	0.173-0.166	0.191-0.187
D, center to flat on head	0.1875-0.1870	0.2500-0.2495	0.2500-0.2495	0.2500-0.2495	0.2812-0.2807	0.3125-0.3120	0.3750-0.3745
E, head diam.	0.565-0.558	0.685-0.675	0.685-0.675	0.685-0.675	0.748-0.738	0.875-0.865	1.005-0.995
F, head thickness	0.1255-0.1245	0.1875-0.1865	0.1875-0.1865	0.1875-0.1865	0.1875-0.1865	0.2505-0.2495	0.2505-0.2495
G, height	0.047-0.042	0.060-0.056	0.074-0.067	0.091-0.084	0.102-0.092	0.111-0.101	0.122-0.112
H, height of form	0.113-0.110	0.125-0.120	0.135-0.130	0.147-0.140	0.160-0.150	0.170-0.160	0.180-0.170
J, seat radius	1/8	5/32	5/32	5/32	5/32	5/32	3/16
K, from center to axis of R^1	0.062	0.080	0.088	0.092	0.110	0.125	0.150
R, radius (end of cut, 1/4p and 3/4p)	0.032	0.035	0.040	0.047	0.050	0.062	0.080
R^1, radius (at 1/2 pitch)	0.100	0.170	0.187	0.187	0.150	0.150	0.250
R^2, radius (at end 1/2 pitch)	0.060	0.070	0.078	0.093	0.100	0.117	0.125
W, angle (at 1/4 pitch)	32°50'	23°25'	26°13'	26°	26°21'	24°15'	21°11'
X, angle (at 3/4 pitch)	10°0'	31°11'	30°8'	38°33'	33°10'	37°38'	35°20'
Z, angle (at cutting edge)	11°38'	33°35'	38°2'	41°34'	41°43'	40°35'	37°53'
Die Buttons (for dimension diagram, see Fig. 18-15, B)							
A, cone diam.	0.300-0.304	0.523-0.518	0.535-0.530	0.541-0.536	0.606-0.601	0.676-0.671	0.707-0.702
B, hole diam.	0.071-0.068	0.091-0.086	0.106-0.101	0.106-0.101	0.130-0.136	0.170-0.177	0.190-0.196
D, center to flat on head	0.2505-0.2500	0.3130-0.3125	0.3130-0.3125	0.3130-0.3125	0.3755-0.3750	0.3755-0.3750	0.4380-0.4375
E, body diam. (retainer type)	0.6240-0.6247	0.7400-0.7407	0.7400-0.7407	0.7400-0.7407	0.8740-0.8747	0.8740-0.8747	0.9990-0.9997
E', body diam. (die-set type)	0.6260-0.6255	0.7510-0.7505	0.7510-0.7505	0.7510-0.7505	0.8760-0.8755	0.8760-0.8755	1.0010-1.0005
G, depth	0.047-0.042	0.061-0.056	0.074-0.067	0.091-0.084	0.102-0.092	0.111-0.101	0.122-0.112
H, depth of die	0.110-0.108	0.120-0.118	0.130-0.128	0.140-0.138	0.150-0.148	0.160-0.158	0.170-0.168
J, seat radius	1/8	5/32	5/32	5/32	5/32	5/32	3/16
K, from center to axis of R^1	0.079-0.082	0.070-0.074	0.098-0.093	0.102-0.097	0.120-0.115	0.135-0.125	0.160-0.150
R, radius (end of cut, 1/4p and 3/4p)	0.070-0.060	0.077-0.067	0.090-0.080	0.100-0.090	0.110-0.100	0.130-0.120	0.155-0.145
R^1, radius (cutting edge)	0.100	0.150	0.204	0.219	0.250	0.375	0.375
R^2, radius, bottom (at 1/2 pitch)	0.092-0.087	0.108-0.103	0.130-0.125	0.147-0.142	0.161-0.156	0.182-0.177	0.192-0.187
R^3, radius, top (at 1/2 pitch)	0.075-0.070	0.138-0.133	0.141-0.136	0.138-0.133	0.100-0.095	0.091-0.086	0.187-0.182
W, angle (at 1/4 pitch)	38°40'	30°33'	31°12'	31°18'	33°21'	31°31'	30°7'
X, angle (at 3/4 pitch)	30°10'	22°5'	26°35'	25°12'	21°1'	22°11'	21°3'
Z, angle (below cutting edge)	30°35'	32°19'	35°12'	37°11'	37°17'	35°30'	33°21'

TABLE 18-13. SELF-TAPPING SCREW SELECTION[a]

For dimension diagram, see Fig. 18-15D

Stock-thickness Range, In.	Screw Sizes
0.015-0.025	Nos. 4-24, 6-18
0.020-0.025	Nos. 4-24, 6-18, 8-15
0.025-0.031	Nos. 6-18, 8-15, 10-12
0.031-0.037	Nos. 8-15, 10-12
0.037-0.044	Nos. 8-15, 10-12, 12-11
0.044-0.047	Nos. 10-12, 12-11, 14-10
0.047-0.056	Nos. 12-11, 14-10, 5/16-9
0.056-0.062*	No. 14-10, 5/16-9

	Dimensions of Pressed Holes, Inches		
Screw size	A†	B	C
No. 4-24	0.375	0.091-0.081	0.04167
No. 6-18	0.500	0.107-0.098	0.05556
No. 8-15	0.500	0.120-0.110	0.06666
No. 10-12	0.500	0.130-0.125	0.08333
No. 12-11	0.5625	0.172-0.158	0.09091
No. 14-10	0.625	0.197-0.181	0.10000
5/16-9	0.750	0.248-0.230	0.11111

* Heavier gages require special tools.

† Countersunk diameter. Dimension A may be varied by use of special tools.

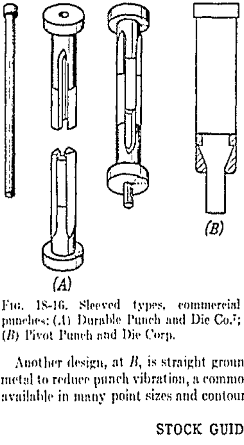


FIG. 18-16. Sleeved types, commercial punches: (A) Durable Punch and Die Co.[7]; (B) Pivot Punch and Die Corp.

TABLE 18-14. PIERCING-PUNCH SIZES[a]

For dimension diagram see Fig. 18-15C.

Screw Size	Punch Diam., In. A
No. 4-24	0.0625-0.0615
No. 6-18	0.0825-0.0815
No. 8-15	0.0955-0.0945
No. 10-12	0.0955-0.0945
No. 12-11	0.1255-0.1245
No. 14-10	0.1625-0.1615
5/16-9	0.1805-0.1795

Commercial Sleeved Punches. A punch commercially available (Fig. 18-16, A) incorporates two intermeshing segmented sleeves inserted, respectively, in the punch and stripper plates, providing excellent alignment and preventing buckling of the punch.

Another design, at B, is straight ground and incorporates a die-cast sleeve of soft metal to reduce punch vibration, a common cause of punch breakage. Both types are available in many point sizes and contours.

STOCK GUIDES OR GAGES

Stock may be solidly guided by suitable slots in a stripper, by stock rails or, as shown in Fig. 18-17, by pins, buttons, or angle iron. Solid guides may or may not require spring guides or spring pushers for optimum stock guiding. These may be of the preliminary type (Fig. 18-18, A) to be used before a running gage is used, or of the typical adjustable-spring type, shown at B. Rollers may be used instead of pins or buttons to position the stock.

Stock guides are not always mounted to the die shoe; the types shown in Fig. 18-19, views A and B, are mounted on the stripper plate and can be called stock pushers although they do guide the stock. The guide pins (D3, view C) project through the pressure plate (D2) which holds the stock as it is severed by the cutoff punch (D1). A sliding plate (D2, view D) pushes and guides the stock between its edge and a slot in the stripper plate and is actuated by a cam (D1) mounted on the upper shoe. Cam adjustment is varied by a setscrew (D1) mounted in a plate (D3) secured to the upper shoe.

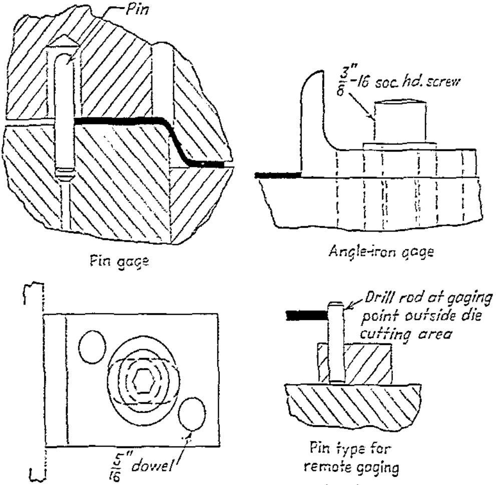


FIG. 18-17. Solid gage design.[2] (*Ford Motor Co.*)

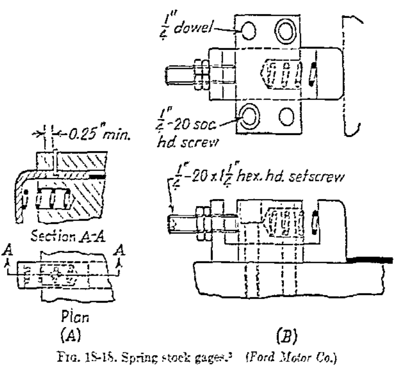


FIG. 18-18. Spring stock gages.[3] (*Ford Motor Co.*)

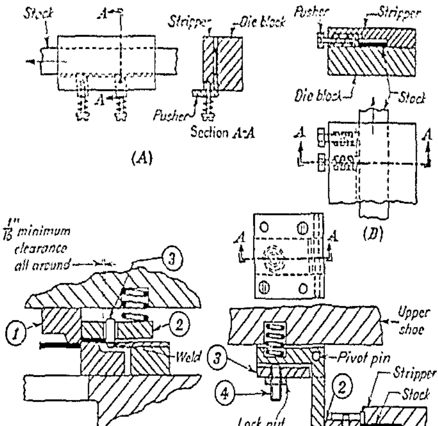


FIG. 18-19. Stock guides: (A, B) pusher types;[3] (C) pin type[3] (*Ford Motor Co.*); (D) lever-actuated pusher type.[3]

A spring-loaded disappearing guide or gage (Fig. 18-20) is entirely depressed after the die operation is completed, avoiding any interference with a stripper plate or other upper moving die components. The slot in the hollow stop clears the straight portion of the eyeleted rod which supports the spring.

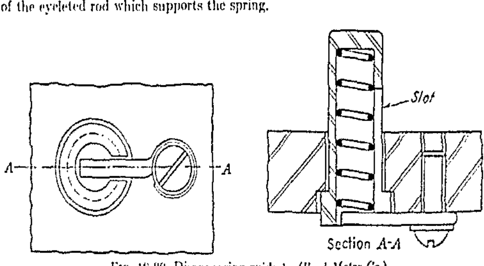


FIG. 18-20. Disappearing guide.[3] (*Ford Motor Co.*)

Movable gages shown in Fig. 18-21 hold the blank level for a square cutoff. The punch forces the blank into the stacker and the projecting lips of the gages prevent the blank from emerging from the stacker opening.

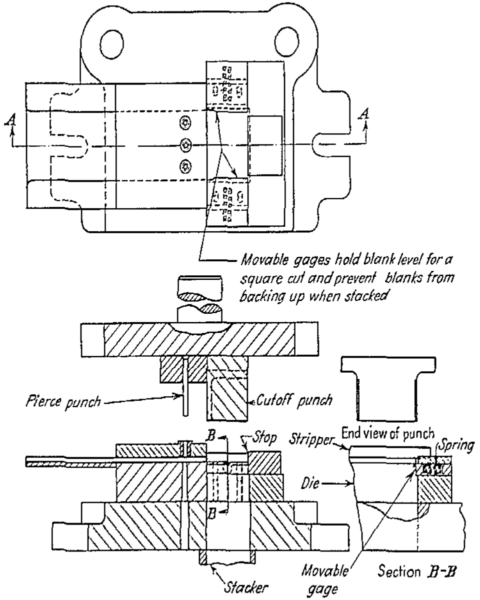


Fig. 18-21. Movable gages position and stack blanks. (*Stanley Works.*)

A light constant pressure is maintained on pusher slides (*D*1, Fig. 18-22); this compact design is practical for large stock areas in progressive and cutoff dies.

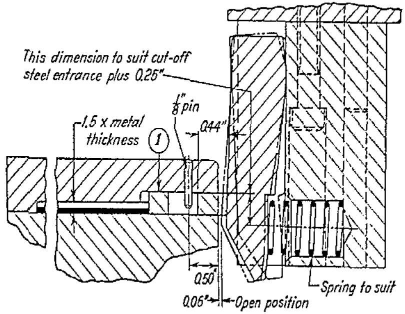


Fig. 18-22. Constant-pressure pusher-type stock guide. (Ford Motor Co.)

STOPS

Solid Stops. Solid blocks are commonly used with final blanking and cutoff operations to position the end of the stock or workpiece. A design for a solid stop, commonly incorporated in the final cutoff station of a progressive die, gages one end of a completed part which remains attached to the advancing strip. The part, bearing against the stop, is confined in the station for accurate severance to the desired dimensions along the cutoff line by a shear-type cutoff punch. The finished part drops through the die.

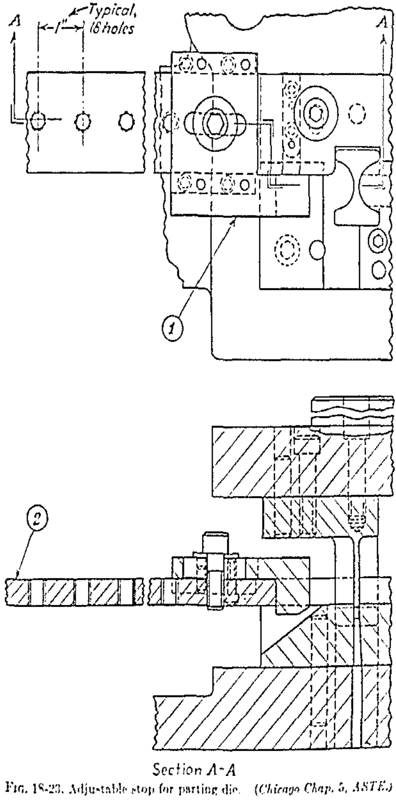


FIG. 18-23. Adjustable stop for parting die. (*Chicago Chap. 5, ASTE.*)

Another design incorporates a cutoff punch having a heel which bears against the vertical surface of a stop, gaging the part and confining it (attached to the strip) to the station. The punch, thus prevented from cocking, shears the part from the strip along the cutoff line, located at the entrance to the station.

An adjustable type of solid block (Fig. 18-22, *D1*) can be moved along a support bar (*D2*) in increments up to 1 in. to allow various stock lengths to be cut off.

Pin Stops. One design incorporates a small shouldered pin, pressed in the die block, to engage an edge of blanked-out portions of manually fed strip stock. Since the operator must force the stock over the shoulder to secure a desired feed length, this stop is suitable for low- and medium-production dies, but not for high-speed dies; nor is it feasible where frail die sections would be injured by a misfeed.

Another design that may be used with a double-action blank-and-draw die, or a die in which very little or no scrap is left between blanked-out areas in strip stock, also has a small pin pressed in the die block, but the pin has a sharp edge which faces the incoming stock strip. The edge cuts through and thrusts aside the thin fins of stock left between successive blanked-out openings as the strip is fed into the die. The pin functions as a stop when it engages the trailing edge of a blanked-out area before, and only before, the next succeeding area is cut out.

Latch Stops. A latch pivoting on a pin, as shown in Fig. 18-24, is held down by a spring. The latch is lifted by the scrap bridge and falls into the blanked area as the stock is fed manually into the die. It is then necessary to pull the stock back until the latch bears against the scrap bridge. This design is suitable for low production only.

Trim Stops. Trimming or notching stops bear against edges previously cut out of strip edges. A trimming punch cuts the strip to the exact width desired and to a length equal to the feed distance or pitch. The punch length is slightly greater than the feed advance so that no scrap can remain attached to the strip to impede proper stock travel.

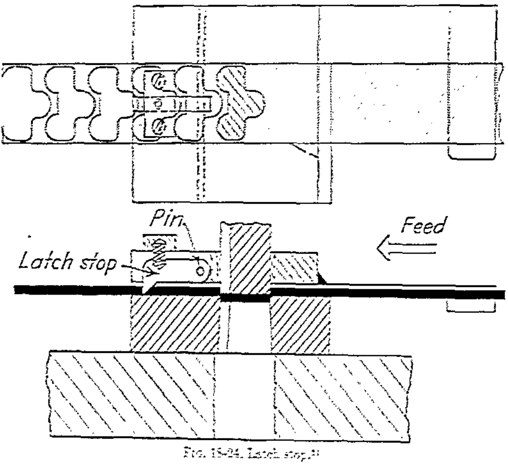


FIG. 18-24. Latch stop.[21]

Double trimming stops are shown in Fig. 18-25; stop *D1* is a starting stop as well as a running stop. It bears against the trimmed edge cut by the first notching or trimming punch (*D2*). The second punch (*D3*) trims the stock to width and provides a cut stock edge for the second stop (*D4*) to ensure proper stock positioning for severing the workpiece from the scrap skeleton.

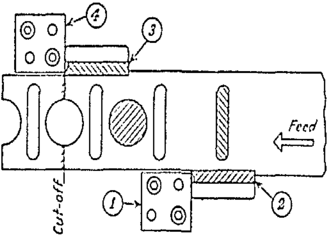


FIG. 18-25. Trim stop.[20]

Starting Stops. A starting stop, used to position stock as it is initially fed to a die, is shown in Fig. 18-26, view *A*. Mounted on the stripper plate, it incorporates a latch which is pushed inward by the operator until its shoulder (*D1*) contacts the stripper plate. The latch is held in to engage the edge of the incoming stock; the first die operation is completed, and the latch is released. The stop will not be used again until a new strip is fed to the die.

The starting stop shown at view *B*, mounted between the die shoe and die block, upwardly actuates a stop plunger to position incoming stock initially. Compression springs return the manually operated lever after the first die operation is completed.

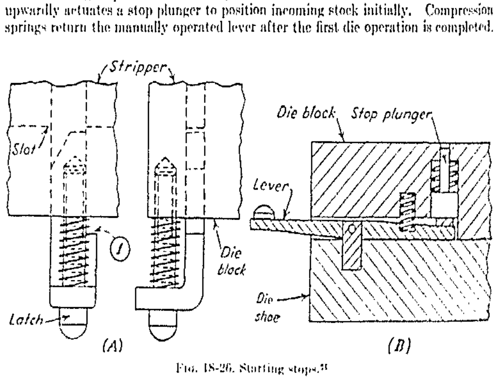


FIG. 18-26. Starting stops.[21]

Stops for Double Runs. The stops shown in Fig. 18-27 were designed for double runs in the same direction. The stock is turned over for the second run. A conventional automatic trigger stop (*D3*) functions continuously after the starting stop (*D2*) for the first run is pushed in to engage the notch in the strip. The rough starting stop (*D4*) for the second run and the accurate stop (*D5*) are actuated by handle *D1* for the cutting of the first blank of the second run; the automatic trigger stop then functions for the remainder of the run.

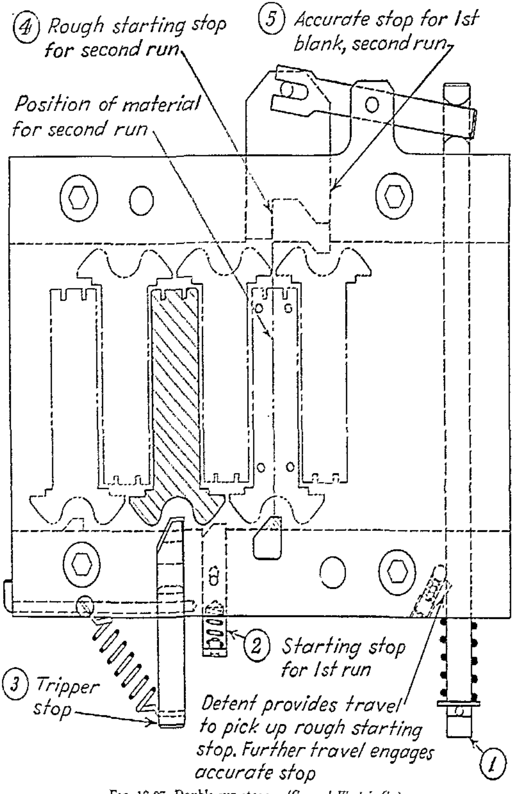


Fig. 18-27. Double-run stops. (*General Electric Co.*)

Another stop design for double runs in the same direction is shown in Fig. 18-28, in which flat spring-returned pin stops (*D1*) are actuated by a rod terminating in handle *D2* which is swung to either of the two positions for corresponding stock runs.

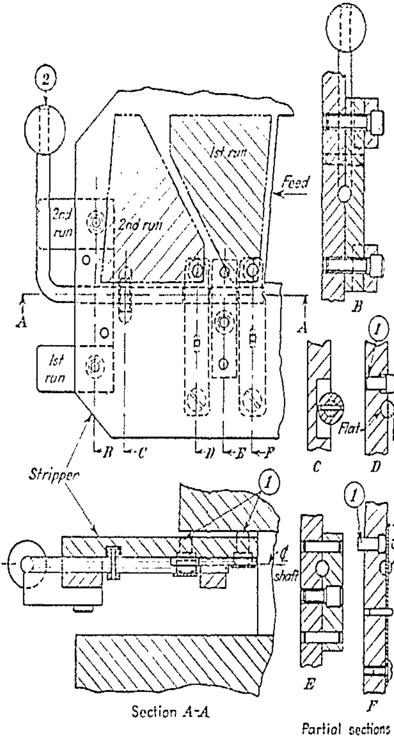


FIG. 18-28. Two-position stop. (*General Electric Co.*)

Trigger Stops. Trigger stops incorporating pivoted latches (*D*1, Fig. 18-29, views *A*, *B*) at the ram's descent are moved out of the blanked-out stock area by actuating pins (*D*2). On the ascent of the ram, springs *D*3 control the lateral movement of the latch (*equal to the side relief*) *which rides on the surface of* the advancing stock and drops into the blanked area to rest against the cut edge of cutout area.

STRIPPERS

Strippers are of two basic types, fixed or spring-operated. The primary function of either type is to strip the workpiece from a cutting, bending, forming, drawing, or coining punch or die. Coining includes extrusion, swaging, or any squeezing or compressing action that causes metal flow in the workpiece. A stripper that forces a part out of a die may also be called a knockout, an inside stripper, or any ejector. Besides its primary function, a stripper may also hold down or clamp, position, or guide the sheet, strip, or workpiece.

Fixed or Positive Strippers. A common type incorporates a slot in the stripper plate; such a "tunnel" also guides but does not hold the incoming stock.

Spring-operated Strippers. Typical spring-actuated strippers which also hold the stock down are shown in Fig. 18-30. At *A*, the springs surround the stripper bolts; at *B*, the springs are retained in pockets in the upper shoe and stripper plate. A guided design, at *C*, should be used to align and support slender punches.

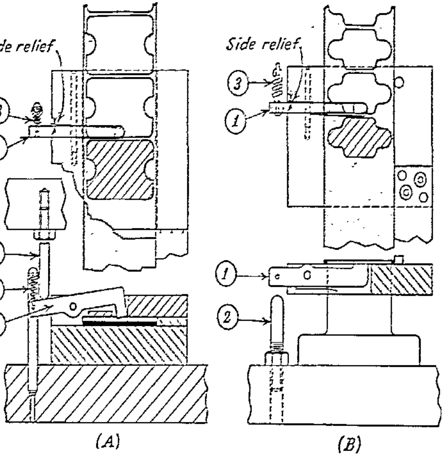


FIG. 18-29. Trigger stops: (*A*) top stock engagement; (*B*) bottom stock engagement.[20]

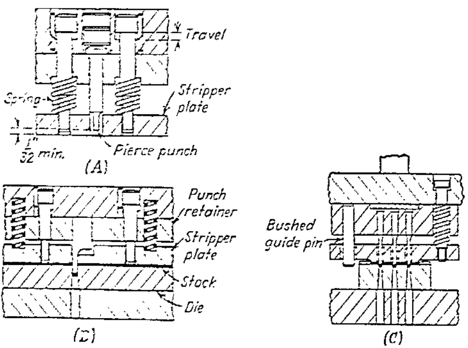


FIG. 18-30. Typical spring-operated strippers.[22,23]

Interchangeable Punch and Stripper Design. Ball-lock punches and retainer (Fig. 18-31, *D7*, *D8*, *D9*, *D10*) in various sizes are used with matching stripper assemblies, permitting quick changes of the assemblies through the use of spring-loaded locking devices for both stripper inserts (*D14*, *D15*, *D16*) and punches. To facilitate punch removal without having to remove the stripper plate, a hole may be drilled in the stripper plate, as indicated in lower view of Fig. 18-31, for inserting a releasing tool. This assembly is used with the die set shown in Fig. 5-12. The dimensions of the component parts of the assembly are listed in Table 18-15.

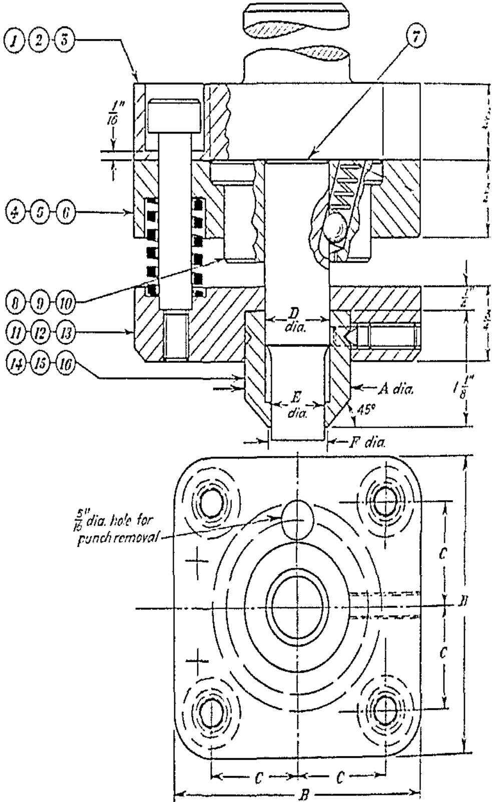


Fig. 18-31. Interchangeable stripper and punch design. *(General Electric Co.)*

TABLE 18-15. PART DIMENSIONS FOR ASSEMBLY OF FIG. 18-31

Part No.	Dimension, in.		Part No.	Diam., in.	
	B	C		A	D
1-4-11	3	1	11	1.251	0.752
2-5-12	$2\frac{3}{4}$	$\frac{25}{32}$	12	1.001	0.502
3-6-13	$2\frac{1}{2}$	$\frac{13}{16}$	13	0.876	0.376

Part No.	Diam., in.			
	A	D	E	F
14	1.250	0.752	$\frac{47}{64}$–$\frac{3}{4}$	$\frac{3}{4}$
15	1.000	0.502	$\frac{31}{64}$–$\frac{15}{32}$	$\frac{1}{2}$
16	0.875	0.376	$\frac{1}{16}$–$\frac{3}{16}$	$\frac{3}{8}$

Double Stripper Design. An upper stripper (Fig. 18-32, *D1*) functions as a pressure pad on the downstroke to hold the work in the die block (*D3*); on the upstroke it strips the work from the forming punch (*D4*). The lower stripper (*D2*) strips or ejects the work from the die by forcing a plug (*D5*) up. The die block has a slot machined across the bottom to allow for the crossbar of the stripper (*D2*) which supports the plug (*D5*).

Strippers Using Latches. Spring-loaded latches are depressed as the part is formed in the die opening (Fig. 18-33, view *A*). After they clear the part, they snap up against the bottom of the locator block to strip the part from the ascending forming punch.

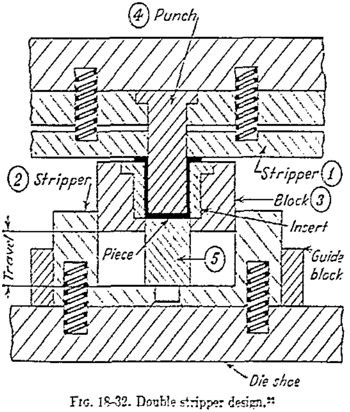


FIG. 18-32. Double stripper design.[23]

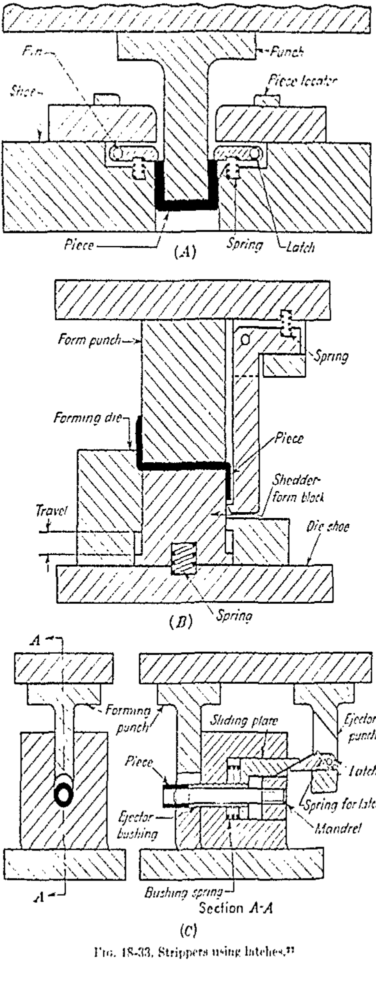


FIG. 18-33. Strippers using latches.[22]

A single latch or spring-loaded hook, shown at view *B*, slides over an edge of a doubly bent part and strips it from the shedder-form block, as the form punch ascends. The shedder-form block functions as a shedder on the upstroke and as a pressure pad and form block on the down stroke.

A latch to strip a part from a mandrel is shown at *C*. On the downstroke the latch snaps upward as it contacts the sliding plate, but on the upstroke it forces the plate to the left. The bushing moves to the left and strips the part from the mandrel.

Stripping Fork. A fork (*D2*, Fig. 18-34) (actuated by an air cylinder *D1*) reciprocates horizontally to strip the part from a form block (*D3*) on the upstroke. This action takes place after the part of 0.022-in.-thick phosphor bronze is pushed out of the form punch (*D5*) by a spring stripper (*D4*). The stripper serves as a hold-down and, with its pilot (*D6*), locates the part.

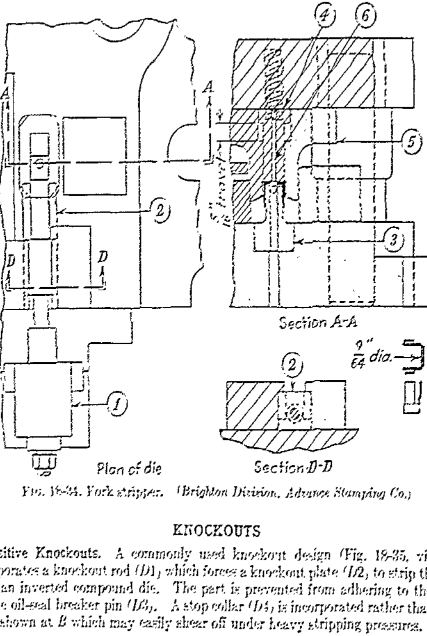


FIG. 18-34. Fork stripper. (*Brighton Division, Advance Stamping Co.*)

KNOCKOUTS

Positive Knockouts. A commonly used knockout design (Fig. 18-35, view *A*) incorporates a knockout rod (*D1*) which forces a knockout plate (*D2*) to strip the part from an inverted compound die. The part is prevented from adhering to the plate by the oil-seal breaker pin (*D3*). A stop collar (*D4*) is incorporated rather than a pin (*D1*) shown at *B* which may easily shear off under heavy stripping pressures.

Indirect Knockouts. Knockout plates with three and four auxiliary rods, as shown at view *B*, Fig. 18-35, are suitable for small dies. A stop pin, such as shown at *D1*, should not be used; a stop collar should be used instead, since extreme pressure may be applied by the upper or main knockout bar if it is set too low. Spider-shaped knockout plates are used in large dies; a recess is end-milled in the punch holder to accommodate the spider.

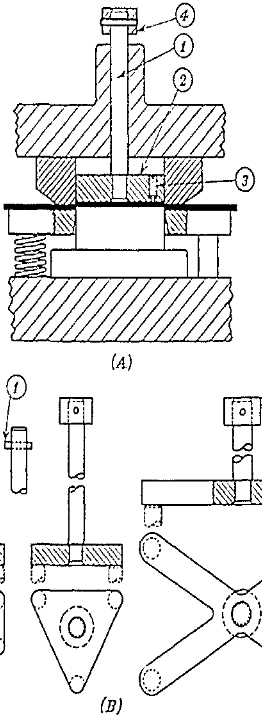


FIG. 18-35. Knockout design: (*A*) for inverted compound dies; (*B*) knockout plates.[11]

Liftout Plates. A liftout plate (*D2*, Fig. 18-36, view *A*) is pulled up by lift bolts attached to the upper shoe; on the upstroke the flanged part is stripped from the lower form die (*D3*) to allow it to be blown off the die set with an air jet, or to slide off if the press is inclined.

Pressure-pad Liftouts. A pressure pad (*D2*, Fig. 18-36, view *B*) actuated by four springs (*D3*) also functions to lift the part from the combination cutoff-trim-form die (*D1*). The part is lifted to a position flush with the top of the die and then blown off with an air jet.

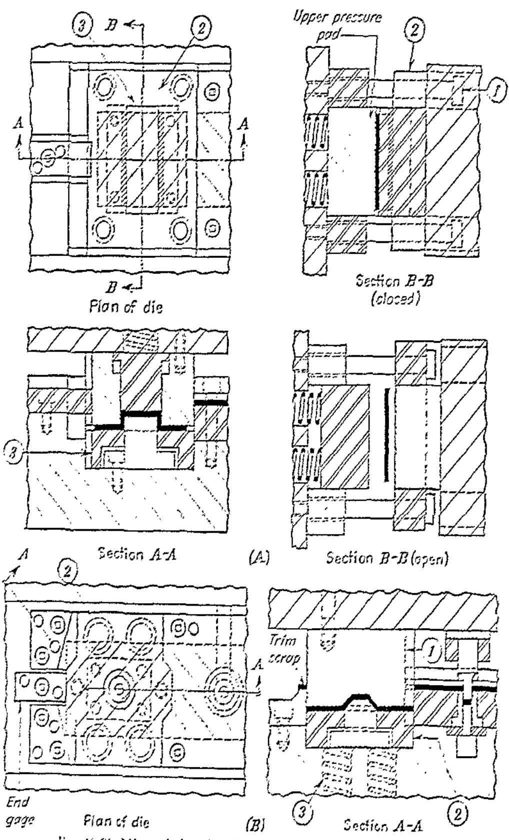


Fig. 18-36. Liftout design: (*A*) liftout plate; (*B*) pressure-pad liftout.

PILOTS

Since pilot breakage can result in the production of inaccurate parts and jamming or breaking of die elements, pilots should be made of good tool steel, heat-treated for maximum toughness and to hardness of Rockwell C57 to 60.

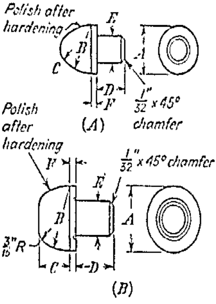


FIG. 18-37. Press-fit pilots: (A) acorn type; (B) flattened-point types.[21]

TABLE 18-16. DESIGN DIMENSIONS FOR DRILL-ROD PRESS-FIT PLOTS

For dimension diagram, see Fig. 18-37, views A and B

Nominal A	B	C	D	E
Acorn Type				
1/8	1/8	1/32	1/4	3/32
3/16	3/16	3/64	1/4	1/8
1/4	1/4	1/16	7/16	3/16
5/16	5/16	5/64	7/16	7/32
3/8	3/8	3/32	1/2	1/4
7/16	7/16	1/8	1/2	9/32
1/2	1/2	5/32	1/2	5/16
5/8	5/8	11/64	5/8	11/32
11/16	11/16	3/16	5/8	3/8
Flattened-point Type				
3/4	3/4	7/16	5/8	3/8
7/8	7/8	17/32	3/4	7/16
1	1	5/8	3/4	1/2
1 1/4	1 1/4	3/4	1	5/8
1 3/8	1 3/8	7/8	1	11/16
1 1/2	1 1/2	15/16	1 1/4	3/4

Dimension F = 1/16 in., or stock thickness, whichever is greater.
All dimensions are in inches.

Press-fit Pilots. Press-fit pilots (Fig. 18-38, view *C*), which may drop out of the punch holder, are not recommended for high-speed dies but are often used in low-speed dies. Recommended dimensions for press-fit pilots are listed in Tables 18-18 for acorn types and flattened-point types. An alternate method of establishing the dimensions of pilots is to make the radius *B* equal to the pilot diameter *A*. The spherical nose radius *C* of the acorn type may be made to 0.25*A*, approximately. Length *C* of a flattened-point-type pilot may be about 0.5*A*.

Pilots may be retained by methods shown in Fig. 18-38. A threaded shank, shown at view *A*, is recommended for high-speed dies; thread length *X* and counterbore *Y* must be sufficient to allow for punch sharpening. For holes ¾ in. in diameter or larger, the pilot may be held by a socket-head screw, shown at *B*; recommended dimensions *X* and *Y* given for threaded-shank pilots also apply. A typical press-fit type is shown at *C*. Pilots of less than ¼ in. diameter may be headed and secured by a socket setscrew, as shown at *D*.

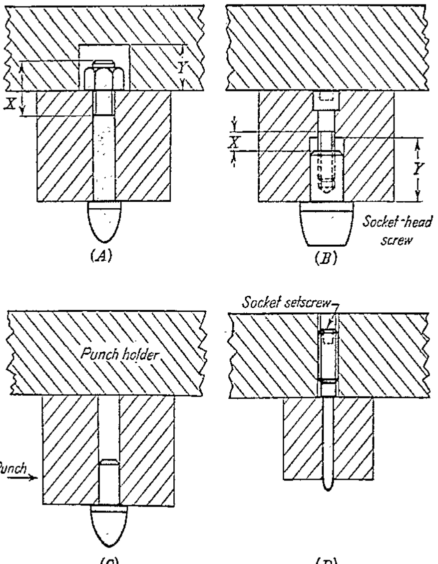


FIG. 18-38. Methods of retaining pilots: (*A*) threaded shank; (*B*) screw-retained; (*C*) press-fit; (*D*), socket setscrew.[25]

Indirect Pilots. Designs of pilots which enter holes in the scrap skeleton are shown in Fig. 18-39. *A headed design, at A, is satisfactory for piloting in holes from 3/16 in.* to 3/4 in. in diameter. A quilled design, at *B*, is suitable for pilots up to 3/16 in. in diameter or less.

Spring-loaded pilots should be used for stock exceeding No. 16 gage. A bushed shouldered design is shown at *C* of Fig. 18-39. A slender pilot of drill rod shown at *D* is locked in a bushed quill which is countersunk to fit the peened head of the pilot.

Tapered slug-clearance holes through the die and lower shoe should be provided, since indirect pilots generally pierce the strip during a misfeed.

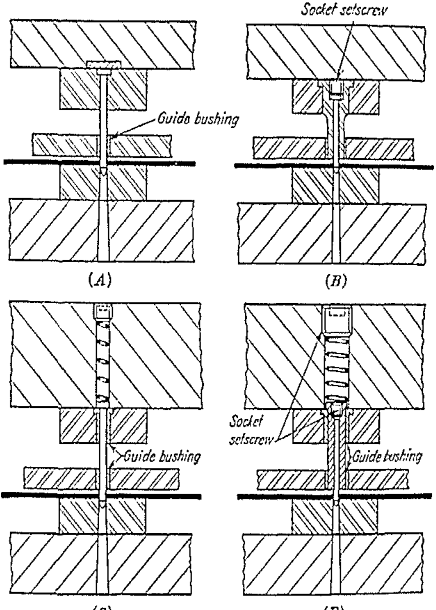


Fig. 18-39. Indirect pilots: (*A*) headed; (*B*) quilled; (*C*) spring-backed; (*D*) spring-loaded quilled.[21]

SPRINGS

Springs for strippers, pressure pads, and other spring-operated die components can be selected from the ratings (pounds per $\frac{1}{8}$-in. deflection) of standard springs listed in manufacturers' catalogues. Total pressure requirements will be the sum of the initial and working deflections plus any deflection for the grinding of or wear of any die component. A general rule for allowable spring deflection, for high-speed dies, limits both medium- and high-pressure springs to one-fourth of their total free length; for heavy, slow-moving presses, total deflection for medium-pressure springs should not exceed three-eighths of their total free length.

Springs should be carefully selected in relation to the service for which they are intended; in addition to required pressures and deflections, space limitations and production requirements must be considered. Die springs are not necessarily helical; washer (Belleville) types or a type using compressed oil (Fig. 18-3, *D*), or rubber may be used.

Spring Mounting. The locating and mounting of springs in pockets around pilots or bolts, in tubes, or by other methods are determined by space available, service requirements, and malfunctioning through slug interference, misalignment, or other causes.

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SECTION 19

FEEDING AND UNLOADING EQUIPMENT*

WORK-HANDLING AUTOMATION

True automation in press feeding and unloading implies not only the automatizing of the several different operations involved but also their integration. Successful automation should plan for, and achieve, the following goals:

1. Maximum safety to operators and equipment. Some manufacturers consider this is to be the prime goal.
2. Higher and more nearly continuous production.
3. Improved quality of the product and less processing scrap.
4. Cost reduction of the finished part.

Where safety is not the paramount and single sufficient reason for automation, then the automation planning must be studied for practicality and optimum economies. The particular conditions, a single press for example, may indicate it to be best practice to feed blanks manually into the die and to automatize only the parts unloading.

Press-line automation starts with close cooperation between the die designer and the process engineer. The shape and position of the part before and after each operation must be carefully studied to determine whether design changes, such as providing tabs or extra stock allowance on the blank for parts-gripping fingers, will facilitate automation.

Eliminate Turnover of Parts between Operations. The turnover of a part between operations should be eliminated wherever possible because such handling can throw the part out of control for a portion of the operation cycle and can cause damage to the part. Many designers believe it is better to use a more complicated die, or even to add another die operation, than to turn a part over. Since the turnover operation often requires extra time, its elimination can result in a shorter operation cycle. Subsequent operations on a part drawn in a double-action press are more likely to require that the part be turned over than when drawn in a single-action press equipped with a die cushion.

Use Shortest and Best Travel. This can be accomplished by feeding the blank or part in a direction perpendicular to its longest dimension. Further, the blank should be fed into one side of the press and the part withdrawn from the opposite side. This eliminates confusion and production delays due to stacks of blanks and finished parts located on the same side of the press. A shorter operation cycle will result since the blank can be fed into the press while the stamping is being withdrawn.

Install Gages Properly. Whether of fixed or retractable type, gages installed in a die will assist fast positioning of the blank in the die.

Fixed gages should be so designed and located that they will not impede removal of the stamping. *Retractable or disappearing gages* may be spring-supported, and retract as the upper die or blankholder closes down upon them.

Pneumatic or hydraulic cylinders are sometimes incorporated in the die to retract gages at the proper time. Such cylinders can be controlled to hold the gages down

* *Reviewed by H. C. Butterfield, Master Mechanic, Pittsburgh Plant, Fisher Body Division of General Motors Corp.*

while a separate cylinder or mechanically actuated device is lifting the workpiece to an elevated position where gripping fingers can engage the stamped part and remove it from the press. Parts may also be ejected by means of air blast, pushers, or gravity. Limit switches are often incorporated in the die to trip the press after gages have properly positioned the blank in the die.

Dies for second operations, such as on preformed panels, can be so designed that the panel will nest itself in the proper position.

When an automatic loader is used, extra-long stop gages may be necessary to prevent the part from overshooting the draw die and falling out of the press or from being improperly positioned in the die when the part is engaged by the blankholder.

Lifting Devices. Lifting devices incorporated within a die greatly facilitate the automatic handling of the parts. Blanks or predrawn parts are fed onto the lifters, then lowered into the nest or between the gages in the die. After the operation is performed on the blank, the lifters raise the part to an elevated position so that it can be removed by one of the various ejection methods.

These devices may be spring-, air-, mechanically or hydraulically actuated, either directly or indirectly through linkages. They may be actuated directly by the press ram through cams or linkages or indirectly actuated by limit switches interlocked with the press controls.

When the surface finish on the panels must be protected, pads or rollers on the lifters contacting the panels are made of brass, leather, plastic, or wood.

Feeding Small Parts into Gap Frame Presses. These presses are usually inclinable, and parts can be fed by employing gravity or slides. The press frame may be inclined, or a chute may be installed at such an angle that the part can slide into position. Gravity, employed alone or assisted by an air blast, can be used to eject the part into a container or conveyor located at the rear of the press. Feeding can also be done by placing the part in the nest of a slide and then pushing it into the working area.

Feeding of Large Parts. Large parts, upon which operations are usually performed in fixed-position straight-side presses, can be positioned in the die manually or by pusher- or kicker-type mechanical devices or by a gravity-type loader. The finished parts may be ejected from the die by mechanical or air-operated kickers, or they can be pulled from the die by mechanical or air-actuated gripping fingers. Smooth- or soft-faced rollers can be attached to the die or lifting device to prevent dragging and scratching the panel as it is fed into or removed from the die.

Scrap Handling. The scrap accumulated from piercing, blanking, or trimming operations in automated press lines can give much trouble if provision is not made for prompt and effective removal. Scrap must be automatically removed from the die area by dropping or pushing it off the die and bolster plate into containers or holes in the floor. When a large volume of scrap is involved, a conveyor system is preferred over containers. Scrap cutters should be strategically located for cutting the scrap into small pieces so that it will slide down chutes or through holes in the die and bolster plate.

FEEDING DEVICES

Manual Feeding. Low production does not warrant the expense of automatic feeds. With no setup time for an automatic feed, an experienced operator can, on a short run, outproduce a mechanically fed press. Hand feeding, from the standpoint of operator efficiency and safety, is facilitated by the use of a hand-held feeding tool such as those shown in Fig. 22-12. These tools may also be used for removing the finished part from the die if it is not ejected by other means.

The manual feeding of parts into a die can be accomplished by the use of a simple chute. The parts are pushed forward in the chute against a suitable stop in position for the stamping operation. The press can be inclined so that the formed parts can fall out the back of the press or a jet of air can eject the finished parts. This die should be provided with a barrier enclosure for complete protection of the operator.

Hand-operated Slide Feed. The pusher in Fig. 19-1 can be used to feed a blank under the punch and withdraw it after the operation is performed. The pusher can

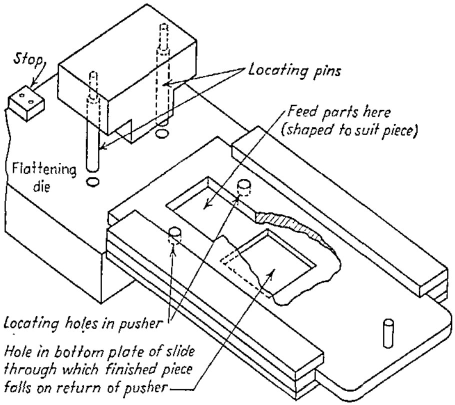

FIG. 19-1. Hand-operated slide for loading and unloading die.[1,*]

have a nest machined in it to fit the shape of the part. Locating pins in the punch are used to position the pusher and blank in the die properly. If the part does not drop through the die or is not ejected by other means, it can be withdrawn by the pusher and allowed to drop through a hole provided in the bottom plate of the slide.

Magazines for Push Feeds. Manually operated push feeds may be supplied with parts from inexpensive magazines which can be attached to the slide rails. For best results, blanks must be flat and free from burrs. These push feeds should be interlocked with the press-tripping mechanism to ensure that the blanks are in proper position to prevent damage to the die and press.

Gravity-chute Feeding. Maintenance of a gravity-chute feed is usually required only if an escapement is incorporated. This type of feed is commonly used with press operations on shells. In a chute-feed die (Fig. 19-2, *A*), the shell is fed by gravity into a locating nest. This cup is redrawn and pushed through the die. In case the shell sticks on the punch, a small recess is machined beneath the draw ring to strip the punch. At *B*, the design utilizes vacuum cups to pull the workpiece up and out of the die, and a knockout rod releases it from the cups. At *C*, an inclined chute on a flat die feeds flat blanks into a bending die. A spring pad is incorporated in the die to lift the part out of the cavity to be ejected by an air jet. When the press can be inclined, a straight chute can be used to load the die.

* Superior numbers relate to References at the end of this section.

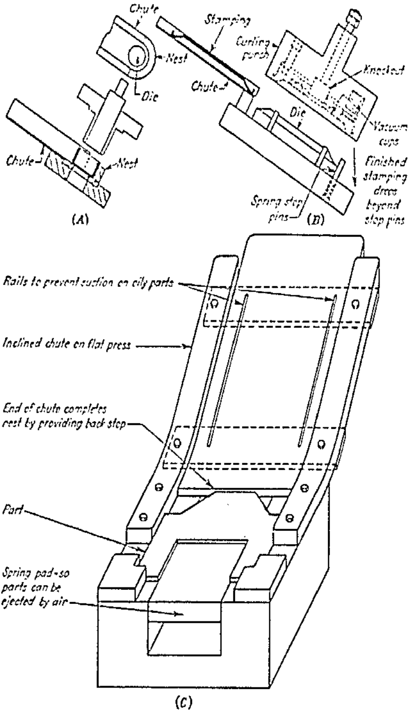

FIG. 19-2. Gravity-chute feeds: (A) for redrawing cups;[2] (B) for stampings;[2] (C) for flat blanks.[1]

Semiautomatic Gravity Feeding. A single-piece feeder for a gravity-feeding device is illustrated in Fig. 19-3. The illustration shows the trip arm at the top of the press stroke with the blank in the nest. As the press slide moves downward, the trip arm frees the lever on the end of the feed shaft. This allows the counterweight to tip the feeder so that the piece held by the upper leg is released and moves down to rest against the lower leg. As the slide continues downward, the part is formed and ejected. As the press slide approaches top center on its upward stroke, the trip arm attached to the slide contacts the lever on the end of the feeder shaft, tips the feeder to a position whereby one piece is released by the lower leg and, at the same time, the upper leg of the feeder catches and holds back the next piece.

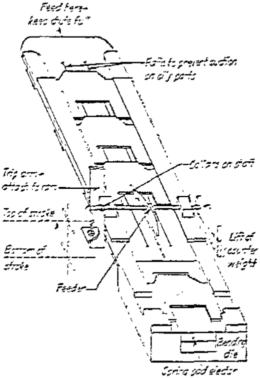

FIG. 19-3. Single-piece feeder for gravity-feed devices.[3]

Designs for gravity-chute feeds integral with progressive dies are shown in Fig. 19-4. At *A*, the blank moves in a straight line to the second station. At *B*, the blank moves at a right angle to the direction of strip movement as it drops from the second station to the third.

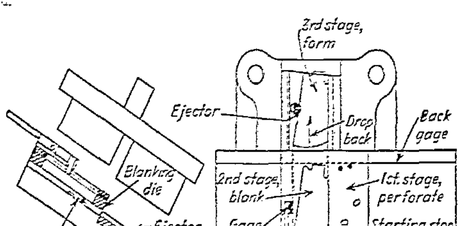

FIG. 19-4. Gravity-chute feeds integral with progressive dies.[3]

Air-chute Feeding. Gravity assisted by a continuous weak air blast drives two balls down a tube (Fig. 19-5, *D6*)* after a selective mechanism allows only two balls per press stroke to be released from the hopper. The selective device comprises a revolving ball carrier (*D1*) with 12 equally spaced holes (0.120 in. diameter) rotated, on the downstroke, by a spring-actuated pawl-engaging ratchet. On the upstroke, the arm (*D10*) is forced to the left by the pivoting and linking members (*D2, D3, D4*). The ball carrier passes under a metal plate (*D5*) and a glass plate (*D5*) (allowing the press operator to check the orientation of the balls), and between the ends of the copper tubes (*D6, D7*). The balls, released on the downstroke, drop through the tube into the die. A slide feed (Fig. 19-10) inserts the balls in the workpiece.

* *D* indicates detail number on drawing.

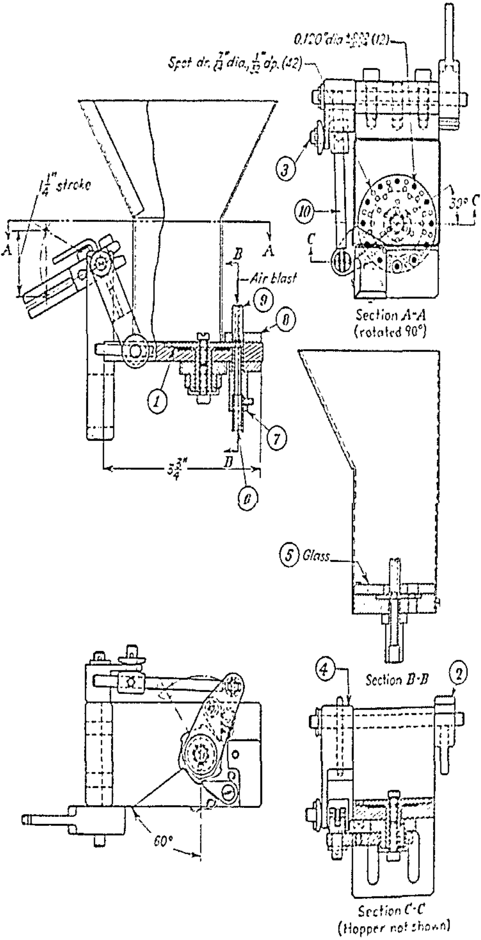

FIG. 19-5. Air and gravity feed. (*Harig Mfg. Corp.*)

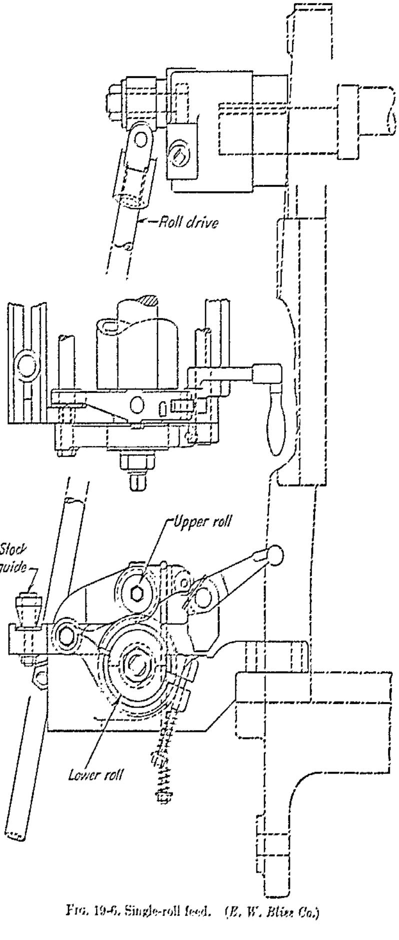

FIG. 19-6. Single-roll feed. (*E. W. Bliss Co.*)

AUTOMATIC MECHANICAL FEEDS

Automatic mechanical feeds can increase press-operation rates up to ten times rates with manual feeds. Volume production usually warrants their initial cost. The most used types of feeds include roll feeds; slide, grip, or hitch feeds; hoppers, chutes, and magazines.

Roll Feeds. Basically this type of feed consists of two rolls, one above the other, driven through a friction or ratchet clutch. The former provides an infinite number of stock feed lengths while the latter provides definitely set amounts of feed lengths that cannot be fractionally altered. Backward movement of the rolls during the nonfeeding cycle is prevented by a brake.

Roll feeds may incorporate either a single pair of rolls (Fig. 19-6) which pull or push stock across the die, or two pairs of synchronized rolls with one pair pushing and the other pair pulling the stock across the die.

Pilots or stops are commonly used to prevent inaccurate feeding caused by dimensional variations, rough edges, and kinks in coil stock. Roll release devices are frequently used; the stock is momentarily disengaged at the time the pilot enters the piloting notches or holes. Speed of feeding varies from 400 to 500 ipm for the average commercial feed, up to 2,400 ipm for a precision type with timed power brakes.

Hydraulic Roll Feeds. Adapted for long feed lengths of wide stock (such as strip for automotive doors and fenders), this type of single-roll feed is driven by a hydraulic motor for constant deceleration and acceleration. Ease of feed-length adjustment and of the control of the motor by limit switches is inherent in this feed design.

Hitch Feeds. A hitch feed consists essentially of a reciprocating head carrying a gripper unit and a similar stationary unit. On the downstroke of the press, a cam attached to the press slide contacts the cam roller on the reciprocating head. The continued downward motion of the press slide pushes the reciprocating head outward, compressing a spring. During the downward press stroke, the gripper plate on the stationary head prevents the stock from moving backward. On the upward stroke of the press, the stock is held by the gripper plate as the head moves inward propelled by the compressed spring. The amount of feed advance is set by a feed-length adjustment nut.

Grip Feeds. A grip feed, similar in principle to a hitch feed, incorporates a reciprocating head and grip shoes instead of gripper plates. The pivoted shoes swing down to grip the stock and feed it to the die, but slide over the stock when the head reverses its direction.

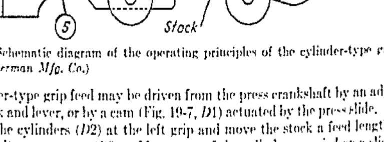

Fig. 19-7. Schematic diagram of the operating principles of the cylinder-type grip feed (*H. E. Dickerman Mfg. Co.*)

A cylinder-type grip feed may be driven from the press crankshaft by an adjustable throw block and lever, or by a cam (Fig. 19-7, *D*1) actuated by the press slide. On the upstroke, the cylinders (*D*2) at the left grip and move the stock a feed length determined by adjustment nuts (*D*3). Movement of the cylinders, carried on a slide (*D*4), is controlled by a spring (*D*5). On the downstroke, the stationary cylinders (*D*6) at the right prevent backward movement of the stock. Both sets of cylinders operate on the principle of the overriding clutch.

Slide Feeds. Driven by an adjustable eccentric, this type of feed (Fig. 19-8) incorporates a reciprocating feed block and a hardened blade which engages and moves the stock. Positive stops ensure extreme accuracy of feed. A stock drag or check unit prevents stock movement as the feed blade returns to reengage the stock.

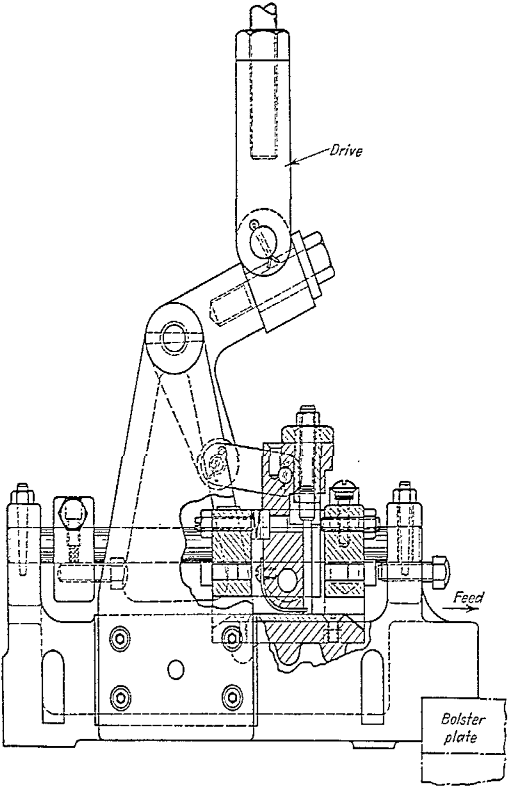

FIG. 19-8. Slide feed. (*U.S. Tool Co.*)

Slide Feed for Blanks. The slide feed shown in Fig. 19-9 is designed to feed precut blanks into a second-operation die. The blanks are oriented in the magazine chute (*D*5) before being pushed into the die by the feeding slide (*D*1). On the downstroke of the press, the linkage levers (*D*2, *D*3, and *D*4) move the feeding slide outward, placing its nest beneath the magazine chute to receive a new blank. The upstroke of the press causes the linkage to move the feed slide into the die area and deposit the new blank in the die. By changing the shape of the magazine chute and the nest in the feed slide, this device can be adapted to various shapes of parts.

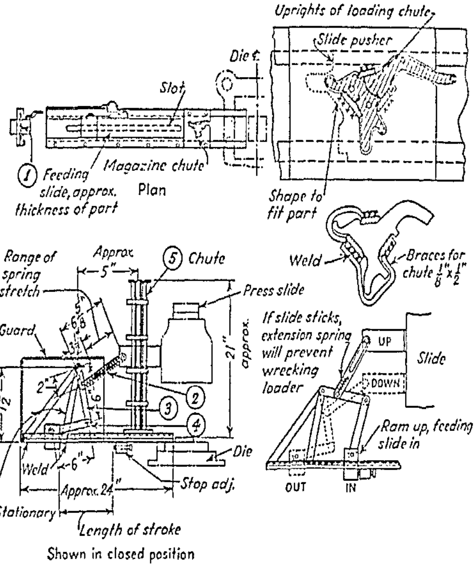

FIG. 19-9. Slide feed for blanks. (*Floyd Tilton, ASTE.*)

Slide Feed for Inserting Balls. A slide feed (Fig. 19-10) built in a progressive die to insert balls into a radio-socket contact operates with the air and gravity feed shown in Fig. 19-5. The latter feed directs two balls through a tube (Fig. 19-10, *D2*) to the proper position in the die. On the downstroke, a cam (*D3*) contacts a roller (*D4*) fastened to a pivoted arm (*D5*). The arm pushes the ball slide (*D6*) to insert the balls; on the upstroke the ball slide is retracted by a spring (*D1*) so that the strip may advance for crimping and to allow two more balls to fall into the die.

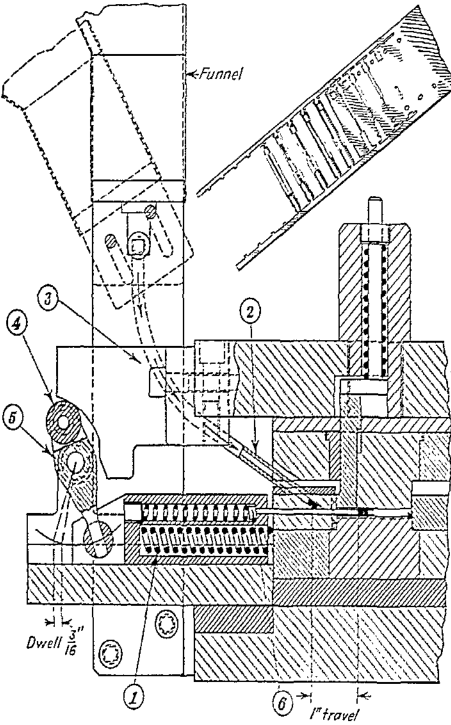

FIG. 19-10. Slide feed for inserting balls. (*Harig Mfg. Corp.*)

Pawl Feed. This type of feed uses pawls (Fig. 19-11, *D1*, *D2*) to engage and push the workpiece (a notched strip) to the die. Toothed latches or hooks (instead of the pawls) to engage notches or blanked-out openings would classify the design as a hook feed. The drive mechanism actuates the slide (*D5*) by means of actuating bars (*D4*). Adjustment is provided by setscrews (*D3*).

Die-slide Attachments. Presses equipped with die slides can be used for almost any press operation. *The attachment slides the die in and out automatically in* synchronization with the press stroke. When it is necessary for the operator to place parts in the die and remove the stamping from the die by the hand, the die slide is an excellent safety device.

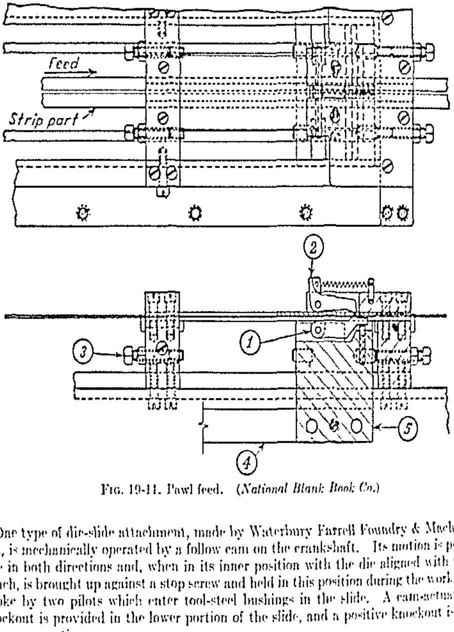

FIG. 19-11. Pawl feed. (*National Blank Book Co.*)

One type of die-slide attachment, made by Waterbury Farrell Foundry & Machine Co., is mechanically operated by a follow cam on the crankshaft. Its motion is positive in both directions and, when in its inner position with the die aligned with the punch, is brought up against a stop screw and held in this position during the working stroke by two pilots which enter tool-steel bushings in the slide. A cam-actuated knockout is provided in the lower portion of the slide, and a positive knockout is in the upper portion.

The feed table has an opening beneath which is a guide plate made to suit the work. The operator slides the work from the table and locates it by the guide plate so that, when the sliding die is underneath the plate, the blank will drop into the die and be carried beneath the punch.

Another well-known die slide is the pneumatic reciprocating type made by E. W. Bliss Co. The slide to which the die is fastened is actuated by a pneumatic cylinder and is timed in such a manner as to remain still while the punch is engaging the workpiece in the die.

The controls are so arranged that depressing the foot treadle operates a lever which in turn operates an air valve directing air into the end of the air cylinder, forcing the die-slide plate under the punch. After the slide is properly located, a safety latch is released allowing the operating treadle to be further depressed, thereby tripping the clutch and allowing the press to make a complete revolution. At the top of the stroke, a valve reverses the flow of the air and forces the die slide from under the punch into the loading position.

Dial Feeds. Dial feeds, or circular conveyors carrying workpieces to dies, are used for primary or secondary operations. When many operations are to be performed at one time, it is necessary to have a well-supported and guided press slide, since the operations will be located at a considerable distance from the slide's center line. Multiple operations require positive-punch stripping so that the parts are correctly positioned in the dial plate to be conveyed to the next station. Two or more operators may load parts to a dial feed for assembly operations. The use of auxiliary feeds (such as chute, magazine, and hopper feeds) with dial feeds, often in conjunction with sorting devices, results in high production rates.

The revolving member of a dial feeding mechanism generally rotates around a vertical axis actuated by the press ram or an air cylinder. An indexing and locking pawl mechanism, driven by an air cylinder (*D*4, Fig. 19-12), rotates a dial (*D*3), which circularly positions a die (not shown) under a punch. The control valves for the air cylinder are actuated by solenoids which are controlled by limit switches synchronized with ram travel. Other limit switches (*D*1 and *D*2) prevent the press from being tripped if registration and indexing are incorrect.

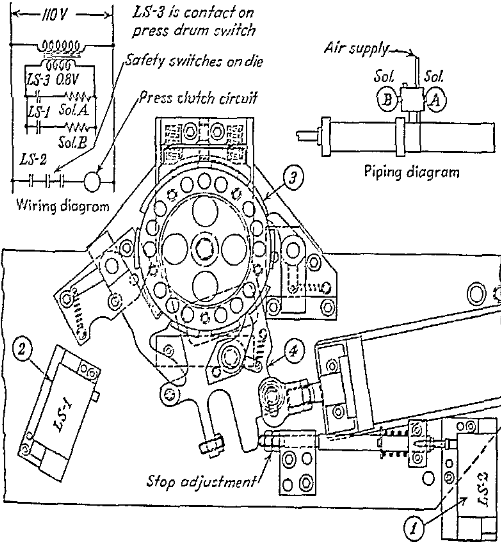

FIG. 19-12. Indexing dial. (Oldsmobile Division, General Motors Corp.)

A pneumatically operated dial feed may be controlled through a camshaft rotating at a speed determined by the work cycle of the dial. The duration of the work cycle is equal to one revolution of the camshaft. The dial indexing frequency is the sum total of the time (in seconds) for the slowest operation, plus total operational time not acting during this period, plus indexing time, and plus dwell time.

The air-control system should provide a synchronized air blast for injection, as well as controlled air power for operations in separate presses, all of which must be considered in calculating time requirements and in designing cams.

A rack (Fig. 19-13, *D*1) on the press slide rotates two top gears (*D*2) of a gear train to move the lower rack (*D*1) back and forth. The pawl (*D*5) engages notches in the dial (*D*3) to move it through an arc of 60° on each press stroke. This feed is used with a cam die to pierce 1,080 holes, shown in Fig. 5-11.

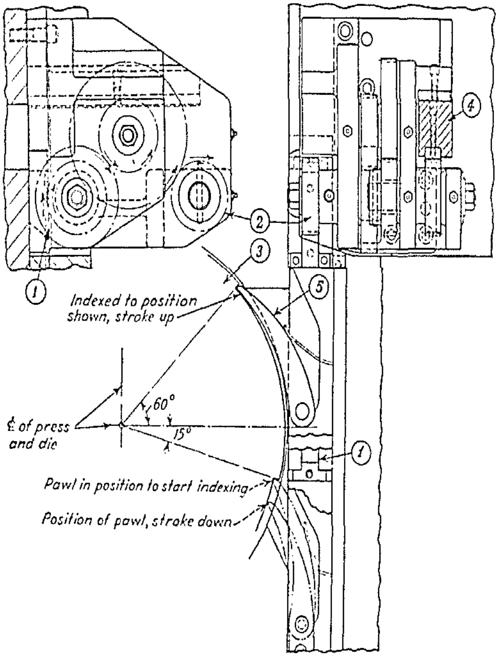

FIG. 19-13. Rack-driven dial feed. (*Maytag Co.*)

Cam-driven Dial Feed. A chain-driven edge cam (Fig. 19-14, *D4*) reciprocates a pawl slide (*D1*) to revolve the dial, which carries 12 stations. A face cam with a slot enclosing the roller could be used instead of the edge cam. The pawl slide is provided with a tension spring (*D2*). The station (*D3*) is for swaging.

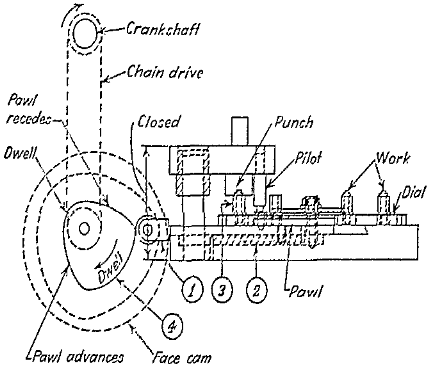

FIG. 19-14. Cam-driven dial feed.[2]

Underdrive Dial Feed. Another driving method, using an eccentric arm from the press crankshaft, is shown in Fig. 19-15. The indexing dial is underneath the work dial which can be easily replaced allowing other stampings operations with the same feed.

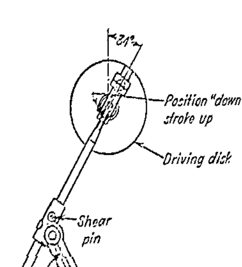

FIG. 19-15. Underdrive dial feed. (*F. J. Littell Machine Co.*)

Drum Feeds. The drum feed of Fig. 19-16 was designed for a die that punched eight slots around the circumference of a basket strainer. It incorporates an indexing ratchet provided with locating pins (not shown) which engage the bottom holes to locate the strainer on the horn. A third pin is pressed into the center of the ratchet, with its opposite end into the inner race of a ball bearing for rotation of the adapter and ratchet. The toggle clamp prevents axial movement of the part.

Single-bar Feeds. A single-bar feed, commonly used with inclinable presses, incorporates a cam-actuated bar which reciprocates over the die to receive a part which it then transfers to the next die station. Various ejectors and knockout pins function during the press cycle so that the part can be stripped from a punch and ejected from a die and into the path of the moving bar.

Double-bar Feed. A double-bar feed has a double bar which moves from right to left or vice versa, and also moves front to back or vice versa. Fingers are attached to the bars for gripping and moving the part progressively. This feed type is generally used with straight-side presses.

For either type, an automatic positive safety stop is necessary to avoid jams and die breakage.

Transfer Feeds. Progressive-die production may be impractical because of the operations involved together with the shape of the stamped part. The work material may be strip stock, or a blank, or a cup fed to the first station of a die set which is *essentially a conventional progressive die, except that interstation transfer of the part* is not done by a moving strip skeleton or web but by a series of gripping fingers. These fingers, shaped to fit part contours at each station, grip the part at one station, carry it to a succeeding station, and then reverse their movements before repeating their initial movements on a following part. Finger movements are cam-actuated through ram travel.

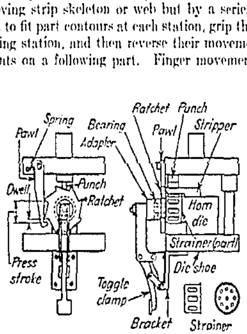

Fig. 19-16. Drum feed.[4]

Sheet-feeding Devices. Where large-sized steel sheets or blanks are to be fed to large draw dies, such as for an auto deck lid, production increases and lessened worker fatigue can be obtained by automatically feeding the sheet to the die through use of a sheet feeder (Fig. 19-17).

In this operation the press operator places a sheet from the stock pile onto the ready table while the press is cycling. As the press opens up, the part just formed is removed from the die mechanically, and at the same instant an air cylinder forces the sheet between rolls. These rolls turn continuously, with sufficient speed to throw the sheet into the proper position within the die.

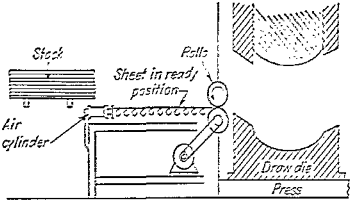

FIG. 19-17. Roll feeder for feeding large sheets to drawing operations. *(K. C. Butterfield.)*

HOPPER FEEDS

In general, a hopper is a mechanism into which parts are dumped without regard to orientation. It may be a funnel, a simple bin, or a complex device which automatically positions, selects, orients, and supplies parts at a predetermined rate to a die. Hopper design is prescribed by the size, shape, kind, weight, finish, and strength of the material to be processed.

Oscillating Centerboard Hopper. A grooved centerboard blade *(D2*, Fig. 19-18, *A)* oscillates vertically to pick up parts on its edge from the hopper *(D4)*. A cam- or crank-actuated arm *(D1)* moves the centerboard up and down. Parts slide down the grooved blade into the tube or track *(D3)* and thence to the die. When the blade goes down for more parts, the ejector *(D5)* advances to the end of the track and gently pushes the incorrectly positioned pieces back into the hopper.

The point of delivery should be as high as possible, and a high angle of inclination of the track is desirable to increase the effect of gravity on the workpiece. A chrome-plated blade allows parts to slide freely and helps to prevent them from wedging underneath it. The blade can be adapted for various types and shapes of parts. For clip-angle-shaped parts, the top edge of the blade can be beveled so that they can be fed into the track in one position only.

Rotary-centerboard Hopper. The hopper with the rotary centerboard in Fig. 19-18, *B*, picks up split rivets and similarly shaped parts, then feeds them onto a track to the machine. The blade *(D1)* is shaped as shown and of the correct thickness and form to suit the part. It is indexed intermittently in the direction shown by a geneva cam or a similar mechanism.

The parts are picked up as the blade rotates through the hopper, and as the blade indexes to a position opposite the track *(D2)*, they slide to the machine. The ejector *(D3)* has an oscillating movement parallel with the track to clear the track opening of possible jams.

The irregular shape of the blade makes this a rather expensive hopper to manufacture, and it is not entirely foolproof against possible jamming.

Barrel Hoppers. These hoppers are valuable in feeding parts which have a tendency to interlock and become a mass. Figure 19-18, *C*, shows a hopper of this type in which the barrel *(D1)*, having vanes *(D2)* cast integral with or fastened to the inside surface, rotates continually. The vanes pick up and to a certain extent preorient the parts and carry them upward until they drop into the guide or chute ($D3$) which leads them to the press. Careful attention should be given the bearings on which the barrel rotates so that there is no contamination of the blanks by the lubricant used. Sealed ball bearings or porous bronze bearings with an adequate oil reservoir will give excellent service to rotary hoppers.

Rotary Hopper. Practical for a wide variety of parts, the hopper shown in Fig. 19-18, *D*, consists of an angularly mounted drum ($D1$) with a radially grooved revolving

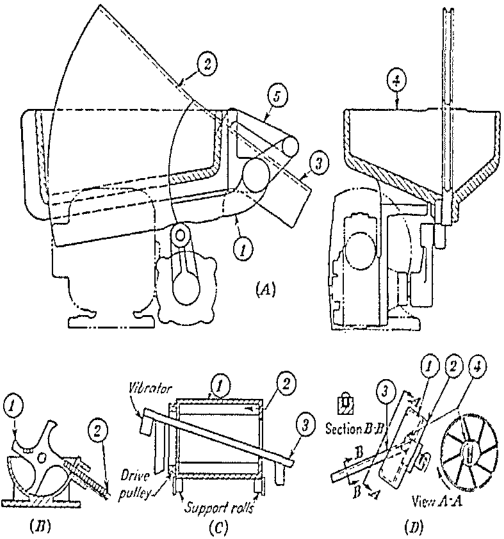

FIG. 19-18. Various hoppers: (*A*) oscillating centerboard (*J. R. Paquin*); (*B*) rotary centerboard; (*C*) barrel hopper;[3] and (*D*) rotary hopper.[7]

base plate ($D2$). Parts are carried upward in the grooves and slide down into the track ($D3$), which is mounted on a stationary bracket. A stationary baffle ($D4$) prevents parts from falling back into the drum before they pass the track opening; if the track is loaded, the parts return to the drum.

Drum-and-belt Feeder. Parts that tend to tangle or have wires attached can be fed and oriented to the position shown at *D1* (Fig. 19-19, *A*). The part shown is either lined up on, or pushed off, the moving belt by guides ($D2$, $D3$). The photocell beam is interrupted only by the ferrule of the part. The time of belt travel between the beam and the solenoid plunger equals the time secured by a condenser-resistor delay circuit. The solenoid plunger can only knock incorrectly positioned clips from the belt. When the drum and belt are properly proportioned, a rain of parts drops from the angle brackets to the belt; the output of parts is high, even if a small percentage are oriented on the belt between the drum and the beam.

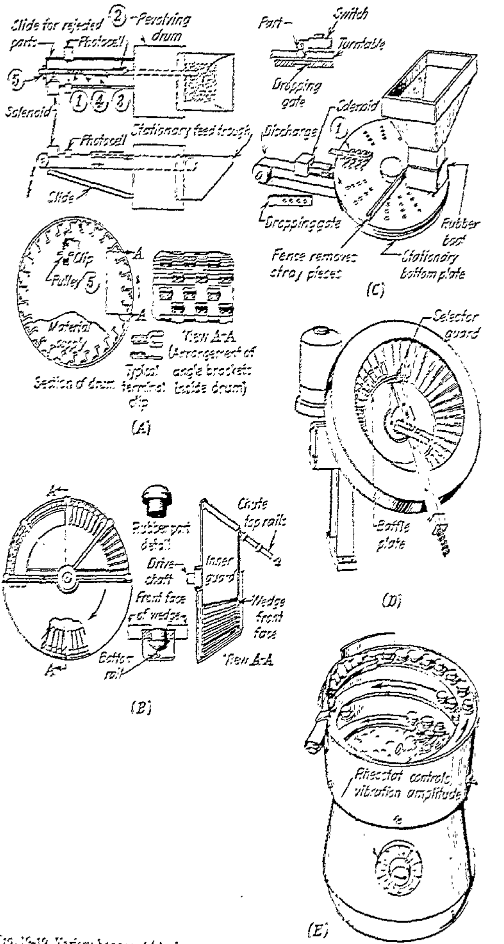

FIG. 19-19. Various hoppers: (A) drum-and-belt feeder; (B) turntable hopper; (C) squirrel-cage hopper; (D) inclined rotary hopper (Detroit Power Screwdriver Co.); (E) vibratory bowl feeder (Syntron Co.).

Turntable Hopper. Identical parts, not too thin, which will easily enter a round hole, can be delivered only in groups of five as shown in Fig. 19-19, *C*. A solenoid-operated dropping gate is actuated only when all five limit switches (*D1*) close. Parts which may be partially seated in the holes are pulled out of the boot and removed by the fence.

Squirrel-cage Hopper. Parts characterized by resilience and high coefficient of friction are easily fed and sorted in the hopper shown in Fig. 19-19, *B*. The rivet-shaped parts which fall, shank down, between the wedges are kept in the slots by the inner guard so that they are discharged at top center.

Inclined Rotary Hopper. The commercial hopper shown in Fig. 19-19, *D*, has been adapted to a variety of symmetrically shaped parts. The wedge-shaped blocks fastened to the rotating ring are spaced so as to permit the part to fall between them when they pass under the supply stored inside the cover. The baffle plate inside the rotating ring is stationary, being attached to the fixed central shaft which also supports the discharge track. This baffle plate keeps the 50-caliber bullet cores from falling inward until they are carried up to the end of the track. The selector guard attached to the baffle plate allows those bullet cores which are oriented point first to pass into the track but rejects those having their blunt end down. This hopper is usually driven by a constant-speed motor, a feed-limiting device or escapement being used to regulate the discharge. Feeds as high as 300 parts per minute can be obtained, but light plastic or sheet-metal objects must be discharged at a much lower rate.

Vibratory-bowl Feeder. The feeder shown in Fig. 19-19, *E*, has a bowl placed above a vibrator and shaken at 60 cycles by an a-c solenoid. Vibration drives the parts to the periphery of the bowl, where a spiral track guides them up to the rim of the bowl. The base containing the vibrator is a standard unit, but the shape of the bowl and track are determined by the objects to be handled. Rate of feed is controlled by a rheostat which varies the amplitude of vibration; it is not normally necessary to vary the frequency. Multiple streams of parts can be discharged by making the helical track of multiple pitch like a screw thread. Gates, fences, air blasts, or variations in the shape of the track at one point can discharge pieces which are improperly oriented. With proper design and regulation, the discharge can be blocked awaiting the needs of the associated equipment, or the vibrator can be turned on and off by counting devices.

MAGAZINE FEEDS

The typical magazine lacks a mechanism for sorting and arranging, and the parts must therefore be stacked in position either by hand or by some automatic means. Magazines may be arranged vertically or horizontally. In a vertical magazine the blanks are stacked one on top of the other and fed singly from the bottom by a reciprocating slide. Parts are sometimes fed by gravity, but it is usually more satisfactory to employ a positive transfer motion or a pneumatic feed mechanism coordinated with the movement of the press slide. Magazine feeding is generally confined to flat blanks. It is comparatively easy to feed thick blanks; thin material requires a more carefully fitted pushing shoe. Steel disks and rings as thin as 0.025 in. have been fed successfully from magazines. It is possible to feed previously formed workpieces from magazines incorporating suitable escapement mechanisms.

UNLOADING DEVICES

The unloading of a finished part from a die can often be achieved by gravity by allowing the part to fall through the die or slide off an inclined surface in the die, or by inclining the press and die. The larger parts which would be damaged or require being placed in a specific location for subsequent operations must be removed by hand or mechanical devices.

Air-blast Ejection. A short blast of air is effective in the removal of small light parts. When the press is near the top of its stroke, a blast of air blows the part out of the die. The air-blast control valve can be actuated by a cam on the crankshaft. This cam is designed to emit a short blast of air just before the top of the stroke or just before the press stops in the case of intermittent operation.

An effective device to aid air in ejecting finished parts or scrap is shown in Fig. 19-20. This device allows the material that is to be ejected to fall on the shelf before the air blast hits it. On this setup the workpiece remains on the punch (D1) and is stripped from the punch by the stripper (D2). As the part falls on the shelf (D3), an air blast from the nozzle (D4) ejects it from the die.

The operation of the device is as follows: The opposite corners of the punch come in contact with the two wedges (D5) causing the oscillating shelf to open up to the right and left. The cams are shaped so that the descending punch opens the shelf wide enough to permit the punch to pass. Springs hold the cams in contact with the punch corners. On the upstroke, the part is stripped from the punch after the shelf has closed. When the punches are to be removed for resharpening, the hinge pins (D6) may be removed and the shelves dropped out of the way.

With slight changes, this device can be adapted to various types of dies.

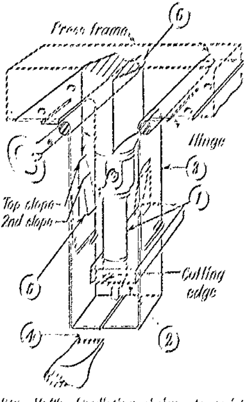

Fig. 19-20. Oscillating shelves to assist air blast to eject parts or scrap from die. (F. W. Curtis.)

Oscillating Die-unloadings Arms. *The oscillating unloading arm shown in Fig. 19-21 is independently driven by an electric motor synchronized with the stamping operation. One or two arms can be used to transfer cups or similar parts from press to press, or to load or unload a press.*

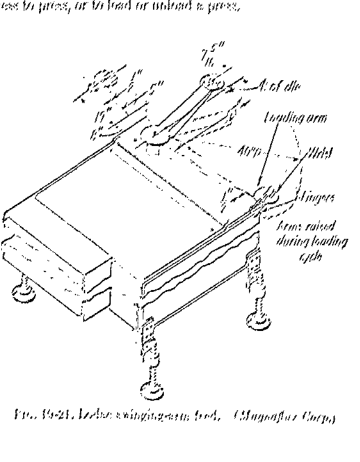

Fig. 19-21. Loader swinging-arm feed. (Magnaflux Corp.)

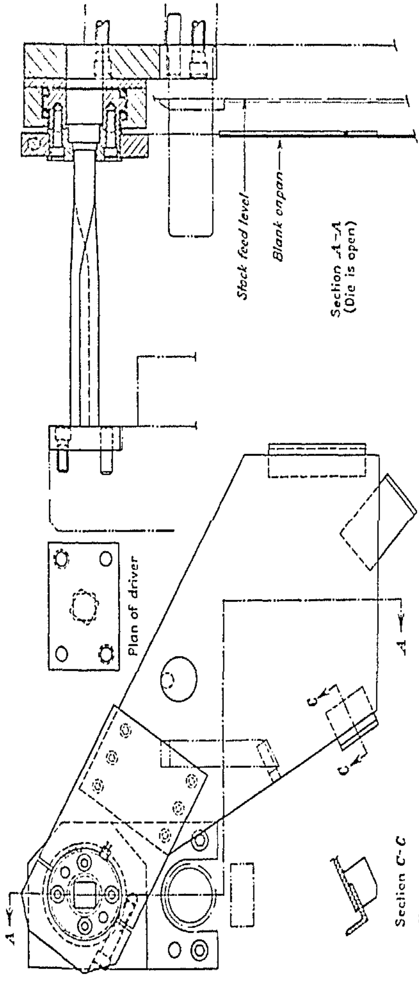

FIG. 19-22. An oscillating die-unloading arm actuated by opening and closing of the die. (*Buick Division, General Motors Corp.*)

Oscillating arms operated by the closing of the die or synchronized mechanical means are used to remove parts from dies. The arm shown in Fig. 19-22 utilizes a cam to swing it inward to receive the finished part as the die opens, and outward to discharge the part as the die closes.

The shape of the arm is designed to receive the part as it is ejected from the upper die by a positive knockout. The arm is supported by a combination radial and thrust bearing which also acts as the pivot. The rotation of the arm is achieved by a square-shaped cam which is twisted to give about 60° of rotation.

Die Shedder Bars. Dies that carry the part up with the punch (or can be made to carry it up) can be unloaded with die shedder bars (Fig. 19-23). These are bars which fold out of the way as the die closes, and move underneath the part when the die opens. At top of stroke, a positive knockout drops the panel on the shedder arms and the part slides out of the die. These arms are helpful on blank-and-pierce dies for long parts.

The placing of shedder bars within the die can also be accomplished by separate floor-mounted devices, either air- or motor-driven. These mechanisms thrust the bars within the die area at the proper instant and are timed entirely with the press cycle.

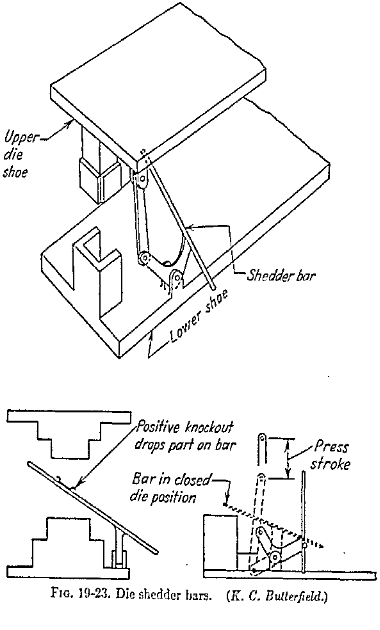

FIG. 19-23. Die shedder bars. (*K. C. Butterfield.*)

Air Kickers. Parts made in small dies are often too heavy for practical air-blast removal. In such case, some form of an air-operated kicker is practical, particularly *if the press cannot be inclined. An air cylinder installed on front of the die is equipped* with some form of kicking mechanism. An elementary type is the direct-action kicker (Fig. 19-24). An air cylinder is equipped with a kicking head made of light tubing. If the head is accidentally in the die at the time of closing, it will collapse, and no damage will be done to the die.

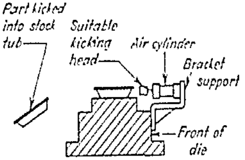

FIG. 19-24. Air kicker for use when the workpiece can be ejected with a blow. (*K. C. Butterfield.*)

Air-operated Tilting Ejector. The air-operated ejector shown in Fig. 19-25 is attached to the blanking die so that the blanked parts are tilted and slide by gravity over balls and rollers, automatically stacking on a pallet placed on the discharge side of the press. After about a dozen blanks are produced, the operator removes the scrap cut away from these blanks and throws it into the boxes provided for this purpose.

For discharging the blanked parts, the ejector arrangement has transfer balls (*D1*) and cloth rollers (*D2*) to avoid scratching the blanks. When the ejector is tilted by the air cylinder (*D3*) inside the die, the blank is inclined to an angle of about 11° and moves by gravity down over the balls and rollers. The linkage is arranged so that the right-hand end of the tilting table containing the sheet stops tilts to a greater angle than the sheet.

Mechanical devices for unloading presses are in use in many pressrooms. These devices are actuated by air or hydraulic cylinders and synchronized with the press stroke. These devices have a swinging or a horizontal reciprocating motion to lift or carry the parts from the dies. The finished parts are raised up out of the die cavities by lifter units built into the die. From this position jaws grip the parts and carry them from the press onto a conveyor or transfer fixture for feeding a press for a following operation. The parts may also be deposited on a skid or truck for transporting to another location.

Mechanical Arms and Jaws. The "Iron Hand" unloading device shown in Fig. 19-26 is mounted on the press frame above the die space. It is operated by two air cylinders, one for lifting the arm and the other for opening and closing the jaws. The *jaws are opened and closed by a cam so that they will not open up under load and also* may be closed on any stock thickness within the range of the jaw without adjustment. The cylinders are controlled by solenoid-operated valves which are actuated by limit switches placed on the press frame in such a position that they can be tripped by the press slide. The device has replaceable jaws which can be designed to suit the part being moved.

The design and adapting of mechanical press-unloading devices may be applied not only to mass production but also to medium and even low production. The dies should be designed to permit the entry of the gripping jaws and should be free from projections which might hinder the free removal of the part.

The transfer fixtures for feeding subsequent presses are sometimes required to turn the part over or rotate it in a horizontal plane. These positions are determined by the nature and part-position requirements of the next operation. The turn-over or

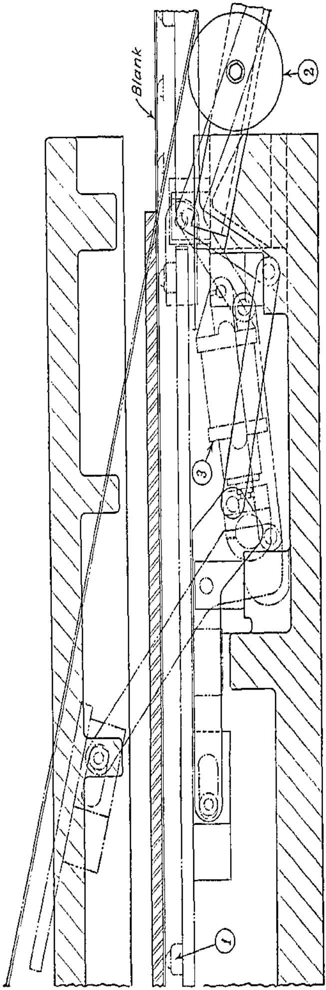

FIG. 19-25. Air-operated tilting ejector. (*The Studebaker Corp.*)

rotary actions as well as pusher or advancing motions may be actuated by air or hydraulic cylinders which have limit-switch-controlled solenoid-operated valves.

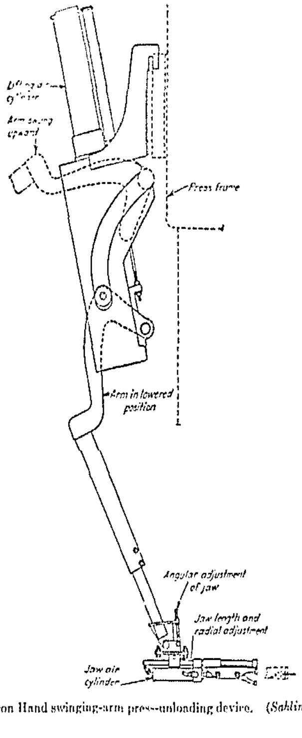

FIG. 19-26. The Iron Hand swinging-arm press-unloading device. (*Sahlin Engineering Co.*)

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SECTION 20

DIE SETTING AND MAINTENANCE*

Standard Die-setting Procedures. Any effective die-setting procedure is predicated upon the use of a press of adequate size and capacity and in good mechanical condition. Another requirement is the use of a bolster incorporating an opening: (1), of minimum size consistent with necessary support of the die; (2), having a location to allow slugs and scrap to fall freely from the die. The following steps have been abstracted from an industrial standard for setting dies used in piercing and blanking strip stock.[1,†]

1. Check and tighten all bolts holding bolster to press.
2. Wipe bolster, bottom face of ram, top and bottom of die, and riser blocks if used.
3. Place die in approximate operating position on bolster or riser block.
4. Check alignment of all slug-clearance openings in all lower die members with corresponding openings in bolster and riser block.
5. Bring ram down (by hand) to its lowest point and insert shank of upper shoe in ram.
6. Adjust ram to approximate shut height of die.
7. Place clamps or bolts in position for securing lower shoe, but do not tighten bolts.
8. Tighten ram bolts to hold shank or upper shoe in contact with ram.
9. Tighten all bolts or clamps to secure lower shoe: tighten opposite rather than adjacent bolts or clamps to equalize pressure and prevent cocking of lower shoe.
10. Adjust ram so that the shortest punch will enter die a minimum distance to ensure travel of slugs (or blanks) below the straight. Tighten ram-adjustment screw.
11. Raise ram, lubricate all cutting edges and moving parts, lubricate leader pins, and examine leader-pin bushings for adequate air venting.
12. Try out die by hand by inching for uniform punch-and-die clearance with plastic sheet instead of stock material. Do not fracture but only mark the sheet.
13. Cut a small number of stampings. Inspect for cut bands, burrs, and dimensional and other standards.
14. If any upper die member needs further tightening, lower ram (by hand) to lowest point and loosen all bolts and clamps holding lower die. Retighten bolts holding upper shoe or shank to ram. Retighten all bolts and clamps holding the lower die. Rerun die as in step 13.
15. Perform final retightening of threaded elements, except those listed in step 14.
16. Install and adjust feeding and unloading devices.
17. Rerun die for production parts: inspect as in step 13 and for limits on production parts.
18. Install and adjust safety devices.

The procedures listed are given only as a guide for the setting of cutting dies: some modification will be needed for the setting of other types of dies, which may incorpo-

* Reviewed by W. N. Bachman, President, Bachman Machine Co.; E. W. Ernst, Manager, Machine Tool Equipment Planning, General Electric Co.; and C. Hall, Assistant Manager, Standards Department, Century Electric Co.

† Superior numbers relate to References at the end of this section.

rate cams, form blocks, ejectors, or other adjustable elements; auxiliary equipment such as press cushions and feeding and unloading mechanisms will also change die-setting procedures.

Setting a progressive die involves manual press operation and feeding the stock by hand through successive stations, with accompanying adjustments of the ram, feed length, and the pilots and other elements at each station.

The uniform distribution of blankholder pressure may be undesirable in the case of forming or drawing dies for large and/or irregular stampings; the die setter uses shims or adjusts the blankholder slide (in some presses) to direct different pressures to the desired areas.

DIE FAILURES AND THEIR CORRECTION

Failures of Die Steels. The use of steels with internal defects such as inclusions, pipe, and excessive segregations is uncommon, because of the extensive use of ultrasonic inspection.

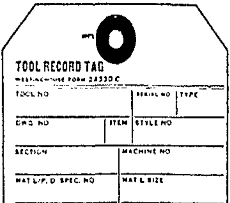
TOOL RECORD TAG
WESTINGHOUSE FORM 24330 C
TOOL NO | SERIAL NO | TYPE
DWG NO | ITEM | STYLE NO
SECTION | MACHINE NO
MAT L/P. O SPEC. NO | MAT L SIZE
TOOL SETTER | DATE IN | TOOL SETTER | DATE OUT
PIECE COUNT | INSP. APPROVAL | DATE
REPAIR REQ NO | FOREMAN S APPROVAL | DATE
REPAIRED BY SEC | DIE REPAIR HRS | TOOL ROOM HRS
AMOUNT GROUND OFF | DIE | PUNCH
REASONS FOR STOPPING RUN
(FILL IN CODE NUMBER AS INDICATED ON CHART)
SPECIAL REMARKS
(SIGNATURE AND DATE)

FIG. 20-1. Die record tag.[2] (*Westinghouse Electric Corp.*)

Failures Due to Faulty Die Design. In addition to an incorrect steel specification for a die component, the design may include incorrect clearances, dimensions, contours, and grain directionality conducive to fragility or other innumerable engineering errors that can result only in unsatisfactory service or failure of the die set.

Die Design Unsuitable for Heat Treating. Die elements having adjacent thin and thick sections, sharp corners, and reentrant angles can easily crack during heat treatment, or later in service, because of stress concentrations in such portions of the die element. Recommendations for die design to lessen the possibility of such cracks are given in Sec. 24.

Failures Due to Improper Heat Treatment. The greatest strain in steel occurs during the quenching period. Cracking results from failure to temper immediately after quenching, from quenching from too high a hardening temperature, from too long quenching time, or from nonuniform chilling of the steel. Soft spots in water-hardening carbon tool steel will eventually crack if the quench solution contains air or other contaminants, is insufficient in quantity, or is inadequately agitated. These cracks may not appear until the tools are ground. The heat treating of die materials is discussed in Sec. 24.

Failures Due to Improper Grinding. Grinding checks and cracks are due to high surface stresses caused by too rapid removal of the metal; by the use of a wheel which is loaded, dull, or of a too fine grit size, or otherwise unsuited to the metal; or by the ineffective use of a coolant. Optimum grinding techniques will not prevent the appearance of grinding cracks if the die has been improperly heat-treated. The detection of checks and cracks is facilitated by inspecting with fluorescent penetrants or magnetic particles.

Failures Due to Improper Inspection and Maintenance. Schedules of periodic die inspection and maintenance are in use in well-run plants. Such schedules, including

TABLE 20-1. CODIFICATION OF DIE FAILURES[*]

Code No.	Condition and reason	Code No.	Condition and reason
1.0	Economical die run complete	8.7	Scored, set too deep
1.1	Economical die run complete (die not ground)	8.8	Loose, poor punch-holder fit
1.2	Economical die run complete (die ground)	8.9	Bent or broken, fragile
2.0	Failure to make economical die run (other than die failure)	9.0	Die-section failure
2.1	End of order	9.1	Chipped, grinding strains
2.2	Production schedule request to change jobs	9.2	Broken, improper heat treatment
2.3	Material out of stock	9.3	Broken, jam up
2.4	Material over or under gage	9.4	Broken, miscuts
2.5	Poor or substitute material	9.5	Scored, improper heat treatment
3.0	Die fails to make economical run	9.6	Scored, lack of lubricant
3.1	Excessive burr because of dull die	9.7	Spread, poor fit in die holder
3.2	Dull die because of lack of lubricant or use of inferior cutting lubricant	9.8	Loose, poor fit in die holder
3.3	Dull die because of wrong die steel or heat treatment	10.0	Stripper
4.0	Sheared punch or die	10.1	Bent or broken, jam up
4.1	Press misalignment	10.2	Bent or broken, broken punch
4.2	Die misalignment	10.3	Bent or broken, broken bolt
4.3	Pins or bushings worn	10.4	Bent or broken, broken springs
4.4	Poor setup	10.5	Bent or broken, too thin
4.5	Pulling slugs	11.0	Knocker failures
4.6	Miscuts	11.1	Bent knocker plate, made of wrong steel
5.0	Miscuts	11.2	Bent knocker plate, too thin
5.1	Poor feeding	11.3	Bent knocker plate, off center
5.2	Improper gaging	11.4	Bent knocker pins, wrong steel
5.3	Lubricant causing blanks to stick	11.5	Bent knocker pins, too weak
5.4	Heavy burr from previous operation	11.6	Bent press knockout, made of wrong steel
5.5	Poor stripping	12.0	Worn guide pins and bushings
5.6	Undersize or wrong shape pilots	12.1	Worn or scored, made of wrong material
5.7	Poor material guiding	12.2	Worn or scored, poor lubrication
5.8	Press retripped	12.3	Worn or scored, improper fits
5.9	Pulling slugs	12.4	Worn or scored, press or die misalignment
6.0	Slugged die	13.0	Die shoes
6.1	Chipped punch	13.1	Bent or broken, made of wrong material
6.2	Not enough taper in die	13.2	Bent or broken, made too weak
6.3	Surface of die too rough	13.3	Bent or broken, improper setting
6.4	Lack of lubricant	14.0	Springs
6.5	Improper slug clearance in bolster or press	14.1	Broken, fatigue
7.0	Pulling slugs	14.2	Weak, fatigue
7.1	Excessive break clearance	14.3	Weak, wrong spring
7.2	Not demagnetized	15.0	Pilots
8.0	Punch failure	15.1	Bent or broken, miscuts
8.1	Chipped, grinding strains	15.2	Bent or broken, poor feeding
8.2	Chipped or broken, improper heat treatment	15.3	Scored, wrong steel or heat treatment
8.3	Chipped or broken, jam up	16.0	Part not to drawing
8.4	Chipped or broken, miscuts	16.1	Dimensional tolerance in question
8.5	Scored, improper heat treatment	16.2	Sizing die required
8.6	Scored, lack of lubricant or inferior lubricant	16.3	Return to toolroom
		17.0	Die damaged in transportation or storage
		18.0	Press difficulties Use press-failure card and report on record tag accordingly
		19.0	Feeder, dereeler, stacker difficulties Report on die-record tag

[*] Westinghouse Electric Corp.

cleaning, lubrication, adjustment for wear, sharpening of cutting areas, and the replacing of die components, are commonly based upon the kind of stampings produced and their production rates. Periodic inspection of finished stampings for burr characteristics, particularly on long runs, will establish a practical frequency for regrinding. Obviously, delayed resharpening, or dilatory replacement of wear plates can result in die failures and high scrap rate. Periodic inspection, adjustment, and maintenance of such press accessories as feeds and cushions, as well as press maintenance and inspection to include out-of-parallel condition of ram and bed faces due to press overloads, are integral with organized schedules for optimum stamping fabrication.

Collection and Analysis of the Causes of Die Failures. Die failures and their causes are coded by a large manufacturer as shown in Table 20-1. Uneconomical die runs due to other factors are also listed. A record tag (Fig. 20-1) is attached to a die at the start of every run and under "Reasons for Stopping Die Run" code numbers applicable to its malfunctioning are listed. For example, a miscut caused by misfeeding, with a broken punch, a damaged die button, and a bent stripper plate indicate the entry of code numbers 5.1, 8.4, 9.4, and 10.2.

TABLE 20-2. CAUSES OF DIE FAILURES, MONTHLY TOTAL[1]

Code No.	Condition and reason	Monthly average, previous year	Jan.	Feb.	Mar.	Apr.	May	June	Monthly average, 6-month period
1.0	Economical die run complete								
1.1	Economical die run complete (die not ground)	25	29	26	34	31	29	37	31
1.2	Economical die run complete (die ground)	17	16	17	11	12	8	9	12
	Total	42	45	43	45	43	37	46	43
2.0	Failure to make economical die run (other than die failure)								
2.1	End of order	15	18	16	12	14	7	6	12
2.2	Production schedule request to change jobs	11	8	4	3	0	0	1	2.7
2.3	Material out of stock	4	3	3	5	2	1	0	2.3
2.4	Material over or under gage	9	10	12	14	8	6	3	8.8
2.5	Poor or substitute material	8	6	8	7	9	11	12	8.8
	Total	47	45	43	41	33	25	22	31.6
3.0	Die fails to make economical run								
3.1	Excessive burr because of dull die	19	22	23	17	11	6	4	14
3.2	Dull die because of lack of lubricant	5	3	2	0	1	0	0	1
3.3	Dull die because of wrong die steel or heat treatment	9	11	10	7	9	6	4	8
	Total	33	36	35	24	21	12	8	23
4.0	Sheared punch or die								
4.1	Press misalignment	5	6	6	7	4	6	8	6.0
4.2	Die misalignment	8	7	8	5	6	3	2	5.0
4.3	Pins or bushings worn	15	12	8	6	0	1	0	4.5
4.4	Poor setup	3	1	3	2	0	4	1	2.0
4.5	Pulling slugs	6	7	8	10	6	4	7	7.0
4.6	Miscuts	14	11	14	9	7	6	2	8.0
	Total	51	44	47	39	23	24	20	32.5

A monthly coded record of die failures and their causes, including economical runs shown in Table 20-2 (through code 4.6 only) is tabulated for analysis and corrective action. If, for example, this record shows dies with sheared punches or die buttons (code number 4.0, Table 20-1), corresponding corrections for coded failures are indicated in Table 20-3.

Miscuts in the stock may occur during or previous to a punch or die failure by shearing (Table 20-4). Shearing is defined as the dulling or scoring of punch or die edges by contact of their cutting edges. Miscuts may misalign the punch and die, or chip or break these elements. A bent stripper plate, knockout, or spread die may result from miscutting, in addition to producing a defective stamping.

TABLE 20-3. CAUSES OF SHEARED PUNCH OR DIE AND CORRECTIVE ACTION

Failure Code No. and Description	Corrective Action
4.1. Press misalignment	Improve press inspection and maintenance
4.2. Die misalignment	Review die-setting and repair methods
4.3. Worn guide pins and bushings	Shorten die-inspection periods
4.4. Poor setup	Consider die setters training program
4.5. Pulling slugs	Check clearance; demagnetize die; avoid excessive blank lubrication; replace punch if necessary
4.6. Miscuts	Check and adjust feeding, piloting, dereeling, or stacking, and as under 4.4

TABLE 20-4. CAUSES OF MISCUTS AND CORRECTIVE MEASURES[1]

Failure Code No. and Description	Corrective Action
5.1. Poor feeding, due to inaccurate setting	Periodical check and maintenance
5.2. Improper gaging	Operator instruction and/or safety gaging device
5.3. Blanks adhere to punch, die, or to each other	Spraying or other control to prevent overlubrication
5.4. Heavy burr from previous operation interferes with strip or blank movement	Decrease burr tolerance, deburr, feed blank with reversed faces
5.5. Poor stripping allows interference with succeeding blank	Adjustment of stripper or knockouts; replace all springs if one or more is weak or broken
5.6. Undersize or wrong shaped pilots	Correct at setup; check low hardness
5.7. Poor stock guiding	Check sheared strip width; provide spring-loaded guides
5.8. Press retripped; premature or delayed clutch or brake operation	Improve press inspection and maintenance
5.9. Pulling slugs	Same as 4.5

Broken or chipped punches (Table 20-5) may result in a major die or press repair; a chipped punch may necessitate regrinding only.

TABLE 20-5. CAUSES OF PUNCH FAILURES AND CORRECTIVE MEASURES[1]

Failure Code No. and Description	Corrective Action
8.1. Chipped-grinding strains	Check grinding-wheel speed, feed, lubrication, and grit size
8.2. Chipped or broken, improper heat treatment	Investigate steel grade and heat treatment used
8.3. Chipped or broken, jam up	Check operator and feeding
8.4. Chipped or broken, miscut	See 5.1 to 5.9
8.5. Scored, no lubrication or inferior lubrication	Use correct quantity and quality
8.6. Scored, set too deep	Check die setting for looseness in press
8.7. Loose, poor punch-holder fit	Check design dimensions
8.8. Bent or broken, fragile	Redesign for heavier sectioning and fillets and/or bushing

The systematic collection of data on the causes of die failures, the analysis of the data, and the corrective action to be taken as outlined have lowered die maintenance and repair costs, decreased down time, and improved die design, product cost, and quality. A similar program includes presses and feeding, dereeling, and stacking devices.

References

1. "Tool Engineering Standards," White-Rodgers Electric Co.
2. Griffiths, S. E.: "Maintenance Expense Control of Tools, Dies, Fixtures and Equipment"; paper presented at the Twenty-First Annual Meeting of the American Society of Tool Engineers, Detroit, 1953.

SECTION 21

PRESSWORKING LUBRICANTS*

The functional requirements of lubricants for pressworking are much more severe than for most journal lubrication. The proper lubrication of shafts and bearings under average conditions, termed "fluid," "thick-film," "viscous," or "hydrodynamic" lubrication, depends primarily upon the viscosity of the lubricant. High sliding or rotating speeds, low unit pressures, and closed design of the machine elements allow the formation of a relatively thick film resulting in low bearing pressures seldom exceeding 5,000 psi, compared with pressworking pressures ranging up to several hundred thousand psi, and in coefficients of friction of not more than a few thousandths.

Coefficients of frictions for various combinations of metals (Table 21-1) can be lowered by suitable pressworking lubricants, but they are seldom reduced to less than 0.01.

TABLE 21-1. COEFFICIENT OF FRICTION FOR VARIOUS MATERIALS[1,†]

Combination of Materials	*Coefficient of Friction*
Tin–mild steel	0.18
Lead–mild steel	0.33
Copper–mild steel	0.36
Hard steel–hard steel	0.42
Cadmium–mild steel	0.45
Mild steel–mild steel	0.57
Copper–copper	0.60
Nickel–mild steel	0.65
Cadmium–cadmium	0.80
Aluminum–mild steel	0.74–1.0
Aluminum–aluminum	1.40

Boundary Lubrication. Pressworking lubricants, usually subjected to high unit pressures, are thin adsorbed films, believed to be only a few molecules thick. Such thin films separating metal surfaces during drawing, heavy forming, or other operations involving high pressures prevent or minimize heat due to friction between working surfaces (chemical cooling) and dissipate heat due to internal friction resulting from grain deformation and displacement (physical cooling). Such thin-film lubrication is considered to be within the range of "boundary lubrication." The coefficient of friction of thin films under so-called boundary lubrication is independent of lubricant viscosity and sliding speed. Thin-film lubricants are of two basic types:

1. *Polar Lubricants.* A lubricant or constituent of a lubricant capable of either physical or chemical adsorption on a solid surface to form a thin film which resists removal by mechanical means and provides lubrication under high unit loading. A thin-film lubricant, so attached, is defined as a polar lubricant.

2. *Extreme-pressure Lubricants.* Lubricants capable of reacting chemically with solid surfaces under rubbing conditions, to prevent welding and provide lubricant reaction products on the surface. Extreme-pressure lubricants permit high unit load-

* Reviewed by E. L. H. Bastian, Staff Engineer, Shell Oil Co.

† Superior numbers relate to References at the end of this section.

ing with a minimum of surface wear and damage. Typical extreme-pressure lubricants contain sulfur, chlorine, and/or phosphorus compounds as chemically active constituents.

TYPES OF DRAWING COMPOUNDS

Oxide Lubricants. Oxide films may be formed by exposure to air or by alkaline washes or other methods to a thickness and adherence desired for proper lubrication under high unit pressures. Such a film is also an extreme-pressure lubricant.

Inorganic Fillers. These fillers function as solid lubricants. The noncleavage type carries particles of such materials as chalk, lithopone, or white lead (in a suitable vehicle), which are pulverized as the punch starts to move. The weak-cleavage type incorporates particles of materials such as graphite, talc, or mica which slide over each other with little friction. Other substances sometimes added to the vehicle (oil-base) are zinc oxide, clay, flour, yeast, and/or bran talc. Flowers of sulfur is also used as a filler.

Low-melting Solid Lubricants. Dried coatings of high-titer (tallow) soda soaps and dried coatings of wax are used as lubricants.

High-melting Solid Lubricants. Phosphate, sulfide, or oxide deposits, generally with a liquid polar lubricant, are used in drawing operations.

Metal Lubricants. Ferrous metals may have a coating (hot-dipped or electroplated) of a dissimilar soft metal, such as copper, lead, zinc, or tin, which acts as a lubricant. Powdered aluminum, copper, brass, or lead are used as fillers in water- or oil-base lubricants.

Soap-and-water Dispersions. Dispersed insoluble powders of acid soaps in water are widely used as drawing compounds; any soap may be used if maximum hydrolysis is attained by low concentrations without the formation of gel.

Soap Dispersions, Fatty Acids, and Fatty Oils. Dispersions of this type are used, and provide good lubrication.

Soap Pastes with Fatty Materials. The paste is mixed with water to form an emulsion. Free fatty acid may be added; stearic rather than oleic acid is often recommended.

Soap, Mineral Oil, and Water. This emulsion is used mainly as a coolant.

Soap, Mineral Oil, Fatty Acids, and Water. Some of these lubricants equal in performance emulsions containing only emulsified fatty material.

SELECTION OF DRAWING COMPOUNDS

Characteristics of Metals as Selection Factors. Some factors in selecting a compound relate to the composition and condition of the stock and die metals, as well as the severity of the die operation. Other factors are properties of the metals:

1. Yield strength
2. Rate of work hardening
3. Coefficient of friction
4. Rate of chemical reaction with a lubricant
5. Tendency to form a surface film

General Characteristics of the Lubricant as Selection Factors. The lubricant used should be specified with regard to the following considerations:

1. Handling, mixing, application, and removal
2. Chemical stability
3. Wetting properties
4. Toxicity and odor
5. Noncorrosive or nonstaining properties
6. Economy

CLASSIFICATION OF PRESSWORKING LUBRICANTS

Nondescriptive trade names, and the number and chemical complexity of components in pressworking lubricants make it difficult to classify the numerous lubricants used, but a proper lubricant is either of a type listed under Types of Drawing Compounds, or else is a compound of the ingredients listed as follows:[2]

Mineral oils are derived from petroleum. Examples are neutral engine oil, bright stock, and straw paraffin oil.

Fats and fatty oils are obtained from either animal or vegetable matter. Examples are tallow, *dégras*, lard oil, sperm oil, fish oils, palm oil, cottonseed oil, rapeseed oil, castor oil, and beeswax.

Fatty acids are derivatives of the fats and can be included in the preceding class. Examples are stearic acid and oleic acid.

Chlorinated oils may be paraffin wax or fatty oils treated and chemically combined with chlorine compounds.

Sulfurized oils are mineral or fatty oils which have been treated with sulfur at elevated temperature to yield an unstable organic compound of sulfur.

Sulfonated oils are obtained by treating certain organic compounds with sulfuric acid, followed by neutralization with an alkali. An example is sulfonated castor oil.

Soluble oils are mineral oils to which an agent, usually the sodium sulfonates of petroleum, has been added to make the oil emulsifiable in water.

Soaps are compounds of fatty acids with a base, usually metallic. Examples are potassium oleate and sodium stearate. Some metallic soaps are insoluble in water. Examples of these are aluminum stearate, zinc stearate, and lead oleate.

Pigments are fine particles of solids which are insoluble in water, oil, and fat. Examples are whiting, talc, lithopone, white lead, and china clay. Graphite may also be included in this class.

Lubricants for pressworking purposes may be generally classified as follows:

Extreme-pressure Lubricants. These are typically sulfurized or chlorinated fatty oils or paraffin waxes in concentrated form or diluted with mineral oil. Compounds, such as lead naphthenate, may also belong to this type.

Pigment-type Drawing Lubricants. These are of three subtypes:

1. Emulsion compounds, which consist of paste composed of fats or fatty oils (sometimes mineral oil), pigment, emulsifier (*e.g.*, soap), and water. They are used occasionally as supplied but are usually diluted with water and sometimes with mineral oil for efficient application.
2. Oil compounds, which are pastes of pigments dispersed in fatty oils and/or mineral oils, which may be sulfurized or otherwise treated. They are used straight or diluted with mineral oil.
3. Dried-on lubricant and pigment coatings, which are widely used in tube drawing and occasionally also in sheet fabrication.

Non-pigment-type Lubricants. These may be divided into four subtypes:

1. Emulsion drawing compounds, which are paste composed of fats and fatty oils and their fatty acids (sometimes also free mineral oil), various emulsifiers, and water. They are usually used diluted with water.
2. Fats, fatty oils, and fatty acids, which are sometimes used straight but usually are mixed with mineral oils for use.
3. Mineral oils and greases, which may be used straight.
4. Soluble oils, which are generally diluted with water.

Soap-type Lubricants. These are of the following four subtypes:

1. Dry powders, which are sodium- or other metallic-type soaps; they are used as furnished in powder form, largely for wire drawing and by some manufacturers for tube drawing.
2. Dried-film compounds, which are usually soluble soaps, often mixed with soluble fillers (*e.g.*, borax), or sometimes containing waxes, wetting agents, and other chemicals. The parts to be drawn are dipped or sprayed with about a 10 to 20 per cent hot solution and dried prior to the forming operation.
3. Bar soap, which is sometimes used as such for spinning and drawing.
4. Soluble soaps, which are sodium or potassium soaps, diluted from ¼ to 10 per cent with water for use.

DRAWING-COMPOUND RECOMMENDATIONS FOR SPECIFIC METALS

A basis for lubricant selection is the severity of the operation. The following recommendations define a *mild* operation typically as a shallow draw on low-carbon steel; a *medium* operation as a deep draw on low-carbon steel; and a *severe* operation as a cartridge-case draw or as a seamless-tube draw.

Drawing of Steel[1]

Mild Operations:

1. Mineral oil of medium-heavy to heavy viscosity
2. Soap solutions (0.03 to 2.0 per cent, high-titer soap)
3. Fat, fatty-oil, or fatty- and mineral-oil emulsions in soap-base emulsions
4. Lard-oil or other fatty-oil blends (10 to 30 per cent fatty oil)

Medium Operations:

1. Fat or oil in soap-base emulsions containing finely divided fillers such as whiting or lithopone
2. Fat or oil in soap-base emulsions containing sulfurized oils
3. Fat or oil in soap-base emulsions with fillers and sulfurized oils
4. Dissimilar metals deposited on steel plus emulsion lubricant or soap solution
5. Rust or phosphate deposits plus emulsion lubricants or soap solution
6. Dried soap film

Severe Operations:

1. Dried soap or wax film, with light rust, phosphate, or dissimilar metal coatings.
2. Sulfide or phosphate coatings plus emulsions with finely divided fillers and sometimes sulfurized oils
3. Emulsions or lubricants containing sulfur as combination filler and sulfide former
4. Oil-base sulfurized blends containing finely divided fillers

Drawing of Stainless Steel[1]

Mild Operations:

1. Corn oil or castor oil
2. Castor oil plus emulsified soap
3. Waxed or oiled paper

Medium Operations:

1. Powdered graphite suspension dried on work before operation (to be removed before annealing)
2. Filler bearing emulsion lubricant at heavy concentration
3. Solid wax films

Severe Operations:

1. Lithopone and boiled linseed oil
2. White lead and linseed oil to a heavy consistency

Drawing of Brass[1]

Mild Operations:

1. Soap solution (0.03 to 2 per cent high-titer soap)
2. Fat or oil emulsions with soap emulsifier
3. Lard-oil blends (10 to 20 per cent lard oil in mineral oil)

Medium Operations:

1. Soap solution. Soap should be high titer (39 to 42 per cent), fatty acids and free alkali should be less than 0.07 per cent. Solution should be low concentration (0.3 to 1.0 per cent), but lubricant should contact work at least 30 *sec*. Addition of about 1 per cent melted tallow and 0.25 per cent stearic acid to 1 to 2 per cent soap solution is desirable for medium to severe draws.
2. Fairly rich fatty-oil emulsions with soap emulsifiers. Free fatty acid in the paste base should be at least 2 per cent.
3. Lard-oil blends (25 to 50 per cent lard oil in mineral oil). Free fatty-acid content of the blend should be 1.5 to 5 per cent.

Severe Operations:

1. Soap solution of 1 to 2 per cent, containing 1 to 2 per cent tallow and/or 0.25 per cent stearic acid. Lubricant and work should be in contact longer than with less severe draws.
2. Rich lard-oil blends (50 to 100 per cent).
3. Dried soap properly applied.

In most instances, brass recommendations apply to copper, although copper welds more rapidly and requires more efficient lubrication than brass.

Drawing of Aluminum[1]

Mild Operations:

1. Mineral oil, increasing in viscosity as severity of operation increases
2. Fatty-oil blends in mineral oil (10 to 20 per cent fatty oil) or petroleum jelly

Medium Operations:

1. Tallow and paraffin
2. Sulfurized fatty-oil blends (10 to 15 per cent), preferably enriched with 10 per cent fatty oil

Severe Operations:

1. Dried soap film or wax films
2. Mineral-oil or fatty-oil blends or sulfurized-oil blends, plus finely divided fillers
3. Fat emulsions in soap water plus finely divided fillers

Drawing of Magnesium[1]

Mild Operations:

1. Graphite (usually colloidal) in mineral-oil diluent
2. Beeswax or paraffin and tallow

Medium Operations. Flake or colloidal graphite in a volatile solvent such as carbon tetrachloride, naphtha, or alcohol spread on the work and solvent-evaporated. Add 20 per cent graphite in tallow on the die.

Drawing of Zinc[2]

1. Neutral soap solutions
2. Soap coatings
3. Low free fatty-acid compounds
4. Light neutral oils

Drawing of Titanium and Zirconium.[4] Zinc phosphate coating plus a film of dried soap, wax, or molybdenum disulfide.

Drawing of Tantalum and Columbium.[4] Sulphonated tallow.

LUBRICANTS FOR STRETCH FORMING OF ALUMINUM[5]

Either emulsion- or oil-type drawing lubricants are suitable for cold *stretch forming* of aluminum. The emulsion types are usually made up from pigmented drawing compounds in order to secure the cushioning effects of the solid fillers. They may consist of talc, clay, carbonates, mica, chalk, etc.

Ordinary calcium-base greases, hard yellow naphtha soaps, and compounded heavy cylinder stock oils are also used for stretch forming aluminum over steel dies. Where the work metal is heated, say above 400°F, to facilitate forming, relatively inert lubricants must be used to lubricate and to prevent forming resinous gummy deposits on the work surface. Although hard yellow soap has been used for this purpose, graphite suspensions are more suitable for high-temperature forming despite the cleaning problem.

Where nonmetallic dies, such as plastic dies, are used for cold-forming aluminum, no lubricant is needed because of the low friction characteristics between the two materials.

Sometimes a rubber pad between die and work is used in stretch forming aluminum. The rubber pad stretches and moves with both metal surfaces to provide required cushioning and prevent metal-to-metal contact.

LUBRICANTS FOR RUBBER-PAD FORMING[1]

For rubber-pad-forming work, such as Marforming, the use of a soft neutral potassium soap, evenly applied to the work blank, has been found effective as lubricant. The soap may be applied by predip in a hot aqueous solution and drying, or by brush or spray application. If adequately neutral, neither too acid nor too alkaline, the soap will have no detrimental effects on the rubber pad. A blend of light mineral oil and neutral lard oil has also proved satisfactory for Marforming of both steel and aluminum at ambient temperatures.

LUBRICANTS FOR COLD EXTRUDING[1]

Both carbon and alloy steels can be cold-extruded, although by the effects of cold working on the metal, even low-alloy steels show remarkable physical properties when cold-extruded.

Lubrication consists essentially of two steps. *First*, a phosphate coating is applied to the slug or billet by the usual methods for such processing. This consists of spray or dip application in a hot (180 to 200°F) acid phosphatizing solution after the pieces have been degreased, pickled, and rinsed to secure a clean surface. The solid phosphate coating acts to prevent metal-to-metal contact during extrusion and also serves as a base for the subsequently applied lubricant.

Second, an aqueous, fatty-acid-type soap emulsion is used for the actual extrusion lubricant. Various substances have been tried in the course of development of the process, including sulfonated tallow, lard, chlorinated waxes, sodium stearate, and fatty-acid soaps. Application is by immersion in a dilute, hot (150°F) solution and drying to secure a thin, uniform, adherent coating adsorbed on the phosphate undercoat. This combination has proved quite successful in commercial application.

As a lubricant on aluminum, such substances as tallow, lanolin, and combinations of waxes, fatty acids, and soaps have been used successfully. Copper and brass are extruded with dried-on soap coatings, soap-fat compounds, beeswax, other wax combinations, tallow, and similar polar-type lubricants. Tin and lead are successfully extruded with hydrogenated cottonseed oil, zinc stearate, waxes, and wax-fatty-acid combinations.

Application of lubricants to the metal slugs is made by either tumbling the slugs and a quantity of lubricant in a drum, or by dip application in the heated fluid lubricant and then air drying. The important aspect in the application of these lubricants is to secure a thin uniform coating over the entire surface of the slug.

DRY-PROCESSED COATINGS

These coatings are coming rapidly into use because of their easy and economic application, freedom from messy conditions at the press, and easy handling and cleaning.

For *dry soap films*, stock or parts should be cleaned in degreasing solution, at about 190°F, rinsed at about 160 to 180°F, and the water-soluble soap solution applied at temperatures in the order of 180 to 200°F. For low production, dip coating may be most economic. For high production, roller coating is preferred for sheet and coil stock.

Wax or wax-fatty coatings for light to medium drawing, especially of nonferrous stock, may be applied by hot dipping at 120 to 150°F, by spraying the material hot, or by cold application in a solvent vehicle. In the last-named method, the vehicle needs to be flashed off, under safety precautions, leaving a dry coating.

Phosphate coatings are properly chemical immersion coatings (see Lubricants for Cold Extruding).

Graphite coatings are useful under high-temperature and heavy-unit-load conditions making it unfeasible to use water-base, oil-base, or other solid lubricants. Graphite has the disadvantage of difficult removal and is consequently used for drawing only when strictly necessary.

In either amorphous or low-ash-flake form, graphite may be used dry or in a vehicle such as an aqueous emulsion or in a volatile vehicle such as naphtha. When used for hot drawing, as in the case of magnesium, the vehicle is flashed off.

References

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SECTION 22

SAFETY IN PRESSWORKING*

SAFETY OF DIES

Limit Switches. Limit switches are used extensively to safeguard the die in case of misfeed or buckling of stock or failure to eject scrap or blank, and to check the position of parts in assembling dies.

In the progressive die in Fig. 22-1, strips of gilding metal and silver are fed crosswise into the die with automatic feeders. Assembly of a small silver slug into a dovetailed cavity in the gilding metal strip must be performed accurately at each stroke of the press. To prevent inaccurate feeding of the strips and misplacement of the silver slugs, probes on the ends of levers operating the limit switches inspect operations and either allow the press to continue or stop the press if the operations have not been completed. The hinge pads (*D*1, *D*2, *D*3, and *D*4)‡ are attached to the punch assembly (not shown) and support the actuating levers. There are two probes on the lever *D*5 which enter the silver strip to assure accurate advance and to check whether or not the

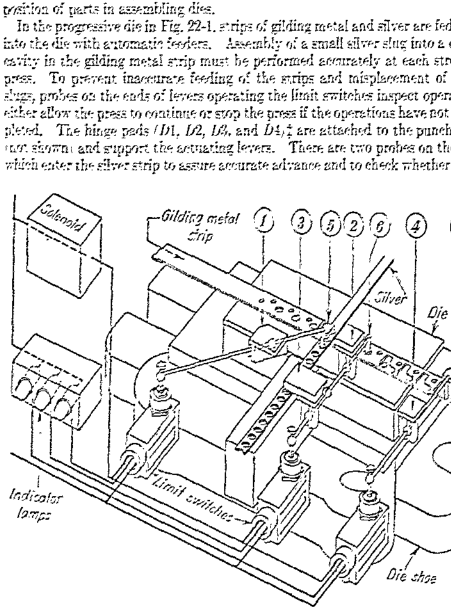


FIG. 22-1. Limit switches guarding progressive die.[1]†

* Reviewed by L. A. Faulkner, Supervisor, Industrial Plant Service, Liberty Mutual Insurance Companies.

† Superior numbers relate to References at the end of this section.

‡ *D* indicates detail number on drawing.

slug has been pushed out of the silver strip. The probe (*D6*) checks whether or not the silver slug is in the cavity in the gilding metal strip. The two probes on lever *D7* check the advance of the gilding metal strip and whether the blank has dropped out of the strip. The lever to which the probe *D6* is attached is jointed and flexes at the center so that the limit switch will remain closed when the probe is resting on the silver slug. Should the silver slug be missing, the end of the probe would assume a lower position, thereby opening the limit switch.

An example of limit switches used to detect misfeed is shown in Fig. 22-2. The lever (*D1*) is held by the tension spring (*D2*) against the limit switch (*D3*) until the stock is fed far enough to open the switch. As long as this switch is closed, the press cannot make another cycle. In case the stock is overfed, the arm opens a limit switch (*D4*), which also prevents the press from operating until the overfeed is corrected.

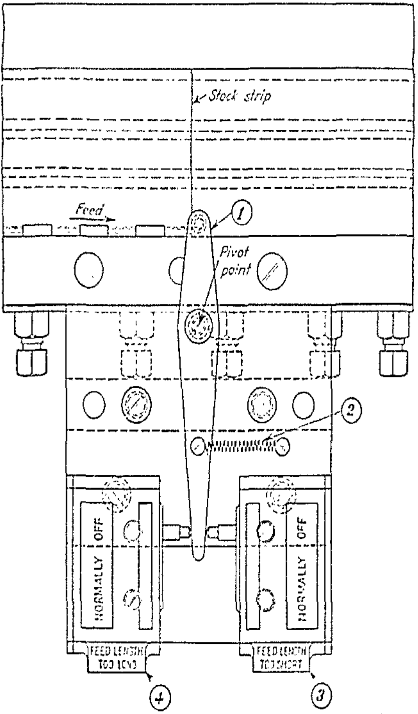


FIG. 22-2. Use of limit switches to indicate misfeed of stock.

Figure 22-3 shows another application of a limit switch to detect misfeed. In ordinary operation the pin (*D*1) acts as a pilot for the strip. In case of a misfeed or a broken punch, the pilot will not be able to enter the hole in the strip; therefore it will ascend and the tapered head will force the latch (*D*2) to slide outward, depressing the limit switch. The limit switch is wired into the control circuit of the machine and the opening of the switch stops the machine.

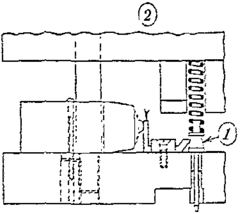


FIG. 22-3. Pilot pin operating a limit switch to detect misfeed. (*Eglinton Carbide Products Inc.*)

A limit switch or a safety stop shown in Fig. 22-4, depending upon the type of controls, can be used to stop tripping the press until a slide feed or a sliding die is in proper position. The bell crank (*D*1) remains under the collar (*D*2) on the trip rod until the pusher (*D*3) pivots the bell crank to enable the trip rod to travel downward. To make this safety stop operative, it is necessary to have a press equipped with an anti-repeat clutch control.

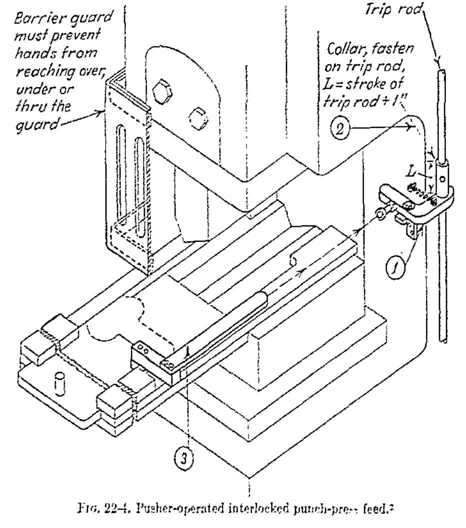


FIG. 22-4. Pusher-operated interlocked punch-press feed.[2]

Safety Stops. For proper protection when using a dial feed on a power press, an automatic positive safety stop should be employed. This safety stop can be either electrical or mechanical. A mechanical stop can be operated from the press shaft by a cam so arranged that, when the dial stops, a pin drops into a hole in the dial plate. As long as everything is functioning correctly, this pin drops into position, and the press continues to operate. If for any reason the dial does not position properly, the pin rests on top of the dial plate, placing a lever in the path of the clutch-release ring. This withdraws the clutch dog from the flywheel, and the press stops before the punches strike the dial plate. Every precaution should be taken to ensure that the clutch dog is withdrawn at the top of the stroke only, because the brake on a mechanical clutch press is seldom large enough to stop the ram when the crank is not on top center. If the crank coasts on down, the clutch may reengage and the press may attempt to complete its cycle. When the faults are corrected and the dial is moved to the proper location, the press is ready to continue operations. If dials are used to assemble parts, pins can be located to check for proper positioning of component parts to eliminate the possibility that the machine may continue to produce unfinished assemblies. If work is being done on a shell, the pins can determine if the right end is up. The incorrectly positioned part could be ejected or the press could be stopped for removal.

Ram Blocks. On all large presses where die-maintenance operations are necessary with the die in position on the press, blocks should be provided to be placed between the ram and bed of the press, since the possibilities of damage to dies and employee accidents are great. Blocks such as those shown in Fig. 22-5 may be provided for placement between the slide and bed of the press to protect a man working in that area setting up or repairing dies. The hardwood wedges are placed on the ram blocks to maintain a space of 4 to 5 in. between the bottom of the slide and the top of the ram block. When used on friction-drive machines, an electrical plug, which must be in its receptacle to complete the electrical control circuit, can be fastened to the block with a short piece of chain. The receptacle should be placed far enough from the press opening so that the block must be moved to a special location in order to insert the safety plug.

Instead of the above-mentioned plug, some plants insert a mushroom-head stop button in the top of the ram block. This stop button is the same type as installed in

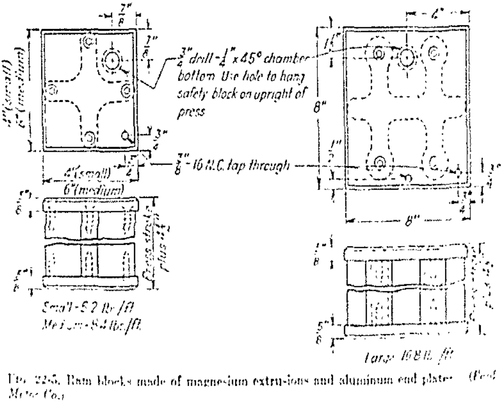


FIG. 22-5. Ram blocks made of magnesium extrusions and aluminum end plates. (Ford Motor Co.)

the control panel of the press. The stop button in the top of the ram block is wired into the existing stop-button circuit.

Locks. Locks on main electrical switches and push-button stations should be provided. Loops for a lock are usually provided on electrical switch boxes to lock them in an open position, and a bar or channel can be designed to lock in place over a group of push buttons. The levers on air and hydraulic valves should be locked in position to protect the setup man, the die, and the press.

Clamping. To prevent the possible shifting of the die shoe during the operation of the press, the die shoe should be securely clamped to the bolster plate. A layout of the bolster plate, tapped-hole pattern, would be an aid in selecting a die shoe with slots in a usable location. If it is necessary to use strap clamps, the hold-down bolt should be as close to the die shoe as possible (see Fig. 22-6). Self-adjusting die clamps are available, designed to provide maximum pressure on the die shoe.

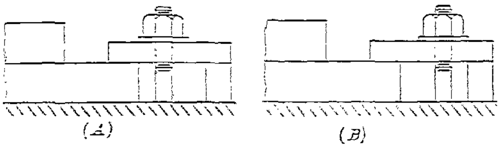


Fig. 22-6. Clamping of die shoe to bolster plate: (A) correct practice with bolt as close to lower shoe as possible; (B) incorrect practice with bolt too far away from lower shoe.

SAFETY OF OPERATORS

Several commercial safety devices are available to protect the press operator. Others can be built to suit the special requirements of the die.

Point-of-operation Guards. The point of operation of the press means the area where the stock is actually inserted or maintained during any processing operation. The following guards are available commercially or can be fabricated as the need may be.

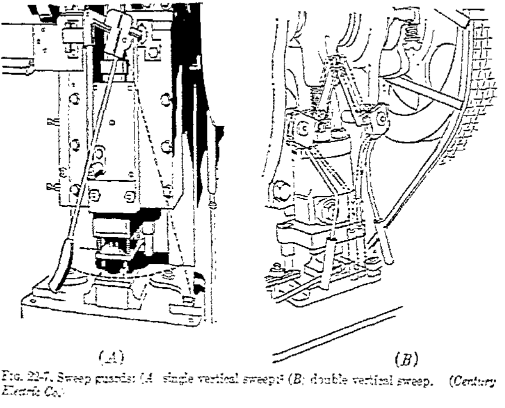


Fig. 22-7. Sweep guards: (A) single vertical sweep; (B) double vertical sweep. (*Century Electric Co.*)

Sweep guards are designed to push the operator's hands out of the danger area as the ram of the press descends. This can be accomplished by an arm pivoted to sweep across the front of the press as shown in Figs. 22-7, *A* and *B*. Another type of sweep guard (not shown) is the rotary plate type. This guard has a horizontal hinged plate extending the full width of the press opening. As the ram descends, a linkage or cam arrangement attached to the ram raises the plate into the vertical position, sweeping any object out of the danger area and at the same time guarding the front of the press. The sweep guard provides protection in case of accidental descent of the ram.

Gate guards are arranged so that the tripping mechanism of the press brings a barrier down in front of the die before the clutch can be tripped. In Fig. 22-8, the gate guard (*D*1) is pulled into position by the treadle rod (*D*2). The tripping angle arm (*D*3) engages the adjustable stop nuts (*D*4) threaded to the clutch trip rod (*D*5). Should the operator's hand or some other object be on the bolster plate and the gate guard be unable to reach the lowered position, the press will not be tripped. The gate guard shown is returned to position by counterweights (*D*6), but mechanical, hydraulic, or air devices can be used. This device offers no protection to the operator in case of press failure. This guard can also be adjusted to act as a stationary barrier for primary operations.

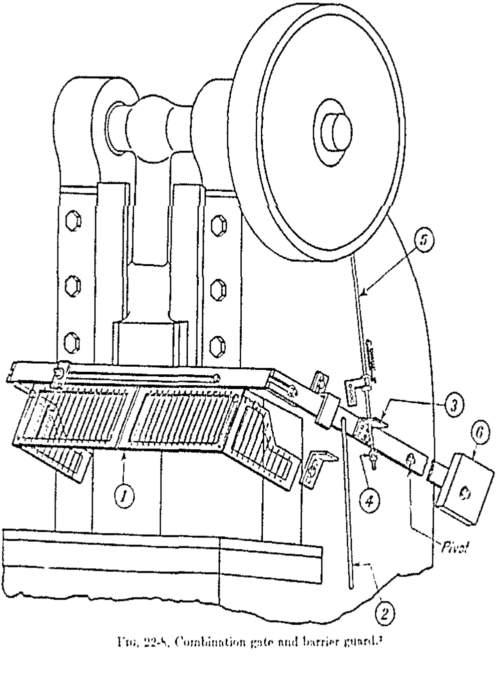


FIG. 22-8. Combination gate and barrier guard.[3]

The *pull-out guard* (Fig. 22-9) actually pulls the hands of the operator out of the danger area. The cables are attached to the ram of the press, running over a suitable framework and a series of pulleys to wristlets which are attached to the operator's wrists. The guard is properly adjusted to fit the operator, the die, and the stroke of the press. As the ram descends, the operator's hands are pulled from the danger area. This device also provides protection in case of accidental descent of the ram.

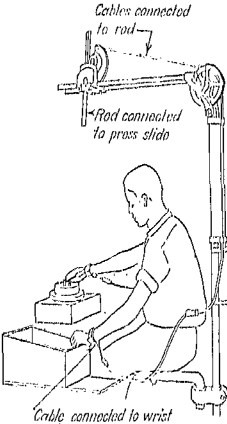


FIG. 22-9. Posson's guard applied to the press. (*The Positive Safety Mfg. Co.*)

Barrier guards can be divided into three groups: (1) fixed-barrier, (2) adjustable-barrier, and (3) interlocked-barrier.

The *fixed-barrier guards* are designed to be permanently attached to a die. They may be constructed of rods, slotted metal, or a transparent material mounted to a suitable framework. If constructed of slotted metal, the openings should be vertical slots, $\frac{5}{16}$ in. wide, to increase visibility and reduce operator's eyestrain. A maximum of $\frac{1}{4}$-in. clearance should be allowed between the fixed barrier and the movable parts. To use guards of this type, it is necessary to provide an opening for feeding, stripping, and ejection devices.

Figure 22-10, *A*, shows a fixed-barrier guard fastened to the die shoe and extending up to guard the punch holder which is the same length as the ram. When the die shoe is shorter than the ram and punch holder, an offset barrier guard may be constructed as shown in Fig. 22-10, *B*. If the punch holder and die shoe are the same length, but shorter than the ram, the guard may be constructed in two parts as shown in Fig. 22-10, *C*. One section is fastened to the die shoe and the other to the punch holder.

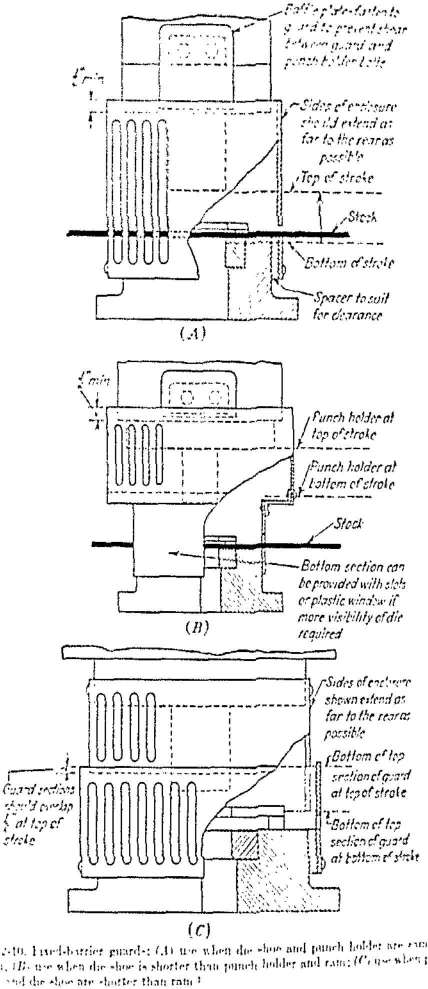


FIG. 22-10. Fixed-barrier guards: (A) use when die shoe and punch holder are same size as ram; (B) use when die shoe is shorter than punch holder and ram; (C) use when punch holder and die shoe are shorter than ram.

The safe opening dimensions for punch-press guards in reference to the shear point are shown in Fig. 22-11. In no case should the operator be able to insert his hands far enough for his fingers to enter the point-of-operation zone. The dimensions shown are such that this condition is impossible even though the guard contact is on the back of the fingers, hand, or forearm.

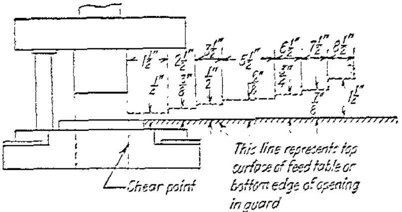


FIG. 22-11. Safe opening dimensions for punch-press guards.[4]

The *adjustable-barrier guards* are made with adjustable front and side panels of slotted metal or rods fastened to a framework, so that they can conveniently accommodate different sizes of dies and still provide the necessary protection. A suggested construction of an adjustable-barrier guard is shown in Fig. 22-12. The brackets (D1) can be fastened permanently to the press. The connecting links (D2) are used

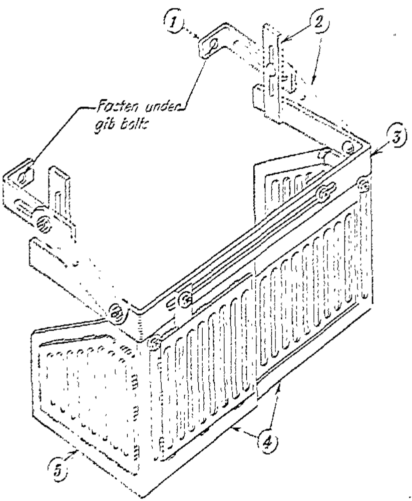


FIG. 22-12. Adjustable-barrier guard.[5]

to adjust the barrier to proper location. The front support bar (*D3*) is used to carry the two front sections (*D4*). The side sections (*D5*), fastened to *D4*, can be set at any desirable angle so that the operator can control his stock at a safe location from the danger zone. Washers with serrated faces should be used between the brackets (*D1*) and the connecting links (*D2*) to make a more rigid joint.

The *interlocked barrier* is so designed and built that, when the barrier is open, the press is inoperative. They are often used on automatic-feed setups that require the opening of the guard to relieve a jam or to repair a breakdown. Pins can be used to disconnect the clutch trip rod or a limit switch to open the electrical circuit of the controls. Figure 22-13 shows an interlocked barrier closed and the press made ready to run by placing the pin in the clutch trip rod. Before the barrier can be swung out of its protective position, the pin must be removed, disconnecting the clutch trip rod.

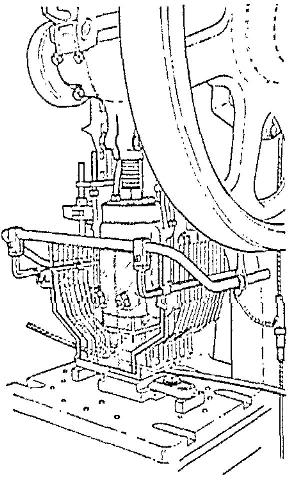


FIG. 22-13. Interlocked-barrier guard. (*Junkin Safety Appliance Co., Inc.*)

Spring for Punch Enclosure. A conical spring for enclosing a piercing punch which, because of the stroke of the press, is withdrawn from the stripper attached to the die is shown in Fig. 22-14. The spring telescopes and requires less space in the closed position than a straight spring. To avoid pinching fingers, the space between the coils in the open position should be a maximum of $^5/_{16}$ in.

Photoelectric Devices. A photoelectric or selenium safety device has a source of light rays, a light receiver, and other electronic control equipment. The light rays are projected to surround the danger area. When the operator's hand or any part of his body is in the danger area, interrupting the light beam, the press cannot be tripped. If the hand or any part of his body interrupts the light beam while the slide is in motion, the press will be stopped immediately. These devices should not be used on positive-clutch presses where the ram continues for a complete stroke after each tripping of the press.

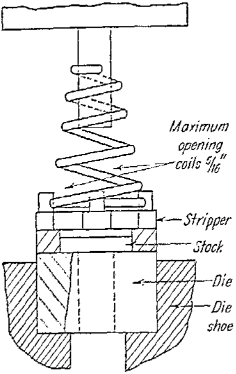


FIG. 22-14. Conical spring enclosure for piercing punch.[2]

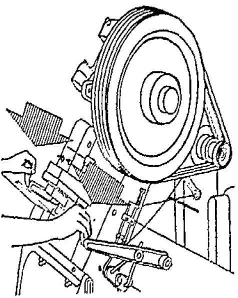


FIG. 22-15. Two-hand tripping device. *(Benjamin Electric Mfg. Co.)*

Two-hand Devices. Two-hand tripping devices are so designed to require the simultaneous use of both hands to trip the press. They also should be designed so that, should one of the buttons be locked in closed position, the press will not operate. The device should be located in such a position or guarded in such a manner that the operator cannot trip the press with his arm or other object while his hand is in the danger area. On friction-clutch-operated presses, the controls should be interlocked *so that, should one of the buttons be released, the descent of the ram would be stopped* instantly. When two or more operators are employed on a press, separate two-hand controls should be provided for each operator. Two-hand tripping devices are available commercially operated by air, hydraulic, electrical, or mechanical means. Figure 22-15 shows a two-hand trip device. Two-hand tripping devices also apply to some types of foot-press operations.

Treadle Guards. Treadle guards should be installed on all foot-operated power presses to prevent accidental tripping of the presses. The guard, except on presses having long treadle bars, should have an opening not more than twice the width of the foot.

Feed Mechanisms. The safety feature of a feeding device is to provide a means of moving the part into the nest by gravity or mechanical motion so that there is no necessity for the operator to place his hands in the danger zone. High-speed presses equipped with automatic feeds operate at such speeds that it would be impractical as well as hazardous for an operator to attempt to feed the stock into the die. Semi-automatic feeds can be simple devices attached to existing dies or incorporated into the design of new dies for the safety of the operator. Small dies may be mounted on a pivot or slide so that they can be moved out from under the punch for nesting and removal of parts. See Sec. 19 for practical designs of feeding and unloading devices in common use.

Limited Stroke. On kick and foot presses it is often possible to minimize finger injuries by adjusting the stroke so as to allow 5/16-in. (maximum) opening between the punch and stripper or die in the "up" position.

Pulley Guards. All belts, pulleys, gears, and shafts which are exposed should be protected by guards. Many states have safety codes which govern the construction of these guards. Figure 22-16 shows the construction of a guard for a flywheel, belt, and motor pulley. The guard shown is made with an angle-iron frame and an expanded metal front panel with a solid outer panel and back panel. A hinged door provides access to the flywheel when setting dies.

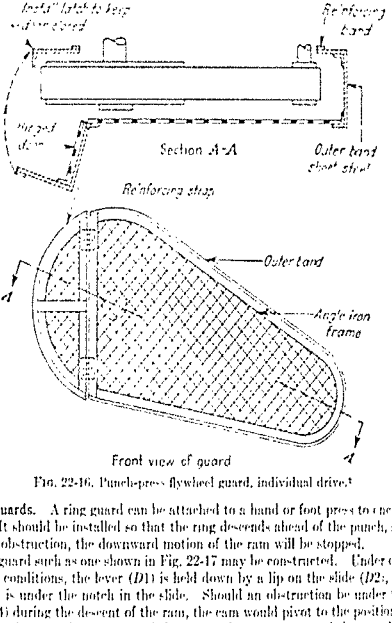


FIG. 22-16. Punch-press flywheel guard, individual drive.[5]

Ring Guards. A ring guard can be attached to a hand or foot press to encircle the punch. It should be installed so that the ring descends ahead of the punch, and if it meets an obstruction, the downward motion of the ram will be stopped.

A ring guard such as one shown in Fig. 22-17 may be constructed. Under ordinary operating conditions, the lever (*D*1) is held down by a lip on the slide (*D*2), and the cam (*D*3) is under the notch in the slide. Should an obstruction be under the ring guard (*D*4) during the descent of the ram, the cam would pivot to the position shown by a slight downward movement of the ram and no movement of the guard and its support which is beneath the cam. This pivoting action moves the slide outward releasing the lever. As the lever is released, a tension spring, fastened to the lever near its pivot point and to the pawl (*D*5), pulls the pawl into contact with the ratchet (*D*6), stopping the motion of the press. In the operating position this pawl is held up off the ratchet by a pin pressed into the pawl and riding in the slot on the left end of the lever. This device must be reset to the latched position to enable further operation of the press.

Sheet Separators. A shielded-handle knife or a magnetic sheet floater can add to the safety of an operator in removing large blanks or sheets from a stack.

The magnetic sheet floater shown in Fig. 22-18 uses two or more permanent magnets. Induction causes a few of the top steel sheets to assume the polarity of the poles of the magnets and, as a result, the oppositely magnetized sheets repel each other and separate enough to facilitate their removal.

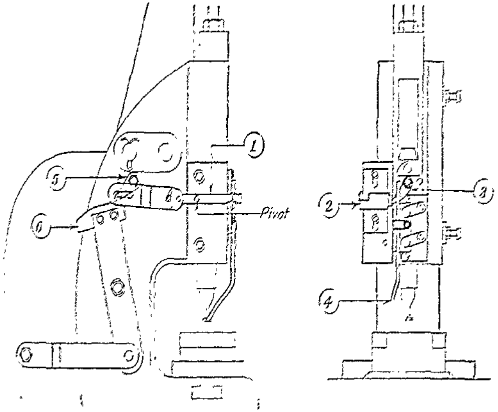


FIG. 22-17. Ring guard for kick or foot press.[3]

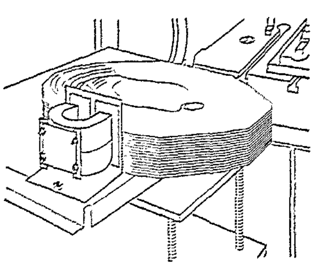
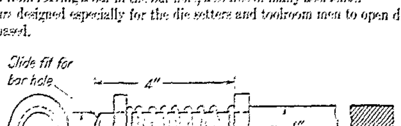


FIG. 22-18. Magnetic sheet floater.

Setup Tools. A spring-fitted turnover bar, as shown in Fig. 22-19, will prevent the die setter from leaving a bar in the bar hole, a source of many accidents.

Pry bars designed especially for the die setters and toolroom men to open dies may be purchased.



Type *A*

FIG. 22-19. Spring-fitted turnover bar.[4]

Single-stroke Devices. Single-stroke or nonrepeat devices are available from most manufacturers of punch-press equipment and some manufacturers of safety devices. These devices are designed to limit the press to one stroke, should the operator's foot remain on the treadle too long. Figure 22-20 shows the device in latched position, as the operator depresses the treadle at the end of the trip rod (*D*1), which pulls the slide (*D*2) and latch (*D*3) downward and trips the clutch. As the ram reaches the bottom of the stroke, the cam (*D*4) contacts the follower (*D*5), which releases the latch from the upper portion of the trip rod (*D*6). Another stroke cannot be started until the treadle is released, allowing the slide (*D*2) to ascend and the latch (*D*3) to reset in operating position. The type shown is one type of a mechanical single-stroke device. Electromechanical devices are also available.

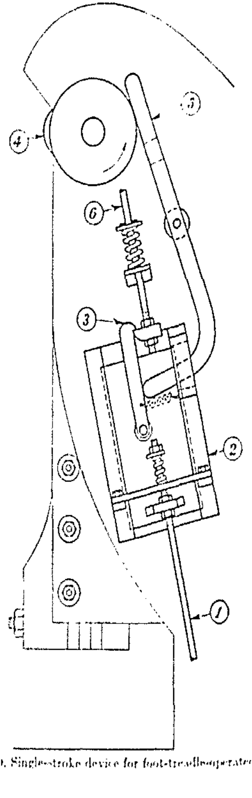


FIG. 22-20. Single-stroke device for foot-treadle-operated clutch.[3]

Hand Tools. The use of hand-loading tools is recommended for loading and unloading a die where it is necessary to reach into the die opening to position the parts to be processed properly. Shown in Fig. 22-21 are some types of commercial hand tools available. A soft-wood dowel is useful in pushing parts and scrap around in a die. Many of these hand tools are made from soft aluminum so that, if the operator accidentally leaves them in the die when the press is tripped, the die is not likely to be damaged.

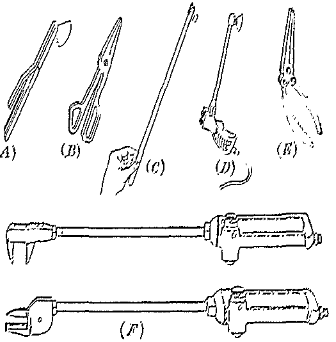


FIG. 22-21. Hand tools: (A) vacuum lifter; (B) special pliers; (C) magnetic pickup; (D) air-line vacuum pickup; (E) adjustable-nose pliers;[4] (F) air-actuated jaws.

References

1. Enzler, P. R.: Precision Switches Guard Progressive Die, *Am. Machinist*, Apr. 21, 1949.
2. Published data of the Liberty Mutual Insurance Co.
3. "Power Press Point of Operation Protection," Employers Mutual Liability Insurance Co. of Wisconsin, *Bull.* E-540.
4. "Power Presses and Foot and Hand Presses," B11.1-1948, American Standards Association.
5. Faulkner, L. A.: Don't Overlook Operator Safety in Press-tool Design, *Am. Machinist*, Sept. 1, 1952.

SECTION 23

PRESS DATA*

Presses must be capable of exerting pressure in the amount, location, direction, and for the period of time needed to accomplish a specific operation. The machines frequently are required to exert not one but several pressures for various intervals of time. They must coordinate these pressures for the purposes of holding the stock, cutting, trimming, and forming the part, and then for releasing and ejecting the finished part. Automatic means for feeding blanks and material and ejecting the finished parts are often incorporated in presses (see Sec. 19).

PRESS CLASSIFICATION

Presses are classified by one or a combination of some of the following characteristics which include source of power, method of actuation of slides, number of slides incorporated, frame type, bed type, and their intended use. Table 23-1 lists the common types of presses and the features available in each type.

SOURCE OF POWER

The source of power for presses is either manual, mechanical, or hydraulic.

Manual. These presses are either hand- or foot-powered through levers, screws, or gears. The most common press of this type is the bench-type arbor press. Frequently these presses are converted to power presses by the addition of air or hydraulic cylinders.

Mechanical. There are three major types of mechanical press drives. These are the nongeared or flywheel type, single-reduction-gear type and multiple-reduction-gear type, which are illustrated schematically in Fig. 23-1. In all three types a flywheel stores energy. The source of power is a motor which returns the flywheel to operating speed between strokes. The permissible slowdown of the flywheel during the work period is about 7 to 10 per cent in nongeared presses and 10 to 20 per cent in geared presses.

The flywheel-type drive (Fig. 23-1, *A*) transmits the energy of the flywheel to the main shaft of the press. The main shaft may be mounted right to left (parallel to the front of the press) with the flywheel on either side, or the shaft may be mounted front to back (at right angles to the front) with the flywheel in the back. Flywheel or nongeared presses are generally applicable to light blanking, small high-speed progressive dies, or other light high-speed operations.

The single-reduction-gear drive (Fig. 23-1, *B* and *C*) transmits the energy of the flywheel to the main shaft through one gear reduction and is recommended for heavier blanking operations or shallow drawing. This drive operates a press at speeds of approximately 30 to 40 strokes per minute and in some high-speed presses up to 150 strokes per minute.

The multiple-gear drive (Fig. 23-1, *D*) transmits the energy of the flywheel to the main shaft through two or more gear reductions. These reductions reduce the

* Reviewed by J. C. Danly, Chief Engineer, Danly Machine Specialties, Inc.; John Vernon, Vernon Allsteel Press Co.; Albert Clements, Vice-President, Hamilton Division, Clearing Machine Corp.; N. J. Kirk, Vice-President, and William Staecker, Chief Engineer, Canton Division of E. W. Bliss Co.

strokes per minute of the slide without reducing the flywheel speed. Large presses with heavy slides use a multiple-gear drive since it is impractical to accelerate and decelerate large amounts of mass at high speeds. Dependent upon the tonnage capacity of the press and the length of its stroke, speeds normally range from 8 to 2[illegible] strokes per minute, although designs are available which have a speed up to 50 strokes per minute.

Whether the press is single- or multiple-geared, energy can be transmitted to the main shaft from one or two gears on each shaft. They are respectively called single- or twin-drive presses, according to the use of one or two pairs of gears on each shaft to transmit the energy (Fig. 23-1, *B* and *C*). The twin-drive arrangement is used to

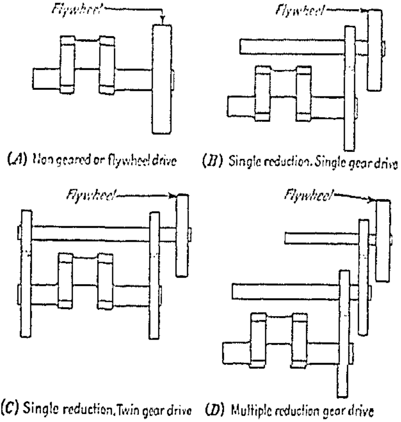


Fig. 23-1. Types of mechanical press drives.

reduce the torsional strain on the shaft since it applies power to both sides of the point of resistance. Crank presses of low tonnage capacities, short stroke, and a narrow span of the main shaft from bearing to bearing are generally not twin-driven. The shaft on these presses is not subjected to so great a torsional stress as the shaft on presses with a greater span. It is advisable to twin-drive long-stroke presses, whether or not they have a short or long span between the bearing housings.

Most presses are of the top-drive type in which the driving mechanism is located in the crown and pushes the slide down to perform the operation. The underdrive type has the mechanism under the bed with connecting linkage in the uprights to pull the slide downward. The mechanisms of the large underdrive presses are below the floor level, thus requiring a minimum of headroom above the production floor, but either a basement or trench-type pit is required to service them. Machine repair does not result in obstruction of the production floor.

Hydraulic. Water or oil pressure in a cylinder with a closed end reacting against a piston moves the slide in this type of power source. A pump supplies the pressure to the cylinder. Hydraulic mechanisms are capable of maintaining constant pressure and speed throughout the entire stroke or of exerting maximum pressure at any desired point within the limits of slide travel and press capacity.

The modern self-contained hydraulic presses have their own pump, motor, and

TABLE 23-1. TYPES AND FEATURES OF PRESSES

	Frame type							Frame position				Action			Method of actuation								Drive				Suspension				Ram		Bed		
	Open back	Gap	Straight-sided	Arch	Pillar	Solid	Tie rod	Vertical	Horizontal	Inclinable	Inclined	Single	Double	Triple	Crank	Front-to-back crank	Eccentric	Toggle	Screw	Cam	Rack and pinion	Piston	Over direct	Geared	Under direct	Geared	1 point	2 point	3 point	4 point	Single	Multiple	Solid	Open	Adjustable
Bench-type press	x	x				x		x		x	x	x			x		x						x				x				x		x	x	x
O. B. inclinable press	x	x				x		x		x		x	x		x		x			x			x	x			x	x			x	x		x	
Gap-frame press	x	x				x		x		x	x	x			x	x	x					x	x	x			x	x	x	x	x		x	x	
Adjustable bed-horn press		x				x		x				x			x		x					x	x	x			x	x			x				x
End-wheel-type press		x				x		x				x				x	x						x	x			x				x		x	x	
Arch-frame press			x	x		x		x			x	x			x								x	x			x				x			x	
Straight-sided press			x	x		x	x	x			x	x			x		x				x	x	x	x	x	x	x	x		x	x		x	x	
Reducing press			x			x	x	x	x			x			x							x	x	x			x				x			x	
Knuckle-joint press			x			x	x	x			x	x						x						x			x				x		x		
Toggle-draw press			x			x	x	x					x	x	x		x	x						x		x	x	x		x		x		x	
Cam-drawing press	x	x	x			x	x			x			x		x					x				x			x					x		x	
Two-point single-action press		x	x			x	x	x			x	x				x		x						x		x		x			x		x	x	
High-production press			x				x	x			x	x			x		x						x				x	x			x			x	
Dieing machine					x			x				x			x								x				x				x			x	
Transfer press			x				x	x				x			x	x	x							x				x			x			x	
Flat-edge trimming press				x				x					x							x				x							x				
Hydraulic		x	x		x			x				x	x	x								x					x	x			x	x	x	x	x

hydraulic system. No provision is made for the storage of energy; therefore all the energy is applied directly to the cylinders by the pump and motor which must be large enough to take care of the peak-load requirements of the press. The draw speed of the press is directly proportional to the size of the motor and pump. The tonnage capacity is dependent upon the cross-sectional area of the piston or pistons and the pressure in psi developed by the pump.

A few large presses use an accumulator system to supply the energy. Such a system is capable of supplying a large volume of hydraulic fluid at a relatively constant pressure in a short time. This type of system requires smaller volume capacity pumps than direct-connected systems since the pumps can recharge the accumulator during the idle period of the press cycle. The time required for loading and unloading dies is determined by the recharging-time requirements.

METHOD OF ACTUATION OF SLIDES

In all power presses the work is performed by the slide or slides through reciprocating motion to and from the press bed or bolster. In mechanical presses, slide motion originates from:

1. Crankshafts incorporating crankpins or eccentrics
2. Eccentrics cast or welded integrally with or bolted to rotating main gears
3. A pair of knuckles folded and straightened out by a pitman-crankpin mechanism
4. Oscillating rocker shafts and toggles

Main Shafts. *Main shafts in single-action presses of the nongeared type are of conventional crank, semieccentric, or full-eccentric design.* The number of throws or eccentrics on the shaft is determined by the number of points of suspension of the slide. Points of suspension are the number of places where pressure is transmitted by connections to the slide. Press connections, called connecting rods or pitmans, are usually adjustable in length so that the shut height of the press can be varied.

The single-point suspension is used in presses with relatively narrow widths between the uprights or with narrow slides. Two-point-suspension presses have connections on each end of the slide. The slides are wide right to left but shallow front to back to accommodate long but relatively narrow dies.

Four-point-suspension presses have connections on each corner of the press slide. These presses can accommodate work in wide (right to left) and deep (front to back) dies, especially when loads are distributed unsymmetrically. The recommended load on any one corner is not more than 30 per cent of the rated tonnage of the press.

Eccentric Gear. Eccentric-gear presses incorporate a slide actuated by an eccentric cast or welded integrally with, or keyed and bolted to, the main gears. The gear eccentric is mounted on either a rotating or nonrotating shaft which is sometimes used as a power take-off for auxiliary equipment. Torsional stresses are not present in shafts of eccentrically driven presses as they are in those of crankshaft-driven presses.

Knuckle Joint. Presses employing knuckle joints develop tremendous pressures near the bottom of the stroke. They are often used for compression operations requiring high pressures during a short portion of the stroke. The force is applied through a crank or eccentric to the joint connecting two levers of equal lengths. The levers are actuated through a nonadjustable connection from the shaft in the back of the press frame. The slide motion is achieved through the straightening of the two hinged levers which suspends the slide from the crown.

Toggles. A crank or eccentric actuates a series of levers linked in tandem in a sequence of movements through two or more dead-center positions or dissipating points. These are spaced at closely related intervals to accomplish an effective dwell of the holding member. In the toggle mechanism the force is always exerted against one end of a series of levers but should not be confused with the knuckle-joint motion.

Toggle action is widely used in double-action presses to obtain the proper stroke characteristics for the blankholder. Figure 23-2 shows that the reciprocating speed of the toggle-driven slide is faster than and dwells longer than the crank-driven slide. The curve of the knuckle-joint action shows a shorter degree of dwell than the toggle action.

Cams. Cams are utilized to produce motions at angles and in planes not obtainable from simple crankshaft mechanisms. The motions of cams, cranks, and eccentrics are frequently combined, as on single- and multiple-action presses where one or more dwells or certain hold-down or stripping motions are required. The double-action cam press essentially embodies the same motions as the double-action toggle press but can generally be operated at higher speeds. They are usually limited to lower tonnage presses of relatively narrow widths and are primarily used for blanking and cupping operations.

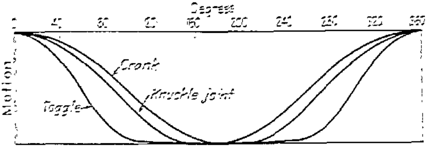


FIG. 23-2. Curve showing relative motions and degree of dwell imparted by crank, knuckle-joint, and toggle action.[2*]

Drag Link. A drag-link mechanism on a press will produce a relatively slow drawing motion with a connection for faster return of the slide. The resulting draw stroke in this type of drive is practically of uniform velocity. It is adaptable for reducing long shells at a maximum and nearly uniform speed and for broaching and burnishing.

NUMBER OF SLIDES IN ACTION

The classification of a press also includes the number of slides incorporated in the press such as single-, double-, or triple-action presses.

Single Action. A single-action press is one which has only one slide.

Double Action. A double-action press is one which has two slides. This type of press is usually used for drawing operations during which the outer slide carries the blankholder and the inner slide carries the punch. The outer or blankholder slide, usually having a shorter stroke than the inner or punch-holder slide, dwells to hold the

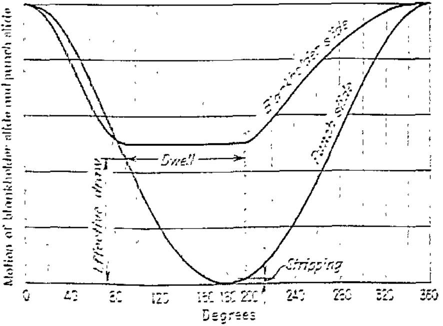


FIG. 23-3. Relation between motions of the blankholder or outer slide and the inner slide or plunger of a double-action press.[2]

* Superior numbers relate to References at the end of this section.

blank while the inner slide continues to descend, carrying the draw punch to perform the drawing operation. The relative motions between the inner and outer slides are illustrated in Fig. 23-5.

Triple Action. A triple-action press incorporates three slides having three motions properly synchronized for triple-action drawing, redrawing, and forming. Two slides, the blankholder (outer) and plunger (inner) slides are located above, and a lower slide is located within the bed. The inner slide develops a small amount of dwell at the bottom of its stroke. The blankholder slide usually has slightly more dwell than that found on a comparable double-action press. The lower slide is usually actuated by an eccentric or a crank. The lower slide mechanism itself as a rule develops a long stroke, but only during the very top portion of the stroke is force transmitted to the lower slide. This is accomplished by limiting the motion of the pressure pin plate and the traveling of the lower slide down from the pin plate proper. Present-day practice is to synchronize the lower slide motion mechanically with the upper slide motions, although separately driven lower motions, electrically interlocked to the upper motions, are often used.

PRESS FRAMES

Power press frames can be broadly classified into two general types, gap frame or C frame and straight side.

Gap Frame. As seen from the side, the housings of a gap-frame press are cut back below the gibs to form the shape of a letter C. This permits feeding of wide strip from the side, or large sheets. Gap-frame presses have a solid back or an open back to permit feeding from front to back or the ejection of finished parts out the back. Open-back frame presses have frames that are in a fixed vertical position or in a fixed inclined position or a frame that can be inclined. The inclined positions permit finished parts to fall out by gravity or to be blown out by air at the rear of the machine. Open-back frame presses have the flywheel and gearing, if any, at either the right or left side of the press. The flywheel and gearing on a solid-back press are available on either the side or the back of the press.

Straight Side. This type of press incorporates a slide which travels downward between two straight sides or housings. The frame construction consists of a base, bed, housings, and crown. The frame may be cast or welded in one piece or the individual parts may be joined by steel tie rods. These presses are used for heavy work but the size of the work is limited by the left-to-right distance between the housings and the work must be fed into the die from front to back. Side-to-side feeding may be achieved if there are openings in the housings.

PRESS CLUTCHES AND BRAKES

Clutches. Timing and control of the intermittent reciprocating movement of the slide in a mechanical power press are provided by a clutch. The clutch is inserted between the flywheel and the drive mechanism. The flywheel rotates continuously, and engagement of the clutch causes the drive shaft to rotate and start the slide on its working stroke. As soon as the stroke is completed, the clutch is automatically disengaged and the brake applied unless the press is set for continuous operation.

Types of press clutches and their application are listed in Table 23-2. They are divided into three major groups:

1. Positive clutches, in which the driven and driving members of the clutch are interlocked in engagement
2. Friction clutches
3. Eddy-current clutches, in which the driven member is caused to follow the driving member by the attraction of two induced magnetic fields

The slide of a press having a positive clutch is usually stopped at its upper position. Lowering (inching) or backing up (lifting) of the slide during the die setting must be done by turning the flywheel or main gear by hand, chain block, or a hand bar passed through the eye of the crankshaft. Many flywheel-type presses (nongeared) have bar holes provided in the rim of the flywheel into which an inching bar may be placed.

for turning the press. Presses with friction clutches allow the slides to be stopped, started, or reversed at any point in the stroke. This feature is convenient for setting and adjusting dies, especially in large presses. Modern air-friction clutches are usually considered safer than positive clutches. A well-designed air-friction clutch is a "fail-safe" mechanism wherein sudden power or air failure will result in the press stopping immediately. Friction clutches using high-pressure oil or magnetic attraction have been employed to some degree. Presses equipped with eddy-current clutches can be started, stopped, and reversed with variable torsional forces; they can be used in larger-sized presses (500 tons and over). They have no friction surfaces or mechanical connections between driver and driven members resulting in long maintenance-free operation. They may be cycled rapidly without serious effects—one of the great limitations of air-friction clutches. With special electronic controls, these

TABLE 23-2. CLASSIFICATION OF PRESS CLUTCHES[a]

Clutch: Group	Clutch: Construction	Crankshaft diam. (up to), in.	Driving-wheel speed, rpm	Drive: Fly-wheel	Drive: Single-geared	Drive: Multiple-geared	Smoothness of engagement*	Repairability by shop maintenance crew
Positive	Sliding-pin	4.5	125	Yes	Yes	No	D	Yes
	Rolling-key	6	150	Yes	Yes	No	C	No
	Sliding-key	5.5	150	Yes	Yes	No	C	Yes†
	Multiple-jaw	6.5	200	Yes	Yes	No	D	No
Friction	Multiple-disk	From 6.5	Up to 650	Yes	Yes	Yes	B	Yes†
	Drum	....	....	No	Yes	Yes	B	Yes†
Special	Air-tube, friction	....	....	Yes	Yes	Yes	B	No
	Eddy-current	....	500	No	No	Yes	A	Yes†

* Smoothness: A, excellent; B, good; C, fair; D, jolting.
† Requires well-equipped repair shop.

clutches can operate under varying degrees of slip resulting in slow draw and fast return motions of the slide.

Brakes. Because of the inertia of the press components which either slide or rotate during the press stroke, a brake is required to stop the slide after the clutch has been disengaged. Brakes in the presses with positive clutches are placed on the outer crankshaft end, opposite to the drive-wheel end. They are, as a rule, a continuous-acting type with a yoke, band, or double-shoe construction. Brakes in presses with friction clutches are single- or multiple-disk or drum type, are interlocked with the clutches, and work only when the clutches are disengaged. Eddy-current-type clutches provide dynamic braking within the clutch unit proper. A supplementary holding brake is required to hold the press in position when the rotation has been stopped. Ineffective brake or clutch action (in hand-fed presses, normally single-stroked) such as an accidental "repeat" can be hazardous to dies, press equipment, and operator.

DIE CUSHIONS

When a single-action press is used for drawing operations, the manner in which pressure is applied to the blankholder to control the flow of the metal blank is important. The application of pressure to a blankholder is one of the features of a double-action press, and the mechanism sustains a fairly constant pressure throughout the stroke. Single-action presses lack this feature and therefore require supplementary blankholding equipment.

Dies are sometimes built with a blankholder using compression springs or pieces of rubber to supply the holding pressure. The pressure exerted by compression springs increases as they are depressed, and in order to obtain a relatively small increase in pressure during the stroke of the die, extremely long springs are required. On shallow draws the pressure increase due to the compression of the springs usually does not affect the quality of the work piece. On deep draws the increase in blankholder pressure and the decrease of flange area under the blankholder result in an increase in the pressure per square inch on the flange or binder stock. This may cause the blank to be gripped so tightly that the pressure required to pull it into the die is greater than the strength of the material, resulting in fracture.

The most common types of pressure-control mediums for single-action-press drawing operations are the pneumatic and hydropneumatic die cushions.

The recommended capacity of a die cushion is about 15 to 20 per cent of the rated press tonnage. The size of the press-bed opening limits the size, type, and capacity of the cushion.

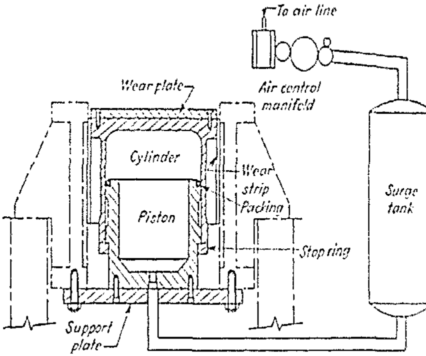


FIG. 23-4. Schematic diagram of a pneumatic die cushion.[a]

Pneumatic Die Cushion. This type of die cushion is recommended when air pressure of not more than 100 psi is required. A pneumatic-die-cushion design normally uses one piston and cylinder. However, two or more cushions may be placed on top of one another should a high-capacity cushion be required in a limited bed area where vertical space is available. A multiple die cushion is often preferable to a hydropneumatic die cushion because of the speed restrictions of the latter.

A schematic arrangement of a pneumatic die cushion is shown in Fig. 23-4. This illustration shows an inverted-type cushion in which the downward movement of the blankholder, through pressure pins, forces the cylinder against a cushion of air inside the cylinder, and moves the air back into the surge tank. On the upstroke, the air in the surge tank returns the cylinder. Other designs function without surge tanks.

Die cushions are often used in double-action presses to keep the bottom of the stamping flat or to hold it to shape or to prevent distortion and slippage while drawing. They are also used to actuate liftout rods or plates to push the finished drawn part out of the die cavity.

The removal of scrap through the bolster on presses equipped with die cushions is aided by using the special arrangements shown in Fig. 23-5. View *A* shows a special stool which may be installed on top of the cushion to allow the slugs to fall out the side of the press. The slug tube shown in view *B* allows smaller pieces of scrap to fall straight through the press.

Hydropneumatic Die Cushions. These die cushions are recommended where the capacity required is greater than can be obtained with 100 psi air pressure on a piston matic cushion. Hydropneumatic cushions are slower acting than the pneumatic cushions; therefore they are usually used on the larger and slower presses. They can be adjusted to hold a large light blank for deep drawing or shallow forming, or to grip heavy-gage material as tightly as required for curved-surface or flat-bottom forming.

The hydropneumatic cushion is connected to a surge tank as shown in Fig. 23-6. Two individually controlled air lines are required, one to the operating valve of the

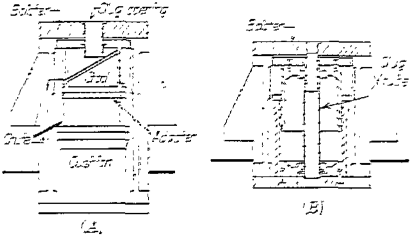


FIG. 23-5. Arrangements for scrap disposal on presses equipped with die cushions: (A) scrap disposal through side of press; (B) scrap to drop straight through the press.

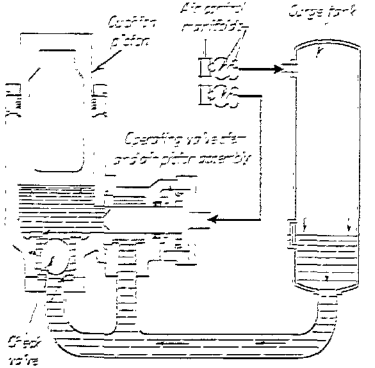


FIG. 23-6. Schematic diagram of a hydropneumatic die cushion.

cushion and one to the top of the surge tank. The air pressure to the operating valve determines the tonnage capacity of the cushion on the downstroke. The pressure of the air in the surge tank determines the number of tons of stripping force available on the upstroke. The surge tank may be separate from, or integral with, the cushion, depending upon the space available beneath the press bed.

The pressure of the air in the surge tank is transmitted to the hydraulic fluid, which is free to pass upward through the check valve and force the cushion piston upward. Pressure is also exerted against the face of the operating valve stem, but it is not sufficient to overcome the opposing air pressure working on the operating air piston.

When a downward force is applied to the cushion, the check valve is immediately closed and the pressure of the fluid trapped beneath the piston begins to rise. When the pressure against the small face of the operating valve stem reaches a predetermined point, it will exceed the magnitude of the air pressure on the larger area of the air piston and will open the operating valve. As long as the cushion piston continues its downward movement, the fluid beneath it is maintained under constant pressure by the throttling action of the operating valve; the additional fluid replaced by the piston is forced through the valve to the surge tank.

When the stroke has been completed, and the downward force on the cushion piston is removed, the pressure of the fluid beneath the piston immediately is lessened, which reduces the air pressure on the air piston which then closes the operating valve. Fluid *from the surge tank under pressure from the air behind it passes upward through the* check valve and raises the cushion piston to top stroke.

The use of hydropneumatic cushions is limited to slow operating speeds. Where long cushion strokes are required, slow operating speeds must be used. Conversely, faster operating speeds can be used only with very short strokes. If the cushion is operated at high speed, the operating valve will be forced open too rapidly, causing the air piston to strike the end of its travel. The piston will bounce back and will oscillate rapidly with a series of extremely hard hammer blows. This will result in unsatisfactory operation and damage to the operating valve.

The following equations may be used for determining the amount of air pressure required to obtain a certain cushion capacity. These equations do not take into consideration friction or loss of air pressure due to the length of piping.

For pneumatic cushions and stripping pressure on hydropneumatic cushions,

$$p = \frac{P}{A_1}$$

For hydropneumatic cushions,

$$p = \frac{PA_3}{A_1A_2}$$

where p = air pressure, psi
P = *cushion capacity, lb*
A_1 = area, cushion piston, in.
A_2 = area, operating air piston, in.
A_3 = area, operating valve stem face, in.

Locking Devices for Die Cushions. A locking device is a hydraulic unit which controls and delays the stripping action of pneumatic and hydropneumatic die cushions by delaying the upstroke of the cushion with respect to the upstroke of the press slide. The net result prevents the damaging of a drawn shell which otherwise might occur if the cushion were permitted to exert pressure on the shell during the upstroke of the press.

A typical installation of a hydropneumatic cushion with a hydraulic locking device and control is shown in Fig. 23-7. The installation and control of the locking unit to a pneumatic cushion are very similar. The locking cylinder is attached to the lower end of the die cushion and the piston rod is extended to receive the locking cylinder piston. The downward motion of the die cushion forces the fluid out of the lower portion of the locking cylinder into the upper portion. The air-actuated operating cylinder retains this fluid until the proper time for the die cushion to return to its up position. Timing of the cycle of the locking device is accomplished by the press rotary limit switch which actuates a solenoid-operated three-way air valve at a *desired point in the press cycle. The limit switch is adjusted to lock the cushion at* the very bottom of the press stroke and release it at any desired point. The relief valve allows the cushion to follow the slide at a safe distance and speed. The lock may be made inoperative by opening the switch in the control circuit.

Slide Counterbalance. This device is used on the slides of large and small presses to reduce vibration and to assist the brake and clutch in functioning properly. *Counter-*

balances are actuated by springs or air pressure which provides a means of literally floating the slide in the air. This relieves much of the load of the slide and punch from the press connection and shaft, thereby reducing the amount of friction on the brake. With the proper adjustment of the air pressure in a counterbalance cylinder the backlash in a press drive can be overcome. If breaking of linkages or other parts between the slide and the source of power occurs an air counterbalance will prevent the normal tendency of the slide to drop, thus minimizing the possibility of costly accidents.

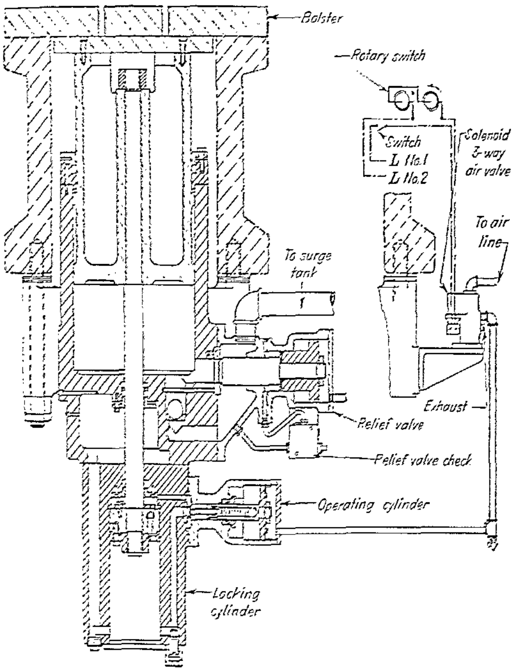


FIG. 23-7. Typical installation of a hydropneumatic cushion with hydraulic locking device and control.[4]

Counterbalances consist of one or more units mounted on the crown or frame of the press with the piston shafts connected to the slide. One mounting method is to place the units on either side of the crown with the shafts extending downward to the slide. A second method is to support or build the units into each end of the press bed and connect the piston shafts to the slide within the press housing.

Air counterbalance cylinders are the most effective and economical means of counterbalancing the slides on most types of presses. Air pressure is controlled by a valve slopes to compensate the weight of the die; heavier dies require more pressure in the surge tank.

Overload-relief Bed. A hydropneumatic overload-relief bed (Fig. 23-8) can be built into a press so that, if an unusual stress arises which would overtax the capacity of the press, the relief bed will yield to compensate for this condition. The bed can be adjusted to a little more than the pressure required to perform the operation, and in case of an overload, the relief valve is forced open and some fluid moves out to the surge tank. On the upstroke of the press, this fluid is returned to the hydraulic cylinder, raising the press bed to normal working position. Working pressures up to 2,000 psi can be obtained by adjusting the pressure in the air cylinder which actuates the combination relief and check valve in the hydraulic cylinder. The pressure in the bed itself is up to the working load only during a brief period near the bottom of the press stroke.

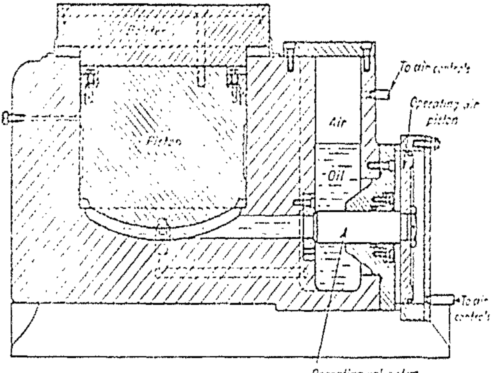


FIG. 23-8. A hydropneumatic overload-relief bed.[4]

PRESS SELECTION

The operational characteristics of a press should be considered in relation to the requirements of definite classes of work to be done. There are five general classifications commonly used to identify the cold pressworking of metals. These are cutting, bending, forming, drawing, and compressing. Some of these are operations best suited to mechanically operated presses and others are most efficiently done on hydraulic presses.

Cutting. This classification includes blanking or shearing metal into the proper size for subsequent operations and piercing or perforating holes in the sheets or blanks.

The majority of the work in this classification may be done on short-stroke mechanical presses with a flywheel or nongeared drive. The frame style may be the single-action straight side or the gap frame with either solid or open-back design. The open-back gap-frame press may be the fixed vertical, fixed inclined, or inclinable type. For heavy, large-sized blanking, a mechanical short-stroke back-geared press may be desirable. The piercing of several holes along the edge of long sheets can be done on a press brake using commercially available punch-and-die units.

Bending. This includes the bending or flanging of various length parts.

Straight-side, gap-frame, or inclined single-action presses with a stroke to suit the operation are suitable for bending operations. Hydraulic presses and press brakes are also suitable.

Forming. Forming of parts not more than 3 or 4 in. in depth is, in most cases, a mechanical-press operation. Forming with the assistance of die cushions is more accurate on a mechanical than on a hydraulic press, as the depth of form is regulated by the throw of the crank. Rubber-pad forming is performed on hydraulic presses. Hydraulic presses having preset pressures increase the life of the rubber pad.

Drawing. Drawing can be done on the same types of presses used for blanking operations if the stroke is suitable and the press is equipped with a die cushion. However, faster operating presses are used for blanking operations than drawing operations.

Deep-drawing, redrawing, and ironing operations require a press rated at fewer strokes per minute to deliver a mid-stroke slide velocity well within the drawing speed limits of the material being worked. For this reason long-stroke hydraulic or gear-driven mechanical presses are recommended. Single-action presses equipped with die cushions or double-action presses supply the required pressures for blankholding purposes. The mid-stroke velocities in feet per minute for presses of various lengths of stroke and strokes per minute are given in Table 23-3. It should be remembered that the slide velocity decreases as the slide passes mid-stroke.

TABLE 23-3. MID-STROKE SLIDE VELOCITIES, FEET PER MINUTE

Length of stroke	Strokes per min														
	47	45	40	35	30	25	20	18	16	14	12	10	8	6	4
6	75	70	63	55	47	40	30	28	25	21					
8	..	..	84	73	63	53	41	38	33	28					
10	..	..	..	..	79	67	52	47	41	36	31				
12	..	..	..	..	..	79	62	56	50	44	37				
14	..	..	..	..	..	92	73	66	60	51	43	37			
16	..	..	..	..	..	..	83	75	67	59	50	41	34	27	
18	..	..	..	..	..	..	..	84	76	66	57	47	38	29	20
20	..	..	..	..	..	..	..	..	83	72	62	52	42	32	21
22	..	..	..	..	..	..	..	..	..	80	70	58	47	35	23
24	..	..	..	..	..	..	..	..	..	88	76	63	50	38	25
26	..	..	..	.	..	..	..	..	..	..	82	69	55	41	28
28	..	..	..	..	..	..	..	..	..	..	88	73	60	44	29
30	..	..	..	..	..	..	.	..	..	.	..	79	63	48	31

Press tonnage ratings are calculated with the slide position close to the bottom of its stroke. Since most drawing operations are initiated at some distance above this position, allowances in the press tonnage required must be made accordingly. Approximate press tonnages at any point on the press stroke can be determined from the nomograph of Fig. 23-9. The curve is plotted for a rated tonnage at ½ in. above dead center.

The example shown on the nomograph employs a 500-ton press having a 32-in. stroke. *The capacity of the press with the slide 3 in. up from the bottom of the stroke* is determined as follows. From point 3 on the 32-in.-stroke ordinate a line is extended to the right until it intersects the curve. From this point a vertical line drawn downward intersects the tonnage constant scale (for 32-in. stroke) at 0.44. Multiplying this constant (0.44) by the rated press tonnage (500) a capacity of 220 tons is obtained for the specified slide position.

This tonnage-capacity curve is based upon a connection length which is twice the stroke of the press. A press with a connection longer than this will have slightly more capacity; a press with a shorter connection will have slightly less capacity.

Compression Operations. These operations compress metal to flow plastically to contours of the die such as coining, sizing, embossing, swaging, and cold extruding.

Very heavy, massively constructed metal spread or hydraulic presses are required for this class of work. Straight-side or eccentric knuckle-joint-type metal spread presses are often used. An overload relief bed is sometimes installed in the press bed to prevent damage to press and dies in case of overloaded blanks.

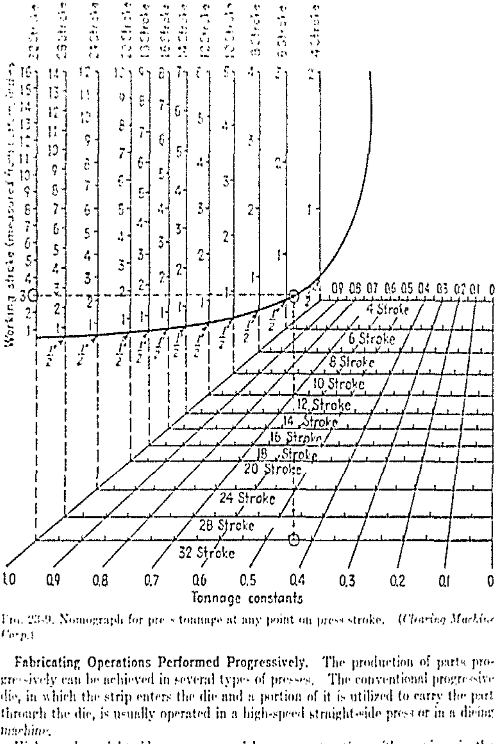


FIG. 23-9. Nomograph for press tonnage at any point on press stroke. *(Clearing Machine Corp.)*

Fabricating Operations Performed Progressively. The production of parts progressively can be achieved in several types of presses. The conventional progressive die, in which the strip enters the die and a portion of it is utilized to carry the part through the die, is usually operated in a high-speed straight-side press or in a dieing machine.

High-speed straight-side presses are of heavy construction with openings in the uprights for feeding of the strip and removal of the scrap. Since many progressive dies require that slugs pierced out by the punches drop through the bed, these presses are designed with openings under the bed for slug removal.

The entire mechanism of the dieing machine, except the upper crosshead and the punch, is usually located below the bed. The punch is pulled down on the die instead of being pushed down as in conventional presses. Unobstructed space above the bed and a low center of gravity adapt the dieing machine to the high-speed production of many parts.

Four-slide or multislide high-speed presses produce many different types of complicated stampings. Basically, the machine is designed so that one horizontally operated press head can be used for piercing, trimming, blanking, etc., and four horizontal forming slides 90° apart converge on a common point.

The blanking, forming, or drawing of parts of a design that does not permit the use of carrier strips can be accomplished in presses equipped with transfer mechanisms. In a transfer press, a blank is cut by a punch in the first station and pushed through the blanking die into the transfer slide. As the press slide ascends, the blank is carried into each successive die where subsequent operations are performed on the blank. High production of small parts may be obtained on these presses without the necessity for expensive dies. The transfer slides are built as a part of specially designed multiple-point straight-side presses or the multiple-crank-type eyelet machines.

Notching or Slotting Operations. The notching or slotting of rotors, stators, and segments in the production of electric motors, generators, etc., for piercing holes in ball- and roller-bearing retainers and for duplicating designs in trays or hollow ware, etc., can be done in high-speed gap-frame presses on which are incorporated internal or external indexing fixtures. Presses with these attachments are often called notching presses.

JIC STANDARD PRESS DIMENSIONS

The Joint Industry Conference (JIC) of press users and press manufacturers has developed standards on the following classes of mechanical presses:

1. Open-back inclinable presses
2. Straight-side, single-action, single-point presses
3. Straight-side, single-action, multiple-point presses
4. Straight-side, double-action, single- and multiple-point presses
5. Rail or frame presses
6. Triple-action, multiple-point presses

The standards developed are for the working area of the press, viz., die space, stroke, bed and slide areas, and other dimensions essential to obtaining interchangeability of dies between all presses of like tonnage and die-space areas, regardless of make.

A visible means of identifying a press according to the action, points of suspension, tonnage, and dimensions of the bed was suggested by the JIC and is in general usage by the press manufacturers.

The following is the recommended method of press marking and is to be placed at a central position on the front of the press.

NAME OF MANUFACTURER
D2—500—66—72

As these symbols appear left to right they represent:

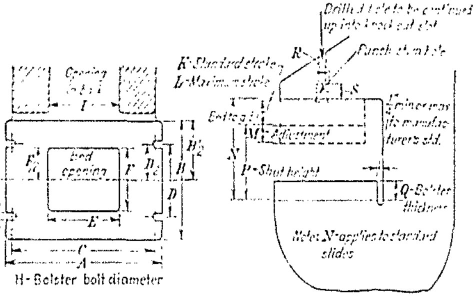
1. Action and points of suspension
2. Tonnage
3. Left-to-right dimension
4. Front-to-back dimension

In item 1, the letter "S" is used to denote single-action; "D," double-action; "T," triple-action, and "O.B.I.," open-back inclinable.

Specification tags are attached to the press which state tonnage, stroke, shut height, adjustment, size, and strokes per minute for the press slide or slides as the case may be. An additional tag is used to give the die-cushion data.

A standard distance above the bottom of the maximum stroke has been established; at this point the press will exert the full rated tonnage. Single-action, straight-side presses of the single-end-geared single-point type will exert full tonnage ¼ in. up from the bottom of the stroke. The double-point eccentric and twin-drive types will exert full tonnage ½ in. above the bottom of the stroke. The main or inner slide of double- and triple-action presses will exert full tonnage ½ in. above the bottom of stroke, and ¼ in. is the corresponding distance for the blankholder or outer slide for the same press. The lower slide of triple-action presses will exert full tonnage ½ in. from the top of the stroke. These dimensions relate to presses with JIC standard strokes. Tonnage requirements for open-back inclinable presses are shown in Table 23-3.

Bolster Plates. Bolster plates are centrally located on the top of the bed by two dowels, one located at the front right-hand side and the other at the rear left-hand side. The dowel-pin centers are measured from the center lines of the bolster at a given fixed dimension, held to a tolerance of ±0.015 in., for each of the various widths and depths. T-slots are machined from front to back to receive 5/8- and 1-in. T-bolts. The center slot is located on the center line and additional slots continue at 6-in. spacings on both sides of this slot. The same pattern for T-slots is followed in the



• Note: Mounting holes or slots in press bed, for bolting bolster plate to bed, to conform to center-to-center distances on bolster plate

Tonnage	A	B	C	D	E	F	H	I	K	L	M	N	P	Q	R	S
22	20	12	18	7½	8	5	¾	9	2½	4	2	11¼	8½	2½	1⅝	2¼
32	24	15	22	9	11	8	¾	11	3	5	2¼	12¾	9½	2½	1⅝	2¼
45	28	18	25½	10½	14	8	1	13	3	6	2½	14¼	11	3	2⅛	3
60	32	21	29½	12	16	11	1	15	3½	7	2¾	16¾	13	3	2⅝	3
75	36	24	33	18	18	14	1¼	18	4	8	3	19¼	15	3½	2⅝	3
110	42	27	39	18	21	15	1¼	21	5	10	3½	23¼	18	4	3⅛	3
150	50	30	47	18	21	17	1¼	21	6	12	4	28¼	22	4½	3⅛	3
200	58	34	55	18	27	21	1¼	27	8	12	4½	32¼	24	5	3⅛	3

Fig. 23-10. JIC standard dimensions for open-back inclinable presses.

slide. Each slot is measured from the center line and the dimension held within a *tolerance of ±0.015 in. The bolster plates for open-back inclinable and single-action,* straight-side, single-point light-series presses have the T-slots machined a fixed distance toward center from all four sides.

The drilling of holes in the bolster plate for pressure pins follows a similar pattern in the medium- and heavy-tonnage presses. Holes are located 3 in. from the bolster center lines and continue on both sides of these holes at 6-in. centers. The rows of holes are dimensioned from the center lines and are held within a tolerance of ±0.015 in. This spacing places rows of holes extending front to back between the T-slots. Light-tonnage, straight-side, and gap-frame presses have holes drilled at 3-in. centers with the same dimensional tolerances.

Open-back Inclinable Presses. The JIC standard dimensions for the open-back inclinable (gap-frame) presses are shown in Fig. 23-10. The dimensions are given according to the established tonnage capacity of the press.

The layout of the ram or slide face is shown in Fig. 23-11, and corresponding tabular data are given in Table 23-4. Included in these data is the size of the slide, location of the die-anchorage holes and the T-slots, if any. The size and depth of the punch or upper shoe stem hole are given in Fig. 23-10. The T-slots and anchorage holes are dimensioned from the center line and held within the ±0.015 in. tolerance.

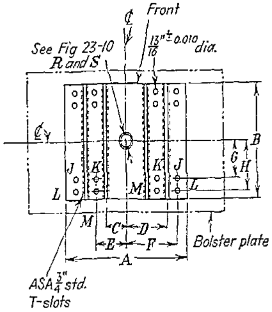


Fig. 23-11. Layout of slide for open-back inclinable presses.

TABLE 23-4. DIMENSIONS OF THE SLIDE FOR AN OPEN-BACK INCLINABLE PRESS
(See Fig. 23-11)

Tonnage	A	B	C	D	E	F	G	H	Hole pattern	No. T-slots
22	12	10	..	..	..	4¾	...	3¾	L	0
32	15	12	..	..	..	6	...	4½	L	0
45	18	14	..	..	..	7½	3	6	J-L	0
60	21	16	..	..	..	9	3	6	J-L	0
75	24	18	6	..	..	9	6	7½	J-L	2
110	28	21	6	..	9	12	7½	9	J-M	2
150	34	24	6	12	9	15	...	9	L-M	4
200	36	28	6	12	9	15	9	12	J-K-L-M	4

TABLE 23-5. MEASUREMENT OF MAXIMUM RATED TONNAGE FOR OPEN-BACK INCLINABLE PRESSES

Tonnage	Above bottom of stroke, in.	
	Air or friction clutch	Geared type
22	1/32	1/8
32	1/32	1/8
45	1/16	1/4
60	1/16	1/4
75	1/16	1/4
110	1/16	1/4
150	...	1/4
200	...	1/4

The layout of the bolster plates for the open-back inclinable presses is shown in Fig. 23-12 with pertinent tabular data listed in Table 23-6. The pressure pinholes and T-slots are machined on the bolster center lines and extend on both sides of the center line as mentioned. The ASA standard ¾-in. T-slots are spaced at 6-in. increments with the spacing held within a tolerance of ±0.015 in. on their distance from respective center lines. The pressure pinholes are drilled at 3-in. centers and are dimensioned from the center lines and held to within ±0.015 in. tolerance. The bolster-plate thicknesses are given in Fig. 23-10.

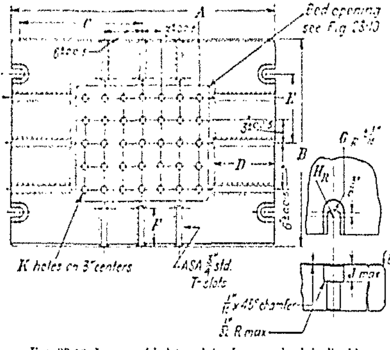


FIG. 23-12. Layout of bolster plates for open-back inclinable presses.

TABLE 23-6. DIMENSIONS OF THE BOLSTER PLATE FOR OPEN-BACK INCLINABLE PRESSES (See Fig. 23-12)

A	B	C	D	E	F	G	H	J	K	Left to right		Front to back	
										T-slots	Pressure pinholes	T-slots	Pressure pinholes
20	12	9	5	3¾	3	¾	13/32	1¼		2	0	2	0
24	15	11	6	4½	2½	¾	13/32	1¼	13/16	2	3	2	3
28	18	12¾	6	5¼	4	⅞	9/16	1¼	13/16	2	5	2	3
32	21	14¾	7	6	4	⅞	9/16	1¼	13/16	2	5	2	3
36	24	16½	8	9	4	1 1/16	11/16	1½	13/16	6	5	6	5
42	27	19½	9½	9	5	1 1/16	11/16	1½	13/16	6	7	6	5
50	30	23½	11	9	6	1 5/16	13/16	1½	1 1/16	6	7	6	5
58	34	27½	14½	9	6	1 5/16	15/16	1½	1 1/16	10	9	6	7

Straight-side, Single-action, Single-point. This press classification has been divided into 10 bed sizes with 15 tonnage ratings. A schematic layout of the bed and slide for this press classification is shown in Fig. 23-13 with its corresponding tabular data given in Table 23-7. The total number of die-anchorage holes in the slide is given, and they are evenly spaced to the right and left of the center line along the front and back edges of the slide face. T-slots are machined in the slide face extending from front to back, and the number of T-slots listed in the tabulation are evenly spaced on each side of the front-to-back center line. Holes for knockout pins through the slide are provided as shown.

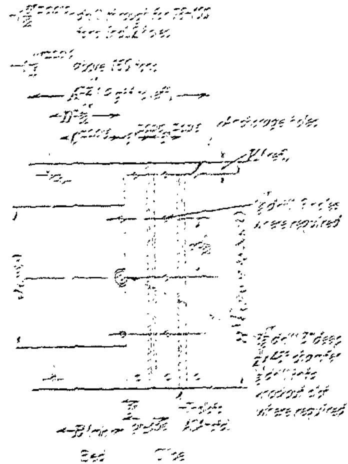


Fig. 22-11. Layout of bed and slide for straight-side, single-action, single-point presses, light and heavy series.

TABLE 22-7. BED AND SLIDE DIMENSIONS FOR STRAIGHT-SIDE, SINGLE-ACTION, SINGLE-POINT PRESSES. See Fig. 22-11

Left to right								Front to back						
A ±1/8	B min	C ±0.005	D ±0.005	Knockout holes, slide No.	Knockout holes, slide Diam.	T-slots No.	T-slots Size	E ±1/16 Bed	E ±1/16 Slide	F	G*	Knockout pin holes	Tonnage Min	Tonnage Max
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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* Reference dimension only; none located from left-to-right center line and held to a tolerance of ±0.005 in.

The bolster-plate dimensions, number of T-slots, and number of rows of pressure-pinholes are given in Table 23-8 and the tabulated layout is shown in Fig. 23-14 for this press classification.

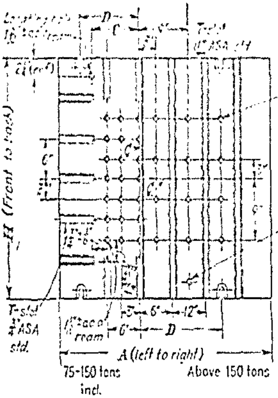


FIG. 23-14. Bolster plate for straight-side, single-action, single-point presses.

TABLE 23-8. BOLSTER-PLATE DATA FOR STRAIGHT-SIDE, SINGLE-ACTION, SINGLE-POINT PRESSES (See Fig. 23-14)

Left to right					Front to back			
A	C	D	No. T-slots	Rows pressure pinholes	H	No. T-slots	Rows pressure pinholes	Thickness*
21	3	8½	6	5	24	6	5	3½
24	4	9	6	5	30	6	5	4 (100T) 4½ (125T)
27	4	9	6	7	33	10	7	5
30	4	9	5	4	36		4	5 (200T) 5½ (250T)
36	9	15	5	4	42		4	6 (300T) 6½ (400T)
42	9	15	7	4	48		4	7 (500T) 7½ (600T)
48	15	21	7	6	54		6	8½ (800T) 9 (1,000T)
54	15	21	9	6	60		6	9½
60	15	21	9	6	66		6	10
66	21	27	11	8	72		8	11

* Values in parentheses denote press size or tonnage.

TABLE 23-9. TOOLING DIMENSIONS FOR SINGLE-ACTION MULTIPLE-POINT PRESSES*

Left to right											Front to back		Range of tonnage	
A	B	C	D	E	F	G	No. mounting slots, bed	Rows of pressure pistons	Total anchorage bolts, holes	Daylight ram and bolster	H	J	Min	Max
48	33	9	15				4	6	12	7	30	21	50	125
											36	27	75	125
											36	21	150	250
											42	33	100	125
											42	27	150	250
											48	33	150	250
60	45	15	21			.	4	6	16	9	30	21	50	125
											36	27	75	125
											36	21	150	200
											42	33	100	125
											42	27	150	200
											48	33	150	300
											54	39	200	300
											60	45	250	300
72	57	21	9	27		. . .	8	10	20	11	36	21	75	200
											42	27	100	250
											48	33	150	300
											54	39	200	300
											54	33	400	500
											60	45	250	300
											60	39	400	500
84	69	27	9	33		. . .	8	12	24	12	36	21	75	200
											42	27	100	250
											48	33	150	300
											54	39	200	300
											54	33	400	500
											60	45	250	300
											60	39	400	600
											66	51	250	300
											66	45	400	600
											72	51	400	600
96	81	33	9	39		. . .	8	14	28	15	48	33	150	300
											54	39	200	300
											54	33	400	500
											60	45	250	300
											60	39	400	500
											66	51	250	300
											66	45	500	800
											72	51	400	800
108	93	39	9	45		. . .	8	16	32	17	48	33	150	300
											54	39	200	300
											54	33	400	500
											60	45	250	300
											60	39	400	800
											66	51	250	300
											66	45	400	800
											72	51	400	1,250
											78	57	400	1,250
											84	63	500	1,250
120	105	45	9	27	51	. . .	12	18	36	19	60	45	250	300
											60	39	400	800
											66	51	250	300
											66	45	400	800
											72	51	400	1,250
											72	57	400	1,250
											84	63	500	1,250

TABLE 23-9. TOOLING DIMENSIONS FOR SINGLE-ACTION MULTIPLE-POINT PRESSES* (Continued)

Left to right											Front to back		Range of tonnage†	
A	B	C	D	E	F	G	No. [illegible]	Rows of pressure pinholes	Total anchor [illegible] holes, slide	T-slots ram and bolster	H	J	Min	Max
132	117	51	9	33	57		12	20	40	21	60	45	250	[illegible]
											60	39	400	600
											66	51	250	[illegible]
											66	45	400	600
											72	51	400	1,250
											78	57	400	1,250
											84	63	500	1,250
											90	69	500	1,250
											96	75	500	1,250
144	126	57	9	33	63		12	22	44	23	72	51	400	1,250
											78	57	400	1,250
											84	63	500	1,250
											90	69	500	1,250
											90	63	1,600	2,000
											96	75	500	1,250
											96	69	1,600	2,000
156	141	63	9	39	69		12	24	48	25	72	51	400	1,250
											78	57	400	1,250
											84	63	500	1,250
											90	69	500	1,250
											90	63	1,600	2,000
											96	75	500	1,250
											96	69	1,600	2,000
											102	81	500	1,250
											102	75	1,600	2,000
											108	87	500	1,250
											108	81	1,600	2,000
180	165	75	9	33	57	81	16	28	56	29	84	63	500	1,250
											90	69	500	1,250
											90	63	1,600	2,000
											96	75	500	1,250
											96	69	1,600	2,000
											102	81	500	1,250
											102	75	1,600	2,000
											108	87	500	1,250
											108	81	1,600	2,000
204	189	87	9	33	63	93	16	32	64	33	96	75	500	1,250
											96	69	1,600	2,000
											102	81	500	1,250
											102	75	1,600	2,000
											108	87	500	1,250
											108	81	1,600	2,000
228	213	99	9	45	75	105	16	36	72	37	96	75	1,000	1,250
											96	69	1,600	2,000
											102	81	1,000	1,250
											102	75	1,600	2,000
											108	87	1,000	1,250
											108	81	1,600	2,000

* For rows of pressure pinholes, front to back, and thickness of bolster see Table 23-10.

† Increments, tons:

From 50 tons to 150 tons, incl.; increment, 25 tons
Above 150 tons to 300 tons, incl.; increment, 50 tons
Above 300 tons to 600 tons, incl.; increment, 100 tons
Above 600 tons to 1,000 tons, incl.; increment, 200 tons
Above 1,000 tons to 1,250 tons, incl.; increment, 250 tons
Above 1,250 tons to 1,600 tons, incl.; increment, 350 tons
Above 1,600 tons to 2,000 tons, incl.; increment, 400 tons

TABLE 23-10. SINGLE-ACTION MULTIPLE-POINT PRESS BOLSTER-PLATE THICKNESS AND ROWS OF PRESSURE PINHOLES FRONT TO BACK IN RELATION TO PRESS CAPACITY AND DEPTH

Capacity of press, tons	Thickness of bolster plate	Bolster plate: Total depth front to back	Bolster plate: Total rows of pressure pinholes front to back
50	3½	30	4
75	4	30, 36	4
100	4½	30, 36	4
100	4½	42	6
100	4½	42	4*
125	5	30, 36	4
125	5	42	6
125	5	42	4*
150	5½	36, 42	4
150	5½	48	6
200	6	36, 42	4
200	6	48, 54	6
250	6½	42	4
250	6½	48, 54	6
250	7	60, 66	8
300	7	48, 54	6
300	7	60	8
300	7½	66	8
300	7½	72	10
400	7½	54, 60	6
400	7½	66	8
400	8	72	8
400	8	78	10
500	8	54, 60	6
500	8	66	8
500	9½	72	8
500	9½	78, 84	10
500	9½	90	12
500	11½	96	12
500	11½	102, 108	14
600	8½	60	6
600	8½	66	8
600	10	72	8
600	10	78, 84	10
600	10	90	12
600	12	96	12
600	12	102, 108	14
800	9	60	6
800	9	66	8
800	10½	72	8
800	10½	78, 84	10
800	10½	90	12
800	12	96	12
800	12	102, 108	14
1,000	11	72	8
1,000	11	78, 84	10
1,000	11	90	12
1,000	12	96	12
1,000	12	102, 108	14
1,250	11	72	8
1,250	11	78, 84	10
1,250	12	90, 96	12
1,250	12	102, 108	14
1,600	12	84, 90	10
1,600	12	96, 102	12
1,600	12	108	14
2,000	12	90	10
2,000	12	96, 102	12
2,000	12	108	14

* Applies to 72 by 42 and 84 by 42 press sizes.

Straight-side, Single-action, Multiple-point Press. A schematic layout of the press bed, bolster plate, and press ram or slide for this press classification is shown in Fig. 23-15 and the JIC standardized dimensions are listed in Table 23-9.

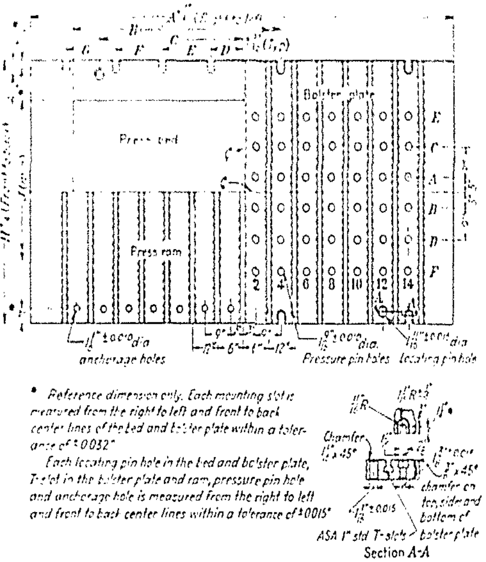


FIG. 23-15. Schematic layout of the press bed, bolster plate, and press slide of straight-side, single-action, multiple-point presses.

Shown on the bolster-plate layout is the method of identifying and marking the rows of pressure pinholes. The even numbers identify the pressure pinholes to the right of the front-to-back center line and odd numbers are used to identify those to the left of the center line. The letter *A* and alternate letters are used to identify the rows of holes back of the right-to-left center line. The letter *B* and alternate letters are used to identify the rows in front of the center line. The letters and numerals are to be stamped in the proper areas using ¼-in.-high characters.

Table 23-10 is supplementary to Table 23-9 and supplies the bolster thickness and rows of pressure pinholes front to back in relation to the rated tonnage of the press.

The JIC standard lengths of stroke of the press slide for straight-side single-action presses are given in Table 23-11. These strokes have been established in relation to the rated tonnage of the press.

TABLE 23-11. JIC STANDARD STROKES FOR STRAIGHT-SIDE SINGLE-ACTION PRESSES

Capacity of Press, Tons	*Length of Stroke, In.*
50–75	4–6–8
100–125	4–6–8–10
150	4–8–12
200	4–8–12–16
250–300	8–12–16
400–500	8–12–16–20
600–800	12–16–20–24
1,000–1,250	16–20–24–28
1,600–2,000	16–20–24–28–32

TABLE 23-12. TOOLING DIMENSIONS FOR DOUBLE-ACTION SINGLE- AND MULTIPLE-POINT PRESSES

Left to right												Front to back			Capacity, tons	
A	*B*	*C*	*D*	*E*	*F*	*G*	*K*	No. mounting slots, bed	Rows of pressure pinholes	Anchorage holes, slide outer	T-slots inner slide and bolster	*H*	*J*	*L*	Outer slide	Inner slide
Single-point Presses																
36	27	9	14				24	4	4	8	3-slide 5-bolster	42	27	30	125 150	250 300
48	40	9	15				36	4	6	8	5-slide 7-bolster	54	33	42	200 250	400 500
60	52	15	21				42	4	8	12	7-slide 9-bolster	60	45	48	300 400 500	600 800 1,000
72	60	21	9	27			54	8	10	12	9-slide 11-bolster	78	51	60	625 800 1,000	1,250 1,600 2,000
Multiple-point Presses																
72	57	21	9	27			60	8	10	12	9-slide 11-bolster	48 60	33 45	36 48	125 125 150 175	200 200 250 300
84	69	27	9	33			72	8	12	16	11-slide 13-bolster	48 48 60 60	33 27 45 39	36 36 48 48	175 225 175 225	300 400 300 400
96	81	33	9	39			78	8	14	16	13-slide 15-bolster	48 48 60 60 72 72	33 27 45 39 57 51	36 36 48 48 54 54	175 225 175 225 175 225	300 400 300 400 300 400
108	93	33	9	45			90	8	16	20	15-slide 17-bolster	60	39	48	225 350	400 600
												72	51	54	225 350	400 600
120	105	45	9	27	51		102	12	18	20	17-slide 19-bolster	60	39	48	225 350 500	400 600 800
												72	51	54	225 350 500	400 600 800
												84	63	66	225 350 500	400 600 800

TABLE 23-13 TOOLING DIMENSIONS FOR DOUBLE-ACTION SINGLE- AND MULTIPLE-POINT PRESSES (Continued)

[illegible]												[illegible]			[illegible]	
A	B	C	D	E	F	G	K	No. of [illegible] bed	[illegible]	[illegible]	[illegible] slide and bolster	H	J	L	[illegible]	[illegible]
[illegible]	117	51	9	23	37		111	12	20	24	19-slide 21-bolster	72	51	54	350	600
															500	800
															600	1,000
												84	63	66	350	600
															500	800
															600	1,000
144	129	57	9	33	63		126	12	22	24	21-slide 23-bolster	72	51	54	350	600
															500	800
															600	1,000
															700	1,250
												84	63	66	350	600
															500	800
															600	1,000
															700	1,250
												96	75	78	350	600
															500	800
															600	1,000
															700	1,250
156	141	63	9	33	69		138	12	24	28	23-slide 25-bolster	84	63	66	350	600
															500	800
															600	1,000
															700	1,250
												96	75	78	350	600
															500	800
															600	1,000
															700	1,250
180	165	75	9	33	57	81	156	16	28	32	25-slide 29-bolster	96	75	78	350	600
															500	800
															600	1,000
															700	1,250
												108	87	84	350	600
															500	800
															600	1,000
															700	1,250
204	189	87	9	33	67	93	180	16	32	36	29-slide 33-bolster	108	87	84	500	800
															600	1,000
												108	81	84	700	1,250
															500	1,000
228	213	99	9	45	75	105	204	16	36	40	33-slide 37-bolster	108	81	84	500	1,000

TABLE 23-[illegible]. BOLSTER-PLATE THICKNESS AND NUMBER OF ROWS OF PRESSURE PINHOLES FRONT TO BACK FOR DOUBLE-ACTION PRESSES

Capacity, tons		Bolster plate		
Outer ram	Inner ram	Thickness	Total depth front to back	Total rows of pressure pinholes front to back
Single Point				
125	250	7	42	4
150	300	7½	42	4
200	400	8	54	6
250	500	8½	54	6
300	600	9	66	8
400	800	11	66	8
500	1,000	11	66	8
625	1,250	12	78	8
800	1,600	12	78	8
1,000	2,000	12	78	8
Multiple Point				
125	200	6½	45	6
125	200	6½	60	8
150	250	7	60	8
175	300	7½	45	6
175	300	7½	60	8
175	300	8	72	10
225	400	8	45	4
225	400	8	60	6
225	400	9½	72	8
225	400	9½	84	10
350	600	9	60	6
350	600	11	72	8
350	600	11	84	10
350	600	12	96	12
350	600	12	108	14
500	900	11	60	6
500	800	12	72	8
500	900	12	84	10
500	900	12	96	12
500	900	12	108	14
600	1,000	12	72	8
600	1,000	12	84	10
600	1,000	12	96	12
600	1,000	12	108	14
700	1,250	12	72	8
700	1,250	12	84	10
700	1,250	12	96	12
700	1,250	12	108	14
900	1,600	12	108	14

The bolster plates on straight-side presses have horizontally tapped holes for attaching of mounting hooks. The location and size of these holes are shown in Fig. 23-16.

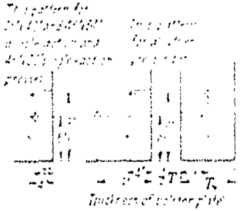


FIG. 23-16. Location, spacing, and size of holes for mounting handling hooks to the bolster plate in straight-side presses.

Straight-side, Double-action, Single- and Multiple-point Presses. The JIC standard dimensions for the working area of this press classification are listed in Tables 23-12 and 23-13. A schematic layout of the slide showing the sizes of the inner slide, T-slot, and anchorage-hole arrangement is shown in Fig. 23-17. The schematic arrangement of the bolster plate and press bed of double-action presses is similar to that of single-action presses; therefore part of Fig. 23-15 applies to double-action presses as well as single-action presses.

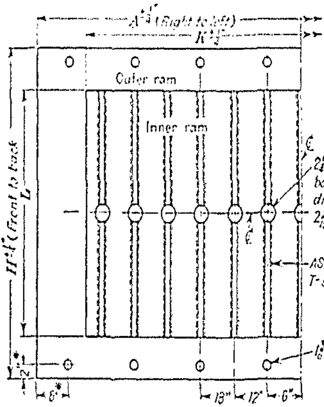


FIG. 23-17. Slide layout for double-action press.

References

1. American Society of Tool Engineers, "Tool Engineers Handbook," McGraw-Hill Book Company, Inc., New York, 1949.
2. Brostekkos, S. D.: How Modern Mechanical Presses Operate, Am. Machinist, Nov. 17, 1949.
3. "Die Cushions for Mechanical Presses," Danly Machine Specialties, Inc., 1950.
4. "Bliss Power Press Handbook," E. W. Bliss Co., Toledo, Ohio, 1950.

SECTION 24

FERROUS DIE MATERIALS*

SELECTION AND CHARACTERISTICS OF DIE STEELS

The steels listed in Table 24-1 will, and do, perform over 95 per cent of the metal-stamping operations required. The list contains 26 steels, 9 of which are widely applied and readily available from almost all tool-steel sources. These are steels W1, W2, O1, A2, D2, D4, M2, S1, and S5. The other steels included represent slight variations for improved performance in certain instances, and their use is sometimes justified because of special considerations. They may enjoy exceptionally heavy usage for certain types of metal-stamping or forming operations.

The steels are identified by letter and number symbols. The letter is significant in representing the group of the steel involved, as given in the footnote to Table 24-1. The number symbol is not significant except to indicate a separation of one grade or type from another.

All the steels in the list except those in the S and H groups can be heat-treated to a hardness greater than Rockwell C62 and, accordingly, are hard, strong, wear-resistant materials. Some, such as T15, are capable of heat treatment to a hardness as high as Rockwell C67. Frequently hardness is proportional to wear resistance, but this is not always true, because the wear resistance usually also increases as the alloy content, and particularly the carbon content, increases. The toughness of the steels, on the other hand, is inversely proportional to the hardness and increases markedly as the alloy content or the carbon content is lowered.

Table 24-2 lists the basic characteristics, and Table 24-3 the hardening and tempering treatments, of the various tool steels listed. A careful study of these characteristics will be of great assistance in making the selection of the proper grade. For each job a different one of the basic characteristics may assume major importance, depending upon the material being formed or worked and the requirements for economy, toughness, wear resistance, or the design, which may affect the heat-treating characteristics or the need for machinability.

A brief statement of the merits of the different groups is as follows:

W, Water-hardening Tool Steels. W1 and W2 are both readily available and of low cost. W2 contains vanadium and is more uniform in response to heat treatment, and of a finer grain size with a higher toughness. Both are shallow-hardening, and when hardened with a hard case and a softer internal core, these steels have high toughness. They are quenched in water or brine and should be applied where movement in hardening is not important.

O, Oil-hardening Tool Steels. Steels O1 and O2 have, for many years, been the work horses of the die-steel industry and are familiarly known as manganese oil-hardening tool steel. Readily available and of low cost, these steels, which can be hardened in oil, have less movement than the water-hardening steels and are of equal toughness when the water-hardening steels are hardened throughout. Steel O7 is a tungsten oil-hardening steel of greater wear resistance because of its higher carbon and tungsten

* Reviewed by G. A. Roberts, Vice-president, Vanadium-Alloys Steel Co., and E. Von Hambach, Research and Development Engineer, The Carpenter Steel Co.

a steel selected for specialized applications. Its availability is not so great as that of steels O1 or O2.

A. Air-hardening Die Steels. The principal air-hardening die steel employed is steel A2. This steel has a minimum movement in hardening and has higher toughness than the oil-hardening die steels, with equal and greater wear resistance. It is

TABLE 24-1. DIE STEELS

Steel type*	Average composition, %							
	C	Mn	Si	Cr	W	Mo	V	Other
W1	1.00							
W2	1.00						0.20	
O1	0.90	1.00		0.50	0.50			
O2	0.90	1.60						
O7	1.20			0.75	1.75	0.25		
A2	1.00			5.00		1.00		
A4	1.00	2.00		1.00		1.00		
A5	1.00	3.00		1.00		1.00		
A6	0.70	2.00		1.00		1.00		
D2	1.50			12.00		1.00		
D3	2.25			12.00				
D4	2.25			12.00		1.00		
D6	2.25		1.00	12.00	1.00			
S1	0.50			1.50	2.50			
S2	0.50		1.00			0.50		
S4	0.50	0.80	2.00					
S5	0.50	0.80	2.00			0.50		
H11	0.35			5.00		1.50		
H12	0.35			5.00	1.50	1.50	0.50	
T1	0.70			4.00	18.00		1.00	
T15	1.50			5.00	12.00		5.00	5.00 Co
M2	0.80			4.00	6.00	5.00	2.00	
M4	1.30			4.00	5.50	4.50	4.00	
L3	1.00			1.50			0.20	
L6	0.70			0.75		0.25	...	1.50 Ni
F2	1.25				3.50			

Adapted from Report of SAE Iron and Steel Technical Committee, approved January, 1949, and revised January, 1952.

* W, water-hardening; O, oil-hardening, cold-work; A, air-hardening, medium-alloy; D, high-carbon high-chromium, cold-work; S, shock-resisting; H, chromium-base, hot-work; T, tungsten-base, high-speed; M, molybdenum-base, high-speed; L, special-purpose, low-alloy; F, carbon-tungsten, special purpose.

becoming increasingly popular and has only the disadvantage of a higher than normal hardening temperature. Steels A4, A5, and A6 are newer developments of manganese air-hardening steels which can be hardened from lower temperatures but which have lower wear resistance. The availability of A2 is excellent.

D, High-carbon High-chromium Die Steels. *The principal steels of wide application* for long-run dies are steels in this group. D2, containing 1.50 per cent carbon, is of moderate toughness and intermediate wear resistance, whereas steels D3, D4, and D6, containing additional carbon, are of very high wear resistance and somewhat lower toughness. Selection between these is based on the length of run desired, machining and grinding problems, and the necessity for controlling movement in hardening. Steels D2 and D4, containing molybdenum, are air-hardening and have minimum movement in hardening.

S, Shock-resisting Tool Steels. These steels contain less carbon and have higher toughness. They are employed where heavy cutting or forming operations are required, and where breakage is a serious problem with higher-carbon materials that might have longer life through higher wear resistance alone. Choice among the grades is a matter of experience. All steels are readily available, with steel S5 being

TABLE 24-2. COMPARISON OF BASIC CHARACTERISTICS OF STEELS USED FOR PRESS TOOLS

Steel No.	Nondeforming properties	Safety in hardening	Toughness	Resistance to softening effect of heat	Wear resistance	Machinability
W1	Poor	Fair	Good	Poor	Fair	Best
W2	Poor	Fair	Good	Poor	Fair	Best
O1	Good	Good	Fair	Poor	Fair	Good
O2	Good	Good	Fair	Poor	Fair	Good
O7	Good	Good	Fair	Poor	Fair	Good
A2	Best	Best	Fair	Fair	Good	Fair
A4	Best	Best	Fair	Poor to fair	Fair to good	Fair to poor
A5	Best	Best	Fair	Poor to fair	Fair to good	Fair to poor
A6	Best	Best	Fair	Poor to fair	Fair to good	Fair to poor
D2	Best	Best	Fair to poor	Fair	Very good	Poor
D3	Good	Good	Poor	Fair	Best	Poor
D4	Best	Best	Poor	Fair	Best	Poor
D6	Good	Good	Poor	Fair	Best	Poor
S1	Fair	Good	Very good	Fair	Fair	Fair
S2	Poor	Fair	Best	Fair	Fair	Fair
S4	Poor	Fair	Best	Fair	Fair	Fair
S5	Fair	Good	Best	Fair	Fair	Fair
H11	Best	Best	Best	Good	Fair	Fair
H12	Best	Best	Best	Good	Fair	Fair
T1	Good	Good	Fair	Very good	Good	Fair
T15	Good	Fair	Poor	Best	Best	Poor
M2	Good	Fair	Fair	Very good	Very good	Fair
M4	Good	Fair	Fair	Very good	Best	Fair
L3-W	Poor	Poor				
L3-O	Fair	Fair	Fair	Poor	Fair	Good
F2	Poor	Poor	Poor	Fair	Very good	Fair

widely employed. This grade is an oil-hardening type of silicomanganese steel and is more economical than steel S1, which has equivalent toughness properties with greater wear resistance.

H, Hot-work Die Steels. These steels are included because of their high toughness and air-hardening ability, and are occasionally used for cold-working operations. They are sometimes employed as holders for inserted dies where their high strength and low movement when heat-treated to an intermediate hardness level make them effective materials; however, a less expensive alloy steel will serve in most cases.

T and M, Tungsten and Molybdenum High-speed Steels. Steels T1 and M2 are equivalent in performance, representing standard high-speed steels which have excellent properties for cold-working dies. They have higher toughness than many of the other die steels, combined with excellent wear resistance. They are more expensive than the other steels included in the list but are readily available. They may be harden in the standard manner or carbonitride-hardened, in which case they are more wear-resistant to a greater extent than the high-carbon high-chromium steels. Carburizing is not usually done because it is a treatment in which it is difficult to control warpage, size changes, or soft spots in steel. Steels T15 and M4 may also be hardened by these two methods, but, in general, they are hardened by the standard method because they already contain a very high carbon content combined with a high vanadium content. Steel T15 is the most wear-resistant of all steels in the list, and steel M4 is slightly greater in

TABLE 24-2. HARDENING AND TEMPERING TREATMENTS FOR PRESS TOOLS

Steel No.	Preheat temp, deg F	Rate of heating for hardening	Hardening temp, deg F	Time at temp, min	Quenching medium	Tempering temp, deg F	Depth of hardening	Resistance to decarburization
W1		Slow	1425-1550	10-30	Brine or water	325-550	Shallow	Poor
W2		Slow	1425-1550	10-30	Brine or water	325-550	Shallow	Poor
O1	1200	Very slow	1450-1500	10-30	Oil	325-500	Medium	Good
O2	1200	Very slow	1400-1475	Do not soak	Oil	325-500	Medium	Good
O7	1200	Slow	1575-1625	10-30	Oil	350-550	Medium	Good
A2	1450	Very slow	1700-1800	20	Air	350-700	Deep	Fair
A4	1250	Slow	1450-1550	15-30	Air	300-500	Deep	Very good
A5	1250	Slow	1450-1550	15-30	Air	300-500	Deep	Very good
A6	1250	Slow	1500-1600	15-30	Air	300-500	Deep	Very good
D2	1450	Very slow	1800-1900	20-45	Air	400-1000	Deep	Fair
D3	1500	Very slow	1750-1825	15-45	Oil	400-1000	Deep	Fair
D4	1450	Very slow	1800-1850	20-45	Air	400-1000	Deep	Fair
D5	1450	Very slow	1800-1850	20-45	Air	400-1000	Deep	Fair
S1		Slow to 1400	1650-1750	10-30	Oil	300-650	Medium	Fair to good
S2		Slow	1525-1575	10-30	Brine or water	350-700		Fair to poor
S4		Slow	1550-1650	10-30	Brine or water	350-700		Poor
S5			1600-1700		Oil	350-700	Medium	Poor
H11	1400	Slow	1800-1850	15-60	Air	900-1200	Deep	Good
H12	1450	Slow	1800-1850	15-60	Air	900-1250	Deep	Good
T1	1500-1600	Rapid from preheat	2150-2400	Do not soak	Air, oil, or salt	1050-1200	Deep	Good
T15	1500-1600	Rapid from preheat	2175-2270	Do not soak	Air, oil, or salt	1000-1200	Deep	Fair
M2	1500	Rapid from preheat	2125-2225	Do not soak	Air, oil, or salt	1025-1200	Deep	Poor
M4	1450-1550	Rapid from preheat	2125-2225	Do not soak	Air, oil, or salt	1025-1200	Deep	Poor
L3			1425-1500	10-30	Brine or water	300-500		
		Slow	1500-1600	10-30	Oil	300-500	Medium	Good
L6	1200	Slow	1500-1550	15-60	Oil	300-600	Medium	Fair
F2	1200	Slow	1525-1625	15-30	Brine or water	300-500	Shallow	Good

wear resistance to a steel such as D4. These steels are difficult to machine and grind and are of limited application and availability when considering the entire field.

L, Low-alloy Tool Steels. Of the many low-alloy steels to stand out as effective die materials, steel L3 is a chromium-vanadium steel somewhat similar to the familiar SAE 52100. In large sizes it is water-quenched and has a hard case and a soft core, with an attendant high overall toughness. In small sizes it may be oil-quenched. Steel L6 is a nickel-chromium-molybdenum die steel with oil-hardening properties that is frequently used for auxiliary parts as an adjunct to dies and tools. It has less wear resistance and slightly higher toughness than the popular oil-hardening die steel O1. It is of limited availability but of reasonable cost.

F, Finishing Steels. Steel F2 is of very limited use in this field but is occasionally applied where extremely high wear resistance in a water-hardening, shallow-hardening steel is desired. It is moderate to high in cost and difficult to grind after heat treatment. Its availability is limited.

HEAT TREATMENT AND SURFACE COATING OF DIE STEELS

Simplified Theory of Hardening Steel. Iron has two distinct and different atomic arrangements—one existing at room temperature (and again near the melting point), and one above the critical temperature. Without this phenomenon it would be impossible to harden iron-base alloys by heat treatment.

Briefly, what happens in the heat treatment of die steels can be represented graphically by Fig. 24-1. Starting in the annealed machinable condition at *A*, the steel is soft, consisting internally of an aggregate of ferrite and carbide. Upon heating above the critical temperature to *B* the crystal structure of ferrite changes, becomes austenite, and dissolves a large portion of the carbide. This new structure, austenite, is always a prerequisite for hardening. By quenching it—cooling it rapidly to room

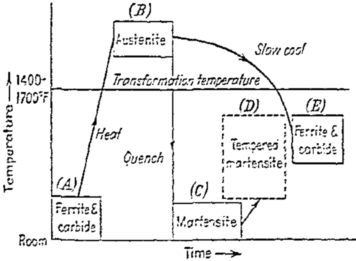


FIG. 24-1. Simplified chart of hardening of steel.[1]*

temperature—the carbon is retained in solution, and the structure known as martensite (*C*) results. This is the hard matrix structure in steels. It is initially highly stressed, for the transformation from austenite involves some volumetric expansion against the natural stiffness of the steel, so it must be reheated to an intermediate temperature (*D*) to soften it slightly and relieve those internal stresses and strains which unduly embrittle the steel.

If quenching is not rapid enough, the austenite reverts to ferrite and carbide (*E*), and high hardness is not obtained. The rate at which quenching is required to produce martensite depends primarily on the alloy content. As we have seen above, *low-alloy material is water- or oil-hardening, while highly alloyed steel usually* can be hardened in air—quenched at a much slower rate. The high alloys make the reactions more sluggish.

Throughout all these heat-treating reactions most die steels retain excess, or undissolved carbides, which take no direct part in the hardening. The high-carbon high-chromium steels, for example, have large quantities of excess iron-chromium carbide, which give them in large measure the high degree of abrasion resistance possessed by this class of steel.

The 4 per cent vanadium steel (M4) owes its even greater abrasion resistance to the presence of excess vanadium carbide. Vanadium carbide is exceedingly hard, having higher hardness than tungsten carbide, and even higher than the silicon carbide in grinding wheels.

Influence of Heat Treatment on Die Life. Figure 24-1 presents simply the basic hardening of steels. Each type of die steel must be handled slightly differently from

* Superior numbers relate to References at the end of this section.

...and expensive results. Hardening temperature, different heating and cooling rates, and careful tempering procedure must be used. The depth of hardening, growth or shrinkage in total size, and size change must also be accurately considered when setting up the detailed heat-treating procedure for any given die. Figure 24-2 shows the size change in a piece of tool steel in inches per inch of various types of tool steels with respect to the tempering temperature.

The properties of die steels as developed in heat treatment bear an important and direct effect on die life. In general, it may be said that the harder a given die the longer it will wear, while the softer a die the tougher it becomes. Thus, assuming the proper die steel is being used and no other factors are operative, dies which are wearing out should be made harder for improved life, and dies which are breaking or cracking should be made softer.

FIG. 24-2. Size change obtained in heat-treating the common die steels. These data are based on normal hardening temperatures for each grade. Note that high-alloy air-hardening steels have low size changes.[4]

Care must be taken to analyze the real cause for failure. Frequently dies spall or break because they first become dull, and extreme pressures build up. This is evidence for increasing, not decreasing, the hardness for added die life.

Within limits, heat treatment can be used to adjust these fine variables to best advantage. An oil-hardening steel may work best on one application at Rockwell C62, and on another involving higher stresses and shock at Rockwell C58. Adjustments of the tempering temperature easily produce the hardness desired.

Hardness is not the only measure of effective heat treating, for it is possible to produce equivalent hardnesses in nearly all die steels by different combinations of hardening and tempering temperatures and times, and usually one of these is superior to the rest. Many steels are very sensitive to slight overheating, their impact resistance and toughness dropping off considerably, yet the hardness may be virtually unaffected. There is no simple test to determine whether a die has been slightly overheated in hardening, though such symptoms as undue size change, abnormal response to tempering, or loss of magnetism frequently indicate it.

It is evident, therefore, that temperature control is of very great importance in heat treating, and every effort should be made to use the proper temperatures for each grade of steel as recommended. The mere presence of expensive pyrometers is not enough. They must be properly maintained and frequently checked for accuracy, for at the high temperatures involved in heat-treating dies, it is easy for the thermocouples to become contaminated and lose their calibration. Errors of up to 200 F have been encountered from this source, yet the equipment appeared to be in good order.

Surface Control in Heat Treatment. Another extremely important factor in the heat treatment of dies to get maximum die life is that of surface control. This becomes vital on dies to be used unground or with a minimum of grinding and dressing after hardening.

Die steels are all high in carbon. The oxygen in the air and the water vapor and carbon dioxide in burned fuel gases rapidly attack the carbon on the surface of the steel at the elevated temperatures used in heat treating, unless the surface is adequately protected. The loss of carbon means loss in hardness.

Surface protection has traditionally been provided by packing the dies, usually in a mildly carbonaceous material such as gray-cast-iron chips. Pack hardening does work well, but is expensive inasmuch as fuel must be consumed to heat not only the die but also the box and packing material. Considerable time is also expended in proper packing, but on the other hand hasty work results in poor protection and spoiled dies.

More modern surface protection is provided by the use of special muffle furnaces, wherein the dies are protected from contact with the combustion gases and are surrounded by specially generated neutral atmospheres. Many atmosphere generators are used commercially today, most of them partially burning and reacting fuel gases to balance their composition to a neutral one between carburizing and decarburizing. Their use, when properly controlled, results in dies with unaffected surface chemistry.

Salt baths, when correctly used, work out well for die steels. Very careful control is required. The highly alloyed air-hardening die steels, for example, must be held at the hardening temperature much longer than either high-speed steel or the low-alloy die steels, to allow sufficient solution of the sluggish iron-chromium carbide in the austenite.

One practice frequently used on stamping or other forming dies subjected to repeated high stresses is to remove the dies from operation after a stated number of pieces are made, and subject them to a redraw. Very often, such a redraw, carried out at a temperature low enough to avoid undue softening (approximately 25°F lower than the original draw), will markedly improve the life of the die by increasing its resistance to failure by fatigue.

Nitriding. This treatment produces a surface hardness on hardened high-speed-steel tools that is substantially greater than that obtained by the usual hardening methods. Liquid nitriding consists simply of immersing the tools in a bath of special molten salts from 12 to 40 min at a temperature of 1025 to 1050°F. Sealed retort furnaces are used in the gaseous nitriding method, with exposure times of up to 72 hr at a temperature of 920 to 980°F.

Subzero Treatment. Chilling in the range of −30 to −120°F, most effective on air-hardening steels, transforms most of the austenite into martensite, resulting in higher hardness and some increase in dimensions, but usually with some loss in toughness. Chilling is done as quenched or after tempering; then the steel is warmed to room temperature. Subzero treating is much less effective when low-temperature tempering operations precede chilling.[4]

DIE DESIGN FOR SUCCESSFUL HEAT TREATMENT

To prevent soft spots, distortion, or breakage of costly dies, the following rules are offered as the practice in one large company:

1. Order stock large enough to allow for machining to remove decarburized surfaces (see Table 24-4).
2. Do not drill screw holes closer than ¼ in. from edges of die blocks where possible.
3. Avoid blind holes if possible.
4. All tools should be designed with round corners and fillets wherever possible.
5. Use air-hardening or high-chrome high-carbon (oil- and air-hardening) tool steel on unbalanced and intricately shaped dies.
6. Add extra holes if possible on heavy unbalanced sections to allow for faster and more uniform cooling when quenched.
7. Do not machine knife blades to a sharp cutting edge before hardening.
8. Avoid all peening on dies.
9. Avoid deep scratches and toolmarks.
10. On long delicate parallels, shafts, etc., rough out and have pieces annealed to remove strains before finish machining.
11. Always use the brand of steel most suitable for the work that the tool or die has to perform. Special consideration should be given as to whether the die or part can or must be ground after hardening.[5]

Dies calling for little to no grinding: Use (1) high-carbon high-chromium tool steel, and heat-treat for zero size change; (2) use an air-hardening tool steel, such as the 5 per cent Cr type, and allow for expansion in hardening; usual allowance is 0.001 in. per in., with 0.0007 in. per in. more accurate; (3) from previous experience with tools of the same size and shape, oil- or water-quenching steels may be used.

TABLE 24-4. MINIMUM MACHINING ALLOWANCE PER SIDE

[illegible]

Rounds, Hexagons, and Octagons

Size, in.	Hot-rolled	Hammered	Rough-turned	Cold-drawn	Rough-ground
0 to 1/2	0.020		.....	0.020	0.005
Over 1/2 to 1	0.040			0.040	0.010
Over 1 to 2	0.063	0.060		0.060	0.015
Over 2 to 3	0.089	0.120	0.025	0.080	0.020
Over 3 to 4	0.110	0.150	0.030	0.110	0.025
Over 4 to 5	0.140	0.180	0.040		
Over 5 to 6	0.190	0.210	0.050		
Over 6 to 8	0.250	0.250	0.060		
Over 8		0.250	0.060		

Hot-rolled and Cold-drawn Square and Flat Bars*

Thickness, in.	Side	Width, in.: 0 to 1/2 incl.	Over 1/2 to 1 incl.	Over 1 to 2 incl.	Over 2 to 3 incl.	Over 3 to 4 incl.	Over 4 to 5 incl.	Over 5 to 6 incl.	Over 6 to 7 incl.	Over 7 to 8 incl.
0 to 1/2	A	**0.025**	**0.025**	**0.030**	**0.035**	**0.040**	**0.045**	**0.050**	0.055	[illegible]
	B	**0.025**	**0.045**	**0.055**	**0.070**	**0.085**	**0.115**	**0.130**	0.150	0.170
Over 1/2 to 1	A		**0.045**	**0.045**	**0.050**	**0.055**	**0.060**	0.070	0.070	0.075
	B		**0.045**	**0.065**	**0.080**	**0.100**	**0.130**	0.150	0.170	0.250
Over 1 to 2	A			**0.065**	**0.065**	**0.070**	0.070	0.075	0.075	[illegible]
	B			**0.055**	**0.085**	**0.105**	0.140	0.155	0.180	0.210
Over 2 to 3	A	.....	.....	.....	0.085	0.085	0.085	0.085	0.090	0.100
	B	.....	.....	.....	0.085	0.115	0.150	0.170	0.200	0.225
Over 3 to 4	A	.....	.....	.....	.....	0.115	0.115	0.115	0.115	0.125
	B	.....	.....	.....	.....	0.115	0.150	0.175	0.225	0.250
Over 4 to 5	A	.....	.....	.....	.....		0.150	0.150	0.150	0.150
	B	.....	.....	.....	.....		0.150	0.190	0.225	0.250
Over 5 to 6	A	.....	.....	.....	.....		.....	0.190	0.190	0.190
	B	.....	.....	.....	.....		.....	0.190	0.250	0.250
Over 6	A	.....		.....	.....		.....		0.250	0.250
	B	.....			.....		.....	.....	0.250	0.250

Hammered Square and Flat Bars

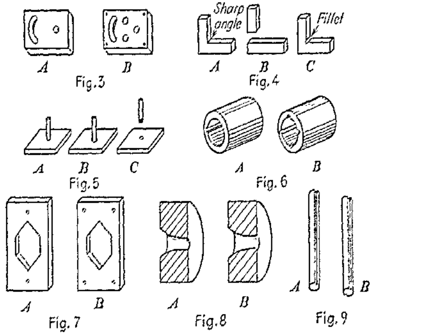
Thickness, in.	Side	Width, in.: 0 to 1/2 incl.	Over 1/2 to 1 incl.	Over 1 to 2 incl.	Over 2 to 3 incl.	Over 3 to 4 incl.	Over 4 to 5 incl.	Over 5 to 6 incl.	Over 6 to 7 incl.	Over 7 to 8 incl.
0 to 1/2	A	0.030	0.030	0.035	0.040	0.045	0.055	0.065	0.070	0.075
	B	0.050	0.050	0.080	0.100	0.125	0.150	0.180	0.210	[illegible]
Over 1/2 to 1	A	.....	0.060	0.060	0.065	0.065	0.075	0.080	0.085	[illegible]
	B	.....	0.060	0.090	0.105	0.125	0.150	0.180	0.210	0.250
Over 1 to 2	A	.....	.....	0.090	0.090	0.090	0.100	0.110	0.115	0.125
	B	.....	.....	0.090	0.120	0.135	0.155	0.185	0.215	0.250
Over 2 to 3	A	.....	.....		0.120	0.120	0.125	0.130	0.135	0.150
	B	.....	.....	.....	0.120	0.150	0.160	0.185	0.215	0.250
Over 3 to 4	A	.....	.....	.....		0.150	0.150	0.160	0.180	[illegible]
	B	.....	.....	.....		0.150	0.180	0.190	0.225	[illegible]
Over 4 to 5	A	.....	.....	.....			0.180	0.180	0.190	[illegible]
	B	.....	.....	.....			0.180	0.210	0.250	[illegible]
Over 5 to 6	A	.....	.....	.....				0.210	0.225	[illegible]
	B	.....						0.210	0.250	[illegible]
Over 6	A	.....					.....	.....	0.250	[illegible]
	B						.....	.....	0.250	[illegible]

Adapted from recommendations of American Iron & Steel Institute.

* Allowances listed in bold type apply to both hot-rolled and cold-drawn bars; other tolerances to hot-rolled bars only.

Dies which must be ground to remove scale or skin: (1) Use air-hardening steels as in 2 above; (2) use oil-hardening steels in sections which will harden through, with 0.0015 in. per in. allowance for the manganese steels, and 0.002 in. per in. for other oil-hardening steels; (3) for water-hardening steels, or oil-hardening steels in sections which do not harden through, distortion allowance can be accurately made only from previous experience with tools of the same size and shape; (4) high-carbon high-chromium steels may be used where the required tool life and wear resistance call for them.

Specific Design Details. In the heat-treating of steels, greatest strain occurs during the quenching period. These strains are developed by the difference in cooling rates between various sections of a piece; hence careful design will materially help to reduce quenching strains. The following rules are of general and useful application (see Figs. 24-3 to 24-9):



FIGS. 24-3 to 24-9. Design for heat treatment; views *A* show poor design; views *B* and *C* are preferred designs.[1]

1. Balance the areas of mass (Fig. 24-3). Heat will not dissipate so fast from central area of die at *A* as from the ends. Drilling holes as at *B* helps balance the areas.

2. Avoid sharp or reentrant angles (Fig. 24-4). Such angles, as at *A*, are a source of warpage and soft spots. To avoid, make assembly from two pieces as at *B*. A fillet as at *C* can be used but should be ⅛ in. in radius except for smallest work.

3. Avoid sharp angles between heavy and thin sections (Fig. 24-5). With a sharp angle as at *A*, heat is dissipated too slowly from the heavier section. A smooth radius as at *B* is an improvement. When a thread or press fit as at *C* can be used, it is preferred construction.

4. Avoid single keyways (Fig. 24-6). Single internal keyways in sleeves, as at *A*, are poor design. Cracking is apt to occur at the sharp corners at the keyway bottom, and the ring is almost certain to take an oval shape when quenched. Equally spaced keyways, as at *B*, opposite and at 90° to each other and with filleted corners, are preferred construction.

5. Do not have screw holes in direct line with die blank opening (Fig. 24-7). Setscrew holes in direct line with the sharp angles of the blanking section, as at *A*, are likely to cause a crack. The remedy is to offset such holes, as at *B*.

6. Avoid a sharp corner at bottom of drawing or piercing die opening (Fig. 24-8). Spalling or flaking, so likely to be produced at the sharp corners of small openings as at *A*, is avoided by use of a radius as at *B*.

7. Avoid single keyways or splines in shafts (Fig. 24-9). The shaft at *A* will tend to warp in quenching. The shaft at *B*, with two opposite keyways or splines, will stay more nearly straight.

HARD FACING

Hard facing, or surfacing, is a process by means of which hard wear-resistant alloys are applied to the surfaces of softer metals, thereby prolonging their life in service. The general standard gas-welding techniques are employed, except that deep melting and fusion of the hard-surfacing deposit with the base metal are avoided. Deep fusion tends to dilute the alloying ingredients in the deposit with resultant loss of hardness. In consequence, only a surface fusion (sometimes called "sweating") is used. Varying degrees of hardness, red hardness, and toughness are obtainable, the prevailing wear-resistant metal to suit conditions.

Hard-facing Rods. There is no standard industry specification for hard-facing rods. However, through the years of use five general groups have been evolved, based upon the evaluation of such properties as hardness, toughness, and shock resistance.

Group 1. Iron-base alloys containing less than about 20 per cent of alloying constituents.

Group 2. Iron-base group containing more than 20 per cent alloying constituents.

Group 3. Includes nonferrous alloys of cobalt, chromium, tungsten, and other elements.

Group 4. Includes the carbides of tungsten, tantalum, etc., pure or with metallic constituents.

Group 5. Includes crushed tungsten carbides of various screen sizes.

TABLE 24-5. RELATIVE MERITS OF HARD-FACING MATERIALS

Characteristics of deposited hard-facing material	Group No. in order of preference*				
Hardness at atmospheric temperature	4	5	2	3	1
Hardness at elevated temperature	4	5	3	2	1
Resistance to hot set	1	2	3	5	4
Resistance to corrosion	3	2	1	4	5
Smoothness of deposit	3	1	2	5	4
Ability to take high finish	3	2	1	4	5
Ability to penetrate	4	5	3	2	1
Thinness of deposited layer welding	5	3	2	1	4

* Group numbers correspond to those in preceding text.

CHROMIUM PLATING

Chromium-plated forming and drawing dies combine hardness with a low coefficient of friction with a nongalling characteristic. For optimum results, the plate should be deposited on a smoothly burnished surface to a thickness of 0.0005 to 0.01 in. *Some reported experience indicates that chromium plating does not stand up satisfactorily* in the stamping of stainless steels and similar tough materials.

CAST IRONS

The high compressive strengths (Table 24-6) and ease of casting of the gray irons are utilized in large forming and drawing dies for parts such as automobile panels, refrigerator cabinets, bathtubs, and other large articles. Conventional methods of hardening result in comparatively little distortion. There is risk of scoring and galling in using cast-iron dies for drawing such materials as stainless steel.

Alloying elements are added to control graphitization, to improve mechanical properties, or to develop a special characteristic.

TABLE 24-6. MECHANICAL AND PHYSICAL PROPERTIES OF PLAIN AND ALLOY GRADES OF GRAY CAST IRONS[a]

Plain Gray Iron

Property	ASTM class					
	20	25	30	35	40	
Tensile strength, psi	20,000	25,000	30,000	35,000	40,000	45,000
Compressive strength, psi	80,000	90,000	100,000	110,000	125,000	125,000
Hardness (Brinell)	130	150	170	200	200	225
Permanent set	5,000	7,000	9,000	11,000	12,000	15,000
Endurance limit	8,000-10,000	10,000-12,000	12,000-15,000	14,000-17,000	17,000-20,000	18,000-22,000
Modulus of elasticity, psi	11,000,000	12,000,000	13,000,000	14,000,000	15,000,000	16,000,000
Toughness (Izod impact)	......	Less than 1				
Creep, 0.1% per 1,000 hr						
800°F		....	6,000	8,000	No data	No data
1000°F		...	6	6		
Machinability	Excellent	Excellent	Excellent	Excellent	Good	Fair
Wear resistance	Good	Good	Good to excellent	Excellent	Excellent	Good to excellent
Corrosion resistance	Fair	Fair	Fair	Fair	Fair	Fair
Vibration damping capacity	Excellent	Excellent	Excellent	Excellent	Good to excellent	Good

Alloy Gray Iron

Property	ASTM class					
	30	35	40		50	60
Tensile strength, psi	35,000	45,000	45,000	55,000	50,000	60,000
Compressive strength, psi	100,000	110,000	125,000	125,000	135,000	175,000
Hardness (Brinell)	175	190	210	200	230	275
Permanent set	9,000	11,000	13,000	15,000	17,000	19,000
Endurance limit	15,000	17,000	20,000	22,000	25,000	26,000
Modulus of elasticity, psi	14,000,000	15,000,000	15,000,000	17,500,000	18,000,000	20,000,000
Toughness (Izod impact)	......	......	Less than 1	...	Up to 2	Up to 2
Creep, 0.1% per 1,000 hr						
800°F	...	6,500	No data	No data	No data	No data
1000°F	...	6	No data	No data	No data	No data
Machinability	Excellent	Excellent	Excellent	Excellent	Good to excellent	Good to excellent
Wear resistance	Excellent	Excellent	Excellent	Excellent	Good to excellent	Fair to good
Corrosion resistance	Fair to good	Fair to good	Fair to good	Fair to good	Fair to good	Good to excellent
Vibration damping capacity	Excellent	Excellent	Excellent	Excellent	Good to excellent	

References

1. American Society of Tool Engineers: "Tool Engineers Handbook," McGraw-Hill Book Company, Inc., New York, 1949.
2. "Tool Design Manual," Boeing Airplane Co.
3. "Metals Handbook," 1948 ed., American Society for Metals, Cleveland.
4. Fletcher, S. G.: The Selection and Treatment of Die Steels, *The Tool Engineer*, April, 1952.
5. Kiedel, J. Y.: Distortion of Toolsteel in Heat Treatment, *Metal Progress*, December, 1956.

SECTION 25

NONFERROUS AND NONMETALLIC DIE MATERIALS

SINTERED CARBIDES*

Many different grades of sintered carbides are available from the various suppliers. The grades differ in their property ranges, according to the particular aggregation of the carbides of tungsten, titanium, tantalum, and columbium, with metallic cobalt as the binder.

Since there is as yet no standardization of carbide grades, Table 25-1 may be followed for a general selection of grades, *by composition*, for various classes of service. The code designations are those in general use in the Buick Motor Division. There may be others not listed which are suitable for particular applications. The carbides suppliers should be consulted for best specification.

TABLE 25-1. COMMONLY AVAILABLE GRADES OF SINTERED CARBIDES FOR DIES

Carbide grade	Composition, %						Hardness, Rockwell A†	Applications
	W	Co	Ta	Ti	Cb	C*		
CQ-5	85.42	9.0				5.57	90.2	Wear surfaces involving light to medium shock and some impact service such as light-duty blanking dies and punches or draw dies
CQ-14	82.55	12.0				5.45	89.2	
CU-1	80.7	11.9	1.4		0.6	5.4	90.0	
CY-4	77.62	12.0	....	3.2	...	5.18	89.5	
CQ-6	81.68	13.0	....	...	...	5.32	88.0	Wear surfaces for dies subjected to medium shock and for light-impact service
CQ-15	79.80	15.0	....	...	...	5.20	88.0	
CQ-8	76.98	18.0	....	...	...	5.02	87.5	Wear surfaces requiring heavy shock or medium-impact service, such as lamination dies and punches, heavy forming dies, heavy heading machine hammers, etc.
CQ-10	78.86	16.0	....	...	...	5.14	86.0	
CQ-12	75.10	20.0	....	...	...	4.90	86.0	
CU-5	77.00	16.0	1.5	...	0.3	5.2	87.5	
CX-5	70.41	20.0	4.69	...	...	4.90	85.0	
CQ-9	70.41	25.0	....	...	...	4.59	85.5	Heavy-impact service, such as heavy blanking punches, cold-heading dies, nail-gripper dies, and nibbling dies
CU-3	65.70	25.0	3.1	...	1.5	4.70	85.0	
CX-7	65.72	25.0	4.60	...	...	4.68	84.3	

* Suppliers prefer to show percentages of the constituent elements in their metallic form, even though they occur as carbides. Therefore, carbon percentage is calculated by subtraction of the total metallic content from 100%.

† Hardness may vary plus or minus 0.3 unit.

NONFERROUS WROUGHT DIE MATERIALS

Aluminum. Dural (duralumin), aluminum 17S sheet is used as a facing over form blocks. Its composition is: copper, 4.0 per cent; manganese, 0.5 per cent; magnesium,

* Reviewed by H. H. Miller, Foundry Superintendent, Buick Motor Division of General Motors Corp.

0.5 per cent, with aluminum and several impurities constituting the remainder. For chemical properties see Sec. 27.

Magnesium. Sheet magnesium is used as a facing over form blocks. For the composition and mechanical properties see Sec. 27.

NONFERROUS CAST DIE MATERIALS

Cast Aluminum Bronzes. Proprietary bronzes (i.e., Ampco metal) cast to the die shape desired are used for forming and drawing stainless steel without scratching or galling. These alloys are characterized by compressive strengths of 160,000 to 171,000 psi, hardnesses of Rockwell C27 to 35, and a coefficient of expansion of 0.000009 in. per in. per deg F.

TABLE 25-2 COMPOSITIONS AND MELTING TEMPERATURES OF SOME LOW-MELTING BISMUTH ALLOYS[1]*

Ref No.	Composition					Melting† temp, deg F	Yield‡ temp, deg F
	Bismuth	Lead	Tin	Cadmium	Other		
1	44.70	22.60	8.30	5.30	19.10 In	117	
2	49.00	18.00	12.00		21.00 In	136	
3	50.00	26.70	13.30	10.00		158	
4	50.50	27.80	12.40	9.30		158-163	159
5	50.00	34.50	9.30	6.20		158-174	162
6	42.50	37.70	11.30	8.50		158-194	163
7	50.72	30.91	14.97	3.40		158-183	163
8	35.10	36.40	19.06	9.44		158-214	167
9	51.60	40.20	..	8.20		197	
10	52.50	32.00	15.50			203	
11	56.00	22.00	22.00	......		203-219	205
12	67.00	16.00	17.00	......		203-300	
13§	33.33	33.34	33.33	......		214-280	214
14‖	54.00	......	26.00	20.00		217	
15	48.00	28.50	14.50	.....	9.00 Sb	217-440	
16	55.50	44.50	..	....		255	
17	56.00	......	40.00	...	4.00 Zn	266	
18	58.00	......	42.00			281	
19	40.00	......	60.00			281-338	302
20	60.00	......		40.00		291	
21	100.00		.	.		520	
22		100.00		.....		620	
23	....		100.00	..		450	
24	......			100.00		610	
25	..			..	100.00 Sb	1167	
26				.	100.00 In	315	
27					100.00 Zn	787	

† Alloys for which single melting points are listed are eutectics.
‡ For eutectics, yield temperature corresponds to melting temperature.
§ Special alloy for anchoring bushings in machinery.
‖ Alloy used in selenium rectifiers.

Zinc-base Alloys. Zinc-base alloys are quickly cast into punch-and-die shapes at low cost. The production of experimental parts with such dies can prove out the design of both the part and the die before permanent tooling for costlier long-run production has started. Compressive strengths between 60,000 and 75,000 psi permit as high as 15,000 parts of light material of simple contours to be produced.

* Superior numbers relate to References at the end of this section.

Lead-base Alloys. Lead punches, composed of 6 to 7 per cent antimony, 0.04 per cent impurities, and the remainder lead, have been used with Kirksite dies.

Cast Beryllium Copper Alloys. Cast alloys of beryllium, cobalt, and copper have characteristics comparable with the proprietary bronzes.

Bismuth Alloys. The alloys of bismuth are used chiefly as matrix material for securing punch-and-die parts in a die assembly, and as cast punches and dies for short-run forming and drawing operations. These alloys are classified as low-melting-point alloys (Tables 25-2 and 25-3).

TABLE 25-3. MECHANICAL PROPERTIES OF SEVERAL WIDELY USED BISMUTH ALLOYS[1]

Ref. No.* / Properties	1	2	3	6	15	16	18	19
Yield temp, deg F	117	136	158	162.5	240	255	281	302
Tensile strength, psi	5,400	6,300	5,990	5,400	13,000	6,400	8,000	8,000
Elongation in 2 in. (slow load), %	1.5	50	200	200	1	60–70	200	200
Brinell hardness	12	14	9.2	9	19	10.2	22	2
Coefficient of thermal expansion, per deg F†	...	...	1.2×10^{-5}	1.2×10^{-5}	...	...	0.9×10^{-5}	0.9×10^{-5}
Max load (30 sec), psi†	...	...	10,000	...	16,000	8,000	15,000	15,000
Max load (5 min), psi†	...	...	4,000	...	10,000	4,000	9,000	9,500
Safe sustained load, psi†	...	...	300	...	200	300	500	500

* Reference numbers correspond to those in Table 25-2.
† Approximate values.

NONMETALLIC DIE MATERIALS

Hardboard. Sheets composed of compressed wood fiber are used as punch-and-die material in drawing and forming operations, as form blocks in rubber forming, and in stretch dies. Die stock, processed for higher tensile strength and the thickness, is available (Tables 25-4 and 25-5).

TABLE 25-4. AVERAGE PROPERTIES OF HARDBOARD PRODUCTS[1]

Nominal thickness, in.	Weight, lb per sq ft	Specific gravity	Tensile strength, psi	Modulus of rupture, psi	Water absorption, 24 hr, % by weight
Standard Hardboard					
1/8	0.76	1.02	3,200	6,000	16
3/16	1.01	1.02	3,200	5,900	13
1/4	1.35	1.02	3,100	5,900	11
5/16	1.72	1.02	3,100	5,800	9
Tempered Hardboard					
1/8	0.79	1.09	5,400	10,500	13
3/16	1.10	1.09	5,000	10,500	7
1/4	1.42	1.08	4,500	9,600	6
5/16	1.76	1.07	4,200	9,000	5

TABLE 25-5. AVERAGE PROPERTIES OF HARDBOARD DIE STOCK[a]

Thickness, in.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]
Weight [illegible], lb	[illegible]	[illegible]	[illegible]	[illegible]	1.70	[illegible]	7.10	9.45	[illegible]	[illegible]
Specific gravity	1.38	1.36	1.40	1.41	1.41	1.41	1.41	1.42	1.42	[illegible]
[illegible], psi	12,750	12,500	12,500	12,500	12,500	12,500	12,000	12,000	[illegible]	[illegible]
[illegible], psi	475	450	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Water absorption [illegible]	1.2	0.9	0.6	0.5	0.5	0.4	0.4	0.4	0.3	[illegible]

Tensile strength, psi, 3,700 — Modulus of elasticity, 1,250,000
Compressive strength, psi, [illegible], 26,500 — Impact [illegible], edgewise 0.6, flatwise 1.5
Shear strength, psi, 7,000 — Hardness, Rockwell M, 90

Densified Wood. Various woods are impregnated with a phenolic resin after which the laminated assembly is compressed to about 50 per cent of the original thickness of the wood layers.

TABLE 25-6. AVERAGE PROPERTIES OF A TYPICAL GRADE OF DENSIFIED WOOD[1]

Compressive strength, psi*	28,000
Shear strength, psi	3,400
Modulus of elasticity, psi	4,300,000
Modulus of rupture, psi*	49,000
Specific gravity	1.35
Rockwell hardness (S scale)	110
Impact strength, Izod, ft-lb per in.	8

* Parallel to the grain and laminations.

Densified wood punches and dies are used in forming and drawing dies; in the latter, scoring of the part is infrequent because of the low coefficient of friction of densified wood when properly finished.

Hardwood. Hardwood can be used for form blocks, but laminated impregnated wood, hardboard, and plastics have largely replaced it. Strengths and properties of the more important hardwoods are listed in Table 25-8.

Rubber. Molded-rubber female dies and rubber-covered punches are used in difficult forming operations, such as the forming of deeply fluted lighting reflectors. Specifications for rubbers so used, in the conventional Guerin, Marform, and Hydroform processes, are confined generally to performance needed for proper *fabrication of a pressed material.*

Forming pads are supplied by one manufacturer under their own specifications (Table 25-7).

Other rubbers, including synthetic rubber, can be furnished to give good service for a given pressworking operation including the hot forming of magnesium.

TABLE 25-7. FORMING PADS AND THROW SHEETS*

Stock grade	Hardness, durometer	Specific gravity	Extension moduli, lb†				Tensile strength, psi	Elongation, %
			300%		500%			
A	20-40	0.99	200	400	650	850	2,700	700
B	40-50	1.15	500	700	1,400	1,700	2,700	650
C	50-60	1.15	850	1,150	1,900	2,300	2,700	600
D	60-70	1.21	1,200	1,500	2,300	2,700	2,700	500
E	70-80	1.26	1,500	1,800	2,700 min		2,700	450

Data courtesy U.S. Rubber Co.
* Throw sheets are used for pad lamination by user.
† Modulus figures are for extension or under strain, and are not to be used in computing [illegible] under [illegible]. They are [illegible] compression [illegible].

Cork. Soft, medium, and hard cork layers, compressed into sheet form, are sometimes used with, or in place of rubber pads. Cork deforms only slightly in any direction other than that of the applied load, while rubber flows in all directions.

TABLE 25-8. STRENGTH AND RELATED PROPERTIES AT 12 PER CENT MOISTURE CONTENT OF SOME IMPORTANT COMMERCIAL WOODS GROWN IN THE UNITED STATES[1]

Wood	Specific gravity, oven-dry based on volume at test	Static bending			Work to max load, in.-lb per cu in.	Compression parallel to grain; max crushing strength, psi	Compression perpendicular to grain; stress at proportional limit, psi	Hardness; load required to embed a 0.444-in. ball to one-half its diameter, side grain, lb	Shear parallel to grain; max shearing strength, psi
		Stress at proportional limit, psi	Modulus of rupture, psi	Modulus of elasticity, 1,000 psi					
Ash, white	0.60	8,900	15,400	1,770	17.6	7,410	1,410	1,320	1,950
Basswood	0.37	5,900	8,700	1,460	7.2	4,730	450	410	990
Beech	0.64	8,700	14,900	1,720	15.1	7,300	1,250	1,300	2,010
Birch, yellow	0.62	10,000	16,600	2,010	20.8	8,170	1,190	1,260	1,880
Cherry, black	0.52	9,000	12,300	1,490	11.4	7,110	850	950	1,700
Cottonwood, northern black	0.35	5,300	8,300	1,250	6.7	4,420	370	350	1,020
Dogwood	0.73	9,200	14,900	1,530	19.5	7,700	1,520	2,150	2,260
Elm, American	0.50	7,600	11,800	1,340	13.0	5,520	850	830	1,510
Elm, rock	0.63	8,000	14,800	1,540	19.2	7,050	1,520	1,320	1,920
Gum, red	0.49	8,100	11,900	1,490	11.2	5,800	860	690	1,610
Hickory, shagbark	0.72	10,700	20,200	2,160	25.8	9,210	2,170	.....	2,430
Maple, red	0.54	8,700	13,400	1,640	12.5	6,540	1,240	950	1,850
Maple, sugar	0.63	9,500	15,800	1,830	16.5	7,830	1,810	1,450	2,330
Oak, red	0.63	8,500	14,300	1,820	14.5	6,760	1,250	1,290	1,780
Oak, white	0.68	8,200	15,200	1,780	14.8	7,440	1,320	1,360	2,000
Poplar, yellow	0.40	6,100	9,200	1,500	8.8	5,290	580	450	1,100
Walnut, black	0.55	10,500	14,600	1,680	10.7	7,580	1,250	1,010	1,370

Plastics. Molded or machined form, draw, and stretch dies of thermosetting plastic are rapidly coming into augmented use. One aircraft manufacturer reports an estimated 60 per cent decrease in fabricating time by molding phenolic resin die elements, as compared with metal tools.

Data from Douglas Aircraft Co., Inc., for four phenolic casting resins, indicates the following ranges of values:

Properties	As-cast	Aged 66 hr at 180°F
Shrinkage, in. per in.:		
Filled	0.0000-0.0022	0.001 -0.0051
Unfilled	0.0035-0.0089	0.0062-0.0138
Yield compression strength, psi:		
Filled	....	6,470-10,820
Unfilled	....	10,250-12,970
Ultimate compression strength, psi:		
Filled	....	7,010-11,810
Unfilled	....	12,860-15,540

But the recent (1951) developments in this class of tool material make it difficult to establish definite ranges of physical properties, or to match plastic types and grades to exact specific applications. Some casting grades are phenolic resin, some epoxy, some ethyl cellulose, etc. Some are primarily formulated with filler; others are offered unfilled.

Various other reports indicate other approximate average properties as: 0.3 to 0.45 ft-lb Izod impact; 5 to 7 × 10^5 modulus of elasticity; 60 to 85 Shore hardness.

Production life for these newer die materials is reported far ahead of older accepted performance for temporary dies. One plastic die for drawing a 0.040-in. steel cowl side panel, after a run of 20,000, had an estimated potential production of 50,000 pieces. For more extended runs (100,000 or more pieces), metal wear plates can be provided for binder rings and draw dies.

References

1. Seeds, O. J.: How to Select and Use Low-melting Alloys as Production Aids, *Materials & Methods*, September, 1950.
2. Cady, E. L.: Compressed Wood-fiber Useful as Engineering Materials, *Materials & Methods*, February, 1949.
3. Densified Wood Applied to Metal-working Operations, *Machinery*, March, 1949.
4. American Society of Tool Engineers: "Tool Engineers Handbook," McGraw-Hill Book Company, Inc., New York, 1949.

SECTION 26

FERROUS STAMPING MATERIALS*

CARBON STEEL

Sheets for stamping are classed as carbon-steel sheets (1) when no minimum content is specified or required for aluminum, boron, chromium, cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium, or zirconium, or any other element added to obtain a desired alloying effect; (2) when the specified minimum content for copper does not exceed 0.40 per cent; or (3) when the maximum content specified for any of the following elements does not exceed the percentages noted: manganese, 1.65; copper, 0.60; silicon, 0.60.

Physical properties of carbon steels are listed in Table 26-1.

TABLE 26-1. AVERAGE MECHANICAL PROPERTIES OF CARBON STEELS
Based on 1-in. round bars. Properties do not form a part or requirement of any specification without specific approval of source of supply

SAE No.	Tensile strength, 1,000 psi		Yield strength, 1,000 psi		Elongation in 2 in. %		Reduction in area, %		Brinell hardness	
	HR*	CD†	HR*	CD†	HR*	CD†	HR*	CD†	HR*	CD†
1006	43	48	24	41	30	20	55	45	86	95
1008	44	49	24.5	41.5	30	20	55	45	86	95
1010	47	53	26	44	28	20	50	40	95	105
1015	50	56	27.5	47	28	18	50	40	101	111
1016	55	61	30	51	25	18	50	40	111	121
1017	53	59	29	49	26	18	50	40	105	116
1018	58	64	32	54	25	15	50	40	116	126
1019	59	66	32.5	55	25	15	50	40	116	131
1020	55	61	30	51	25	15	50	40	111	121
1022	62	69	34	58	23	15	47	40	121	137
1024	74	82	41	69	20	12	42	35	149	163
1025	58	64	32	54	25	15	50	40	116	126
1027	75	83	41	70	18	12	40	35	149	163
1030	68	76	37.5	64	20	12	42	35	137	149
1033	72	80	39.5	67	18	12	40	35	143	163
1034	70	78	38.5	65.5	18	12	40	35	143	156
1035	72	80	39.5	67	18	12	40	35	143	163
1036	83	92	45.5	77.5	16	12	40	35	163	187
1038	75	83	41	70	18	12	40	35	149	163
1039	79	88	43.5	74	16	12	40	35	156	179

* Reviewed by W. L. Davis, Chief Engineer, and H. J. Towell, Superintendent, Armament Department, The Emerson Electric Manufacturing Co., and J. R. Zanetti, Assistant Chief Metallurgist, Great Lakes Steel Corp.

TABLE 26·1. AVERAGE MECHANICAL PROPERTIES OF CARBON STEELS (Continued)

SAE No.	Tensile Strength, 1000 psi		Yield Strength, 1000 psi		Elongation, % in 2 in.		Reduction of Area, %		Brinell Hardness	
	HR*	CD†	HR*	CD†	HR*	CD†	HR*	CD†	HR*	CD†
1040	76	85	42	71	18	12	40	35	149	170
1041	[illegible]	[illegible]	51	87	15	10	40	[illegible]	187	[illegible]
1042	[illegible]	[illegible]	41	75	16	12	40	35	163	174
1043	82	91	45	77	16	12	40	35	163	179
1045	82	91	45	77	16	12	40	35	163	179
1046	85	94	47	79	15	12	40	35	170	187
1049	87	97	48	81.5	15	10	35	30	174	192
1050	90	100	49.5	84	15	10	35	30	179	197
1052	108		59.5		12		30		217	
1055	94		51.5		12		30		192	
1060	98		54		12	..	30		201	
1062	103		56.5		12	..	30		212	
1064	97	..	53.5		12	..	30		201	
1065	100		55		12	..	30		207	
1066	105		58		12	..	30		217	
1070	102		56		12	..	30	..	212	
1074	105		58		12	..	30		217	
1078	100		55		12	..	30		207	
1080	112		61.5		10	..	25		229	
1085	121		66.5		10	.	25		248	
1086	112		61.5		10		25		229	
1090	122		67		10		25		248	
1095	120		66		10		25		248	
1109	50	76	27.5	47	30	20	50	40	101	121
B1111	60	67	33	56	25	10	45	35	121	131
B1112	61	68	33.5	57	25	10	45	35	121	137
B1113	61	68	33.5	57	25	10	45	35	121	137
1114	57	63.5	31.5	52	28	20	50	40	111	126
1115	55	61	30	51	25	20	50	40	111	121
1116	63	70	35	60	23	15	47	40	126	143
1117	62	69	34	58	23	15	47	40	121	137
1118	65	72	36	61	23	15	47	40	131	143
1119	62	69	34	58	23	15	47	40	121	137
1120	62	69	34	58	23	15	47	40	121	137
1126	69	71	35	59.5	23	15	47	40	126	143
1132	83	92	45.5	77	16	12	40	35	167	183
1137	88	98	48	82	15	10	35	30	179	197
1138	73	81	40	68	18	12	40	35	149	156
1140	79	88	43.5	74	16	12	40	35	156	179
1141	94	105	51.5	88	15	10	35	30	187	212
1144	97	108	53	90	15	10	35	30	197	217
1145	85	94	47	80	15	12	40	35	170	187
1146	85	94	47	80	15	12	40	35	170	187
1151	92	102	50.5	86	15	10	35	30	187	207

From Report of SAE Iron and Steel Technical Committee, approved January, 1950.
* Hot-rolled condition.
† Cold-drawn condition.

HOT-ROLLED LOW-CARBON-STEEL SHEETS

Commercial Quality. Commercial-quality sheets are ordinarily produced in low-carbon grades (not exceeding 0.15 per cent) and are suitable for many purposes where the presence of oxide and normal surface defects are not objectionable.

Drawing Quality. Drawing-quality sheets are produced for use in manufacturing identified parts too difficult for the fabricating properties of commercial quality. Because of excessive die scoring, the oxide on hot-rolled and hot-rolled-annealed sheets should be removed by pickling prior to drawing. This quality of sheet is not commonly specified to chemical composition but is left to the discretion of the producer. When chemistry is specified it should be consistent with the drawing requirements.

Physical Quality. Physical-quality sheets are produced to satisfy one test requirement such as hardness, tensile strength, or other commonly accepted mechanical tests other than the bend tests of commercial quality. When chemistry is specified or drawing is required, it should be consistent with the mechanical property specified.

TABLE 26-2. HOT-ROLLED AND HOT-ROLLED-ANNEALED CARBON-STEEL SHEET SIZES

Width	*Thickness*
Over 48 in.	Less than 0.1875 in. (7 *gage*)
Over 22 to 48 in., incl.	Less than 0.2500 in. (3 *gage*)
Over 12 to 22 in., incl.	Less than 0.2500 to 0.014 in. (3 to 10 *gage*)
Over 6 to 12 in., incl.	Less than 0.0568 in. (17 *gage*)
Over 3½ to 6 in., incl.	Less than 0.0344 in. (21 *gage*)
Up to 3½ in.	Less than 0.0255 in. (24 *gage*)

COLD-ROLLED LOW-CARBON STEEL SHEETS

Commercial Quality. Commercial-quality sheets are ordinarily produced in low-carbon grades of steel not exceeding 0.15 per cent carbon unless specified, and are suitable for exposed parts requiring a good surface. They have a dull surface texture intended for the application of organic finishes but not electroplating, and are free from surface disturbances known as fluting or stretcher straining during fabrication, provided that the sheets are properly roller-leveled immediately before fabrication.

Drawing Quality. Drawing-quality sheets are produced to fabricate identified parts too difficult for the drawing properties of sheets of any other quality, and where the surface before and after drawing is of prime importance. They are furnished with a dull surface texture suitable for the application of organic finishes but not electroplating, and are free from surface disturbances known as fluting or stretcher straining during fabrication provided that the sheets are properly roller-leveled immediately before fabrication. Sheets of this quality are not commonly supplied to chemical composition, which is left to the discretion of the producer.

Physical Quality. Physical-quality sheets are produced to satisfy one test requirement such as hardness, tensile strength, or other commonly accepted mechanical tests other than the bend tests of commercial quality. When chemistry is specified or drawing is required, it should be consistent with the mechanical property specified.

TABLE 26-3. COLD-ROLLED CARBON-STEEL SHEET SIZES

Size	*Thickness*
Over 32 in. wide	All thicknesses
Over 24 to 32 in. wide, incl.	0.0142 in. (29 *gage*) and thicker
Over 12 to 24 in. wide, incl.	0.0142 in. (29 *gage*) and thicker when no special edge, finish, or temper is specified

Porcelain-enameling Sheets. Porcelain-enameling sheets are produced to the fabricating and enameling requirements of articles for vitreous coating under proper conditions. Manufacturing tolerances are the same as those for cold-rolled sheets. Two qualities of porcelain enameling sheets are produced: commercial quality and drawing quality.

Commercial Quality. Sheets are produced from low-carbon steel and are processed for the application of porcelain enamels, and when required are free from minimum surface disturbances known as fluting or stretcher strains, provided that the sheets are properly roller-leveled immediately before fabrication.

Drawing Quality. Sheets are suitable for severe drawing or spinning of identified parts too difficult for the fabricating properties of commercial quality. They are processed to minimize surface disturbances known as fluting or stretcher strains provided that the sheets are properly roller-leveled immediately before fabrication.

CARBON-STEEL STRIP

Carbon-steel strip is classified as carbon steel under the same definition as stated previously for carbon-steel sheets.

Hot-rolled Carbon-steel Strip. Hot-rolled steel is generally classified as strip when it falls within the thickness and width listed in Table 26-4.

TABLE 26-4. HOT-ROLLED CARBON-ROLLED STRIP

Width	*Thickness*
Up to 3½ in., incl.	0.0255 to 0.2030 in. (24 to 6 gage)
Over 3½ to 6 in., incl.	0.0344 to 0.2030 in. (21 to 6 gage)
Over 6 to 12 in., incl.	0.0568 to 0.2490 in. (17 to 3 gage)

Hot-rolled carbon-steel strip is available in three qualities: commercial quality, drawing quality, and physical quality.

Commercial-quality hot-rolled carbon-steel strip is ordinarily produced in a low-carbon grade of steel not exceeding 0.15 per cent when not specified, and is suitable for many purposes where the presence of oxide and normal surface defects are not objectionable.

Drawing-quality hot-rolled carbon-steel strip is customarily produced for use in fabricating identified parts too difficult for the fabricating properties of commercial quality, and where the surface before and after drawing is of secondary importance. Because of excessive die scoring, the oxide should be removed by pickling prior to drawing. This product is commonly furnished from steel of carbon content not exceeding 0.10 per cent. When higher carbon is required, the drawing requirements should be consistent with the chemistry specified.

Physical-quality hot-rolled carbon-steel strip is produced when mechanical properties are specified or required other than the bend test of commercial quality, or uniformity of temper is required. Mechanical properties specified should be consistent with any drawing requirements.

Cold-rolled Carbon-strip Steel. Cold-rolled carbon-strip steel is generally produced from carbon steel under 25 per cent carbon and is available in different tempers with various edges and surface finishes. Standard available finishes are:

TABLE 26-5. MECHANICAL PROPERTIES OF COLD-ROLLED CARBON-STEEL STRIP

Temper	Hardness, Rockwell B	Carbon content, %
No. 1 (hard temper) suitable for flat blanking only, not for bending	90 min gage under 0.070 84 min gage over 0.070	Less than 0.25
No. 2 (half-hard temper) intended for bending 90° across grain	70-85	Less than 0.25
No. 3 (quarter-hard temper) for shallow drawing and stamping. Suitable for bending 180° across, and 90° with the grain	60-75	Less than 0.25
No. 4 (skin-rolled temper) for fairly deep drawing where no stretcher strains are allowed	65 max	Less than 0.15
No. 5 (dead-soft temper) for difficult drawing, where stretcher strains are allowed	55 max	Less than 0.15

No. 1 (dull finish) is a lusterless finish, specially suitable for lacquer or paint application, and reduces contact friction in drawing operations.

No. 2 (regular bright finish) is a moderately high finish, not generally applicable to plating, unless ground and buffed.

No. 3 (best bright finish) is a high-luster finish, the highest obtainable particularly suitable for electroplating.

TABLE 25-6. THICKNESS TOLERANCES FOR COLD-ROLLED CARBON-STEEL STRIP[1,*]

All tolerances are plus or minus

Specified thickness, in., to and over, incl.		Width ranges, in.							
		Over ½ less than 1	1 and less than 2	2 to 6, incl.	Over 6 to 9, incl.	Over 9 to 12, incl.	Over 12 to 16, incl.	Over 16 to 20 incl.	Over 20 to 23$\frac{15}{16}$, incl.
0.160	0.2499	0.002	0.003	0.0035	0.0035	0.0035	0.0045	0.005	0.005
0.099	0.160	0.002	0.002	0.003	0.003	0.003	0.0035	0.0045	0.005
0.068	0.099	0.002	0.002	0.0025	0.003	0.003	0.0035	0.0035	0.0035
0.049	0.068	0.002	0.002	0.0025	0.0025	0.0025	0.003	0.0035	0.0035
0.039	0.049	0.002	0.002	0.0025	0.0025	0.0025	0.003	0.003	0.003
0.034	0.039	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
0.031	0.034	0.0015	0.0015	0.002	0.002	0.002	0.002	0.002	0.002
0.028	0.031	0.0015	0.0015	0.0015	0.002	0.002	0.002	0.002	0.002
0.025	0.028	0.001	0.0015	0.0015	0.002	0.002	0.002	0.002	0.002
0.019	0.025	0.001	0.001	0.0015	0.0015	0.0015	0.002	0.002	0.002
0.012	0.019	0.001	0.001	0.001	0.0015	0.0015	0.0015	0.0015	0.0015
0.011	0.012	0.001	0.001	0.001	0.001	0.0015	0.0015	0.0015	0.0015
0.009	0.011	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
0.005	0.009	0.00075	0.00075	0.00075	0.001	0.001	0.001	0.001	0.001
.....	0.005	0.0005	0.0005	0.0005					

TABLE 25-7. WIDTH TOLERANCES FOR SPECIAL EDGES ON COLD-ROLLED-STEEL STRIP[1]

All tolerances are plus or minus

Edge No.	Specified width, in., incl.	Thickness, in.	Tolerance, in.
1	Over ½ to ¾	$\frac{3}{32}$ and thinner	0.005
1	Over ¾ to 5	⅛ and thinner	0.005
4	Over ½ to 1	$\frac{1}{16}$ to 0.025, incl.	0.015
4	Over 1 to 2	0.2499 to 0.025, incl.	0.025
4	Over 2 to 4	0.2499 to 0.025, incl.	$\frac{3}{64}$
4	Over 4 to 6	0.2499 to 0.047, incl.	$\frac{3}{64}$
5	Over ½ to ¾	$\frac{3}{32}$ and thinner	0.005
5	Over ¾ to 5	⅛ and thinner	0.005
5	Over 5 to 9	⅛ to 0.008, incl.	0.010
5	Over 9 to 20	0.105 to 0.015	0.010
5	Over 20 to 23$\frac{15}{16}$	0.080 to 0.023	0.015
6	Over ½ to $\frac{11}{16}$	$\frac{1}{16}$ to 0.025, incl.	$\frac{1}{64}$
6	Over $\frac{11}{16}$ to 2	0.2499 to 0.025, incl.	$\frac{1}{32}$
6	Over 2 to 6	0.2499 to 0.025, incl.	$\frac{3}{64}$

* Superior numbers relate to References at the end of this section.

TABLE 26-8. THICKNESS TOLERANCES FOR HOT-ROLLED AND HOT-ROLLED-ANNEALED CARBON-STEEL SHEETS, COILS AND CUT LENGTHS[1]

All tolerances are plus or minus

Specified width, in	Thickness ranges, in., incl.														
	0.2299–0.1875	0.1874–0.1800	0.1799–0.1420	0.1419–0.0972	0.0971–0.0822	0.0821–0.0710	0.0709–0.0568	0.0567–0.0509	0.0508–0.0389	0.0388–0.0344	0.0343–0.0314	0.0313–0.0255	0.0254–0.0195	0.0194–0.0142	0.0141 and thinner
To 3½													0.003	0.002	0.002
Over 3½ to 6											0.004	0.003	0.003	0.002	0.002
Over 6 to 12								0.005	0.005	0.004	0.004	0.003	0.003	0.002	0.002
Over 12 to 15	0.008	0.007	0.007	0.007	0.006	0.006	0.006	0.005	0.005	0.004	0.004	0.003	0.003	0.002	
Over 15 to 20	0.008	0.008	0.008	0.008	0.007	0.007	0.006	0.006	0.005	0.004	0.004	0.003	0.003	0.002	
Over 20 to 32	0.009	0.009	0.009	0.008	0.007	0.007	0.006	0.006	0.005	0.004	0.004	0.003	0.003	0.002	
Over 32 to 40	0.009	0.009	0.009	0.009	0.008	0.007	0.006	0.006	0.005	0.004	0.004	0.003	0.003	0.002	0.002
Over 40 to 48	0.010	0.010	0.010	0.010	0.008	0.007	0.006	0.006	0.005	0.004	0.004	0.003	0.003	0.002	0.002
Over 48 to 60			0.010	0.010	0.008	0.007	0.007	0.006	0.005	0.004	0.004				
Over 60 to 70			0.011	0.011	0.009	0.008	0.007	0.007	0.005	0.005	0.005				
Only 70 to 80			0.012	0.012	0.009	0.008									
Over 80 to 90			0.012	0.012	0.010										
Over 90			0.012	0.012											

TABLE 26-9. THICKNESS TOLERANCES FOR COLD-ROLLED CARBON-STEEL SHEETS, COILS AND CUT LENGTHS[1]

All tolerances are plus or minus

Specified width, in., incl.	Thickness ranges, in.													
	0.1875 and thicker	0.1874–0.1420	0.1419–0.0972	0.0971–0.0822	0.0821–0.0710	0.0709–0.0568	0.0567–0.0509	0.0508–0.0389	0.0388–0.0314	0.0313–0.0255	0.0254–0.0195	0.0194–0.0142	0.0141–0.0113	0.0112 and thinner
Up to 15 incl.	0.007	0.008	0.006	0.006	0.005	0.005	0.005	0.004	0.003	0.003	0.003	0.002		
Over 15 to 20	0.007	0.007	0.007	0.006	0.005	0.005	0.005	0.004	0.003	0.003	0.003	0.002		
Over 20 to 24	0.007	0.007	0.007	0.006	0.005	0.005	0.005	0.004	0.003	0.003	0.003	0.002		
Over 24 to 32	0.008	0.008	0.008	0.006	0.006	0.005	0.005	0.004	0.003	0.003	0.003	0.002		
Over 32 to 40	0.009	0.009	0.009	0.007	0.006	0.005	0.005	0.004	0.0035	0.003	0.003	0.002	0.002	0.0015
Over 40 to 48	0.010	0.010	0.009	0.007	0.006	0.005	0.005	0.004	0.0035	0.003	0.003	0.002	0.002	
Over 48 to 60	0.011	0.010	0.010	0.008	0.007	0.006	0.005	0.004	0.0035	0.0035	0.003	0.002		
Over 60 to 70	0.012	0.011	0.010	0.009	0.007	0.006	0.006	0.005	0.004	0.004				
Over 70 to 80	0.013	0.012	0.011	0.009	0.007	0.006	0.006	0.005	0.004	0.004				
Over 80 to 90	0.014	0.012	0.012											
Over 90	0.015	0.012	0.012											

Thickness is measured at any point on the sheet not less than ⅜ in. from the edge.

TABLE 26-10. WIDTH TOLERANCES FOR MILL-EDGE, COLD-ROLLED-STEEL STRIP

All tolerances are plus or minus

Specified Width, In., Incl.	Tolerance, In.
Over 1/2 to 2	1/32
Over 2 to 5	3/64
Over 5 to 10	1/16
Over 10 to 15	3/32
Over 15 to 20	1/8
Over 20 to 23 15/16	5/32

TABLE 26-11. WIDTH TOLERANCES FOR SLIT EDGES, COLD-ROLLED-STEEL STRIP

All tolerances are plus or minus

Specified thickness, in., incl.	Width ranges, in., incl.				
	Over 1/2 to 6	Over 6 to 9	Over 9 to 12	Over 12 to 20	Over 20 to 23 15/16
Over 0.160 to 0.250	0.016	0.020	0.020	0.031	0.031
Over 0.099 to 0.160	0.010	0.016	0.016	0.020	0.020
Over 0.068 to 0.099	0.008	0.010	0.010	0.016	0.020
Over 0.016 to 0.068	0.005	0.005	0.010	0.016	0.020
Up to 0.016	0.005	0.005	0.010	0.016	0.020

TABLE 26-12. WIDTH TOLERANCES, COLD-ROLLED SHEETS[1]

Coils or cut lengths, sheets not resquared

Specified Width, In.	*Plus Tolerance, In. (None Minus)*
Up to 20, incl	1/8
Over 20 to 32, incl	3/16
Over 32 to 48, incl	1/4
Over 48 to 80, incl	5/16
Over 80	3/8

TABLE 26-13. WIDTH TOLERANCES, HOT-ROLLED SHEETS

Sheets with sheared or slit edge, not resquared; coils and cut lengths, including pickled sheets

Specified Widths, In.	*Plus Tolerance, In. (None Minus)*
Up to 15, incl	1/8
Over 15 to 20, incl	1/8
Over 20 to 30, incl	3/16
Over 30 to 50, incl	1/4
Over 50 to 80, incl	5/16
Over 80	3/8

TABLE 26-14. WIDTH TOLERANCES, HOT-ROLLED STRIP

All tolerances are plus or minus

Specified thickness, in.	Width ranges, in.			
	Up to 2, incl.	Over 2 to 5, incl.	Over 5 to 10, incl.	Over 10 to 12, incl.
Mill edge and square edge, all thicknesses	1/32	3/64	1/16	3/32
Cut edge:				
To 0.109, incl	0.008	0.008	0.010	0.016
Over 0.109	0.016	0.016	0.016	0.016

STANDARD ALLOY STEELS

Steel is classified as an alloy steel when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits: manganese, 1.65 per cent; silicon and copper, 0.60 per cent; or in which a definite range or minimum quantity of any of the following elements is specified or required within the limits of the recognized field of construction alloy steels: aluminum, boron, chromium up to

3.99 per cent, cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium or zirconium, or any other alloying element added to obtain a desired alloying effect.

Average physical properties of certain commonly used alloy steels are listed in Table 26-17.

TABLE 26-15. THICKNESS TOLERANCES FOR HOT-ROLLED ALLOY-STEEL STRIP
All tolerances are plus or minus

Thickness range, in.	Specified width ranges, in., incl.				
	To 3½	Over 3½ to 6	Over 6 to 12	Over 12 to 15	Over 15 to 24
0.2299–0.2031	.....	.....	0.007	0.008	0.009
0.2030–0.1719	0.006	0.006	0.006	0.007	0.009
0.1718–0.1570	0.005	0.005	0.006	0.007	0.008
0.1569–0.1420	0.005	0.005	0.006	0.007	0.008
0.1419–0.1271	0.005	0.005	0.006	0.007	0.008
0.1270–0.1121	0.005	0.005	0.006	0.007	0.008
0.1120–0.0972	0.004	0.005	0.005	0.006	0.007
0.0971–0.0822	0.004	0.005	0.005	0.006	0.007
0.0821–0.0710	0.004	0.005	0.005	0.006	0.007
0.0709–0.0636	0.004	0.005	0.005	0.006	0.006
0.0635–0.0568	0.004	0.005	0.005	0.006	0.005
0.0567–0.0509	0.004	0.003			
0.0508–0.0449	0.003	0.003			
0.0448–0.0389	0.003	0.003			
0.0388–0.0344	0.003	0.003			
0.0343–0.0314	0.003				
0.0313–0.0284	0.003				
0.0283–0.0255	0.003				

TABLE 26-16. WIDTH TOLERANCES FOR HOT-ROLLED ALLOY-STEEL STRIP
Coils or cut lengths; all tolerances are plus or minus

Thickness range, in.	Specified width range, in., incl.						
	To 2	Over 2 to 3½	Over 3½ to 6	Over 6 to 12	Over 12 to 15	Over 15 to 20	Over 20 to 24*
Mill Edge							
0.2299–0.2031	.....	.....	.....	1/16	3/32	1/8	5/32
0.2030–0.0621	1/32	3/64	3/64	1/16	3/32	1/8	5/32
0.0620–0.0568	1/32	3/64	3/64	1/16	3/32	1/8	5/32
0.0567–0.0410	1/32	3/64	3/64				
0.0409–0.0344	1/32	3/64	3/64				
0.0343–0.0255	1/32	3/64					
Sheared Edge							
0.2299–0.2031	.....	.....	.....	0.015	0.016	0.016	3/32
0.2030–0.0621	0.008	0.008	0.008	0.010	0.016	0.016	3/32
0.0620–0.0568	0.008	0.008	0.008	0.010	0.016	0.016	3/32
0.0567–0.0410	0.008	0.008	0.008				
0.0409–0.0344	0.008	0.008	0.008				
0.0343–0.0255	0.008	0.008					

* Over 20 to 24, exclusive.

TABLE 26-11 AVERAGE MECHANICAL PROPERTIES OF VARIOUS ALLOY STEELS

[illegible]

SAE No.	Condition of steel	Tensile strength, 1,000 psi	Yield strength, 1,000 psi	Elongation in 2 in., %	Reduction of area, %	Brinell hardness
2315	Hot-rolled	105	68	21	50	207
	Cold-drawn	121	110	12	43	223
	Oil-quenched 1525°F; tempered 1000°F	131	106	20	57	262
2340	Hot-rolled, annealed	95	67	17	52	197
	Annealed and cold-drawn	110	95	14	42	223
	Oil-quenched 1425°F, tempered 1000°F	137	119	22	59	277
3140	Hot-rolled, annealed	96	64	26	56	197
	Annealed and cold-drawn	104	91.3	17	48	212
	Oil-quenched 1550°F, tempered 1000°F	149	128	16	45	302
3150	Hot-rolled, annealed	104	73	19	50	212
	Oil-quenched 1550°F, tempered 1000°F	155	132	14	42	311
4130	Hot-rolled, annealed	90	60	30	45	183
	Cold-drawn and annealed	98	87	21	52	201
	0.250 in.-thick sheet, water-quenched 1550°F; tempered 1000°F	152	138	12		302
4140	Hot-rolled, annealed	90	63	27	57	192
	Annealed and cold-drawn	98	90	19	50	223
	Oil-quenched 1550°F, tempered 1000°F	153	131	16	43	311
4150	Hot-rolled, annealed	100	66	21	51	197
	Oil-quenched 1550°F, tempered 1000°F	158	134	14	42	311
4340	Hot-rolled, annealed	101	69	21	45	207
	Annealed and cold-drawn	111	99	16	42	223
	Oil-quenched 1550°F; tempered 1000°F	182	162	15	40	363
52100	Hot-rolled, annealed	100	81	25	57	192
6150	Hot-rolled, annealed	94	58	22	53	183
	Oil-quenched 1550°F, tempered 1000°F	155	132	15	44	302
8640	Hot-rolled, annealed	92	61	27	57	192
	Oil-quenched 1550°F; tempered 1000°F	148	127	15	42	302
8642	Hot-rolled, annealed	93	63	27	57	192
	Annealed and cold-drawn	105	90	18	49	223
	Oil-quenched 1550°F; tempered 1000°F	149	128	16	45	302
8630	Hot-rolled, annealed	99	58	20	48	197
	Oil-quenched 1550°F; tempered 1000°F	155	132	14	42	311
9255	Hot-rolled, annealed	115	78	22	45	223
	Oil-quenched 1625°F; tempered 1000°F	180	160	15	32	352

TABLE 26-15. THICKNESS TOLERANCES FOR HOT-ROLLED ALLOY-STEEL SHEET
All tolerances are plus or minus

Thickness range, in.	Specified width ranges, in., incl.													
	To 3½	Over 3½ to 5	Over 5 to 6	Over 6 to 10	Over 10 to 15	Over 15 to 24*	24 to 32	Over 32 to 40	Over 40 to 48	Over 48 to 60	Over 60 to 70	Over 70 to 80	Over 80 to 90	Over 90
0.2299 0.1930	.....	.....	.....	.....	.....	.....	0.008	0.009	0.010					
0.1929 0.1800	.....	.....	.....	.....	.....	.....	0.008	0.009	0.010					
0.1799 0.1420	.....	.....	.....	.....	.....	.....	0.008	0.009	0.010	0.010	0.011	0.012	0.012	0.012
0.1419-0.1180	.....	.....	.....	.....	.....	.....	0.008	0.009	0.010	0.010	0.011	0.012	0.012	0.012
0.1179 0.1000	.....	.....	.....	.....	.....	.....	0.008	0.009	0.010	0.010	0.011	0.012	0.012	0.012
0.0999 0.0972	.....	.....	.....	.....	.....	.....	0.008	0.009	0.010	0.010	0.011	0.012	0.012	0.012
0.0971 0.0822	.....	.....	.....	.....	.....	.....	0.007	0.008	0.008	0.008	0.009	0.009	0.010	
0.0821 0.0710	.....	.....	.....	.....	.....	.....	0.007	0.007	0.007	0.007	0.008	0.008		
0.0709 0.0610	.....	.....	.....	.....	.....	.....	0.006	0.006	0.006	0.007	0.007			
0.0609 0.0568	.....	.....	.....	.....	.....	.....	0.006	0.006	0.006	0.006	0.007			
0.0567 0.0509	.....	.....	.....	0.005	0.005	0.006	0.006	0.006	0.006	0.006	0.007			
0.0508 0.0449	.....	.....	.....	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.006			
0.0448 0.0389	.....	.....	.....	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.006			
0.0388 0.0344	.....	.....	.....	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.005			
0.0343 0.0314	.....	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.005			
0.0313 0.0255	.....	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003					
0.0254 0.0195	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003					
0.0194 0.0142	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002					
0.0141 and under	0.002	0.002	0.002	0.002	0.002	.....	.....	0.002	0.002					

* Over 15 to 24, *exclusive*.

TABLE 26-12. WIDTH TOLERANCES FOR HOT-ROLLED ALLOY-STEEL SHEETS
(Coils or cut lengths, not resquared; all tolerances are plus only)

Thickness range, in.	To 2	Over 2 to 3½	Over 3½ to 5	Over 5 to 6	Over 6 to 10	Over 10 to 15	Over 15 to 20	Over 20 to 24*	Over 24 to 30	Over 30 to 48	Over 48 to 60	Over 60 to 80	Over 80
Mill Edge													
0.2299-0.1800	...	...							[illegible]	[illegible]			
0.1799-0.1091	...								[illegible]	[illegible]			
0.1090-0.0621	...								[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0620-0.0568									[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0567-0.0410	...				3/16	3/16	1/4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0409-0.0344					3/16	3/16	1/4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0343-0.0255			1/8	1/8	3/16	3/16	1/4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0254 and under	1/16	1/8	1/8	1/8	3/16	3/16	1/4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sheared Edge													
0.2299-0.1800	...				...				[illegible]	[illegible]			
0.1799-0.1091	...				...	...			[illegible]	[illegible]			
0.1090-0.0621	...	...	...			...			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0620-0.0568	...	...	...	...					[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0567-0.0410	...	...	...		[illegible]	[illegible]	[illegible]	3/16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0409-0.0344	...	...			[illegible]	[illegible]	[illegible]	3/16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0343-0.0255	...	...	1/8	1/8	[illegible]	[illegible]	[illegible]	3/16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.0254 and under	1/16	1/8	1/8	1/8	[illegible]	[illegible]	[illegible]	3/16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

* Over 20 to 24, exclusive.

MANUFACTURERS' STANDARD GAGE FOR STEEL SHEETS

The Manufacturers' Standard Gage for Steel Sheets, listed in Table 26-20, has long been used to designate thicknesses of steel sheets, strip, or coils.

Approximate thicknesses, in this standard, are based on a density of wrought iron taken at 480 lb per cu ft, which is 2 per cent lighter than steel. Because of the inconsistencies encountered in the U.S. Standard Gage Table in converting from weight to thickness, steel producers have adopted the Manufacturers' Standard Gage for Steel Sheets, having a definite thickness equivalent for each gage number, based on the weight of steel.

TABLE 26-20. MANUFACTURERS' STANDARD GAGE FOR STEEL SHEETS

Manufacturers' Standard Gage No.	Oz per sq ft	Lb per sq ft	In. equivalent thickness
3	160	10.0000	0.2391
4	150	9.3750	0.2242
5	140	8.7500	0.2092
6	130	8.1250	0.1943
7	120	7.5000	0.1793
8	110	6.8750	0.1644
9	100	6.2500	0.1495
10	90	5.6250	0.1345
11	80	5.0000	0.1196
12	70	4.3750	0.1046
13	60	3.7500	0.0897
14	50	3.1250	0.0747
15	45	2.8125	0.0673
16	40	2.5000	0.0598
17	36	2.2500	0.0538
18	32	2.0000	0.0478
19	28	1.7500	0.0418
20	24	1.5000	0.0359
21	22	1.3750	0.0329
22	20	1.2500	0.0299
23	18	1.1250	0.0269
24	16	1.0000	0.0239
25	14	0.87500	0.0209
26	12	0.75000	0.0179
27	11	0.68750	0.0164
28	10	0.62500	0.0149
29	9	0.56250	0.0135
30	8	0.50000	0.0120
31	7	0.43750	0.0105
32	6.5	0.40625	0.0097
33	6	0.37500	0.0090
34	5.5	0.34375	0.0082
35	5	0.31250	0.0075
36	4.5	0.28125	0.0067
37	4.25	0.26562	0.0064
38	4	0.25000	0.0060

AMERICAN STANDARD PREFERRED THICKNESSES FOR UNCOATED THIN FLAT METALS (UNDER 0.250 IN.)

The preferred thicknesses in this standard provide a simplified system for designating the thickness of uncoated, thin, flat metals and alloys by decimal parts of an inch, thus eliminating the confusion caused by the various gage-number systems. Requirements of industry permit leeway in the choice of thickness in some instances, but it is recognized that for many applications, particularly the tonnage requirements of the mass-production industries, thicknesses, more frequently than not, are determined by critical engineering design or manufacturing considerations. For these special reasons, all decimal thicknesses of metals, contingent on application, shall continue to be recognized as commercial and in no way be construed as nonstandard.

However, for general-purpose applications or where requirements permit some latitude in the selection of thickness, the simplified preferred thicknesses given in the table will facilitate interchangeability of different metals in design, reduce inventory, and increase the availability in warehouse stocks of thicknesses commonly required for general-purpose applications.

The thicknesses in Table 26-21 are applicable to uncoated, thin, flat metals and alloys. Each thickness is approximately the same percentage greater than the next smaller one. Based upon the 40 series of American Standard Preferred Numbers they provide a coverage equivalent to previous systems, and should meet most of the general-purpose needs of industry.

If intermediate thicknesses are required, selections shall be made for all metals and alloys by the use of thicknesses based on the 80 series of American Standard Preferred Numbers (Z17.1-1936).

TABLE 26-21. PREFERRED THICKNESSES FOR UNCOATED METALS AND ALLOYS (ASA B32.1-1952)

	0.125*	0.063*	0.032*	0.016*	0.008*	0.004*
0.236	0.118	0.060	0.030	0.015		
0.224*	0.112*	0.056*	0.028*	0.014*	0.007*	
0.212	0.106	0.053	0.026	0.013		
0.200*	0.100*	0.050*	0.025*	0.012*	0.006*	
0.190	0.095	0.048	0.024			
0.180*	0.090*	0.045*	0.022*	0.011*		
0.170	0.085	0.042	0.021			
0.160*	0.080*	0.040*	0.020*	0.010*	0.005*	
0.150	0.075	0.038	0.019			
0.140*	0.071*	0.036*	0.018*	0.009*		
0.132	0.067	0.034	0.017			

All dimensions are given in inches.
* Indicated thicknesses are 20-series numbers.

ELECTRICAL STEEL

Flat-rolled electrical steel comprises the specially manufactured steels containing up to 6 per cent silicon, in cut lengths or in coils, which are processed to develop definite magnetic and physical properties which suit them for use in transformer cores, rotors and stators of rotating electrical equipment, pole pieces, and relays.

Manufacturers' Standard Electrical Steel Gage Table. As a result of studies conducted by the steel and electrical industries a Manufacturers' Standard Steel Gage Table (ESSG) (Table 26-22) was established. Because the maximum core-loss values can be met only for a definite thickness, and since the actual density of the steel varies with type, electrical steel is produced only to the decimal thickness shown in the table

TABLE 26-22. MANUFACTURERS' STANDARD ELECTRICAL STEEL GAGE[1]

Electrical steel gage number	Thickness, in.	Electrical steel gage number	Thickness, in.
32	0.0100	20	0.0375
30	0.0125	19	0.0435
29	0.0140	18	0.0500
28	0.0155	17	0.0560
27	0.0170	16	0.0625
26	0.0185	15	0.0700
25	0.0220	14	0.0780
24	0.0250	13	0.0940
23	0.0280	12	0.1090
22	0.0310	11	0.1250
21	0.0340		

TABLE 26-23. THICKNESS TOLERANCES FOR FLAT-ROLLED ELECTRICAL STEEL
All tolerances are plus or minus

Electrical steel gage number	Equivalent thickness, in.	Tolerance, in.
32 to 26, incl.	0.0100 to 0.0185, incl.	0.002
25 to 22, incl.	0.0220 to 0.0310, incl.	0.003
21 to 20, incl.	0.0340 to 0.0375, incl.	0.004
19 to 18, incl.	0.0435 to 0.0500, incl.	0.005
17 to 15, incl.	0.0560 to 0.0700, incl.	0.006
14	0.0780	0.007
13	0.0940	0.008

Note: Thickness is measured at any point on the steel not less than ⅜ in. from an edge.

TABLE 26-24. WIDTH TOLERANCES FOR FLAT-ROLLED ELECTRICAL STEEL
Not resquared

Width, In.	*Tolerance, In.*
To 6 incl.	Minus 1/64 plus 1/64
Over 6 to 15 incl.	Minus 1/32 plus 1/32
Over 15 to 20 incl.	Minus 0 plus 3/16
Over 20 to 30 incl.	Minus 0 plus ¼
Over 30 to 48 incl.	Minus 0 plus ⅜

The standard treatments for flat-rolled electrical steel are:

1. *Deoxidized Surface.* Accomplished by use of a reducing gas which, by chemical reduction, substantially lessens the amount of hot mill oxide and minimizes development of annealing oxide.

2. *Pickling.* For certain applications, used to remove surface oxide.

3. *Oiling.* Treatment to retard rusting in storage or in transit, particularly advisable when electrical steel is pickled or deoxidized in final processing. Accumulated condensed or other moisture must be guarded against, since oiling is a temporary protection.

STAINLESS AND HEAT-RESISTING STEELS*

These steels cover a very wide range of properties. With careful selection they can, with few exceptions, be used for all applications for which the carbon and lower-alloy steels are used and where, in addition, corrosion or heat resistance is an essential requirement.

* Reviewed by Robert Sergeson, Chief Metallurgical Engineer, Rotary Electric Steel Co.

TABLE [illegible]. CLASSIFICATION BY SIZE, STAINLESS AND HEAT-RESISTANT STEELS

[illegible]	[illegible]	[illegible]
[illegible]	[illegible] ... 24 in. or over in width, ... [illegible] ... all widths ... [illegible]	Hot-rolled ... [illegible] ... under 24 in. wide ... [illegible] ... under 24 in. wide, under [illegible] in. thick

Stainless and heat-resisting steel is available in the following finishes in hot- and cold-rolled sheets:

No. 1	Hot-rolled, annealed and pickled
No. 2D	Full-finish (dull cold-rolled)
No. 2B	Full-finish (bright cold-rolled)
No. 4	Polished
No. 6	Polish tampico brushed
No. 7	High-luster polished
No. 8	Mirror finished

Hot-rolled strip is not manufactured to a surface specification other than that given by its hot rolling, annealing, and pickling.

Cold-rolled strip is produced in two finishes: No. 1, cold-rolled, annealed, and pickled; No. 2, cold-rolled, annealed, pickled, and rerolled.

TABLE 26-26. THICKNESS TOLERANCES FOR HOT- AND COLD-ROLLED STAINLESS-STEEL SHEET

All tolerances are plus or minus

Specified Thickness, In.	*Permissible Variations, In.*
0.005	0.001
0.006 to 0.007, incl.	0.0015
0.008 to 0.016, incl.	0.002
0.017 to 0.026, incl.	0.003
0.027 to 0.040, incl.	0.004
0.041 to 0.058, incl.	0.005
0.059 to 0.072, incl.	0.006
0.073 to 0.083, incl.	0.007
0.084 to 0.098, incl.	0.008
0.099 to 0.114, incl.	0.009
0.115 to 0.130, incl.	0.010
0.131 to 0.145, incl.	0.012
0.146 to less than 3/16 in.	0.014

TABLE 26-27. THICKNESS TOLERANCES FOR HOT-ROLLED STAINLESS-STEEL STRIP

All tolerances are plus or minus

Specified thickness, in.	Width ranges, in.			
	5 in. and under	Over 5, up to 10 in., incl.	Over 10, up to 15 in., incl.	[illegible]
[illegible] to [illegible], incl.	0.003	0.004		
[illegible] to 0.12[illegible], incl.	0.004	0.005	0.006	0.007
[illegible] to 0.187, incl.	0.005	0.006	0.007	[illegible]
[illegible] to 0.249, incl.	0.006	0.007	0.008	[illegible]

TABLE 26-28. THICKNESS TOLERANCES FOR COLD-ROLLED STAINLESS-STEEL STRIP¹
All tolerances are plus or minus

Specified thickness, in., incl.	Width ranges, in., incl.							
	Under 1 to 3/16	Under 3 to 1	3 to 6	Over 6 to 9	Over 9 to 12	Over 12 to 16	Over 16 to 20	Over 20 to 23 15/16
Under 3/16 to 0.161	0.002	0.003	0.004	0.004	0.004	0.005	0.006	0.007
0.160 to 0.100	0.002	0.002	0.003	0.004	0.004	0.004	0.005	0.005
0.099 to 0.069	0.002	0.002	0.003	0.003	0.003	0.004	0.004	0.004
0.068 to 0.050	0.002	0.002	0.003	0.003	0.003	0.003	0.004	0.004
0.049 to 0.040	0.002	0.002	0.0025	0.003	0.003	0.003	0.004	0.004
0.039 to 0.035	0.002	0.002	0.0025	0.003	0.003	0.003	0.003	0.003
0.034 to 0.029	0.0015	0.0015	0.002	0.0025	0.0025	0.0025	0.003	0.003
0.028 to 0.026	0.001	0.0015	0.0015	0.002	0.002	0.002	0.0025	0.003
0.025 to 0.020	0.001	0.001	0.0015	0.002	0.002	0.002	0.0025	0.0025
0.019 to 0.017	0.001	0.001	0.001	0.0015	0.0015	0.002	0.002	0.002
0.016 to 0.013	0.001	0.001	0.001	0.0015	0.0015	0.0015	0.002	0.002
0.012	0.001	0.001	0.001	0.001	0.0015	0.0015	0.0015	0.0015
0.011	0.001	0.001	0.001	0.001	0.001	0.0015	0.0015	0.0015
0.010*	0.001	0.001	0.001	0.001	0.001	0.001	0.0015	0.0015

Thickness measurements are taken 3/8 in. from edge of the strip, except that on widths less than 1 in. the tolerances are applicable for measurements at all locations.

* For thicknesses under 0.010 in. in width and up to and including 16 in., a variation of plus or minus 10% of the thickness is to apply; for widths over 16 to 23 15/16 in., inclusive, a variation of plus or minus 15% of the thickness is to apply.

Width tolerances for hot- and cold-rolled stainless-steel sheet, less than 3/16 in. thick (not resquared), are as follows: widths up to 48 in., plus 1/16 in., minus zero; widths 48 in. and over, plus 1/8 in., minus zero.

TABLE 26-29. WIDTH TOLERANCES FOR HOT-ROLLED STAINLESS-STEEL STRIP¹
All tolerances are plus or minus

Specified thickness, in.	Width ranges, in., incl.					
	To 2	Over 2 to 5	Over 5 to 10	Over 10 to 12	Over 12 to 15	Over 15 to 26
Mill edge, all thicknesses	3/64	3/64	3/32	1/8	1/8	3/8
Slit edge, thicknesses to 0.150, incl.	3/64	1/64	1/64	1/16	3/32	3/32
Slit edge, thicknesses over 0.150	1/32	1/32	1/32	1/8	1/8	1/8

TABLE 26-30. WIDTH TOLERANCES FOR COLD-ROLLED STAINLESS-STEEL STRIP, NO. 1 OR NO. 5 EDGE¹
All tolerances are plus or minus

Specified edge	Width, in.	Thickness, in.	Tolerance, in.
Nos. 1 and 5	3/32 and under	1/16 and under	0.005
Nos. 1 and 5	Over 3/32 to 3/4, incl.	3/32 and under	0.005
Nos. 1 and 5	Over 3/4 to 5, incl.	1/8 and under	0.005
No. 5	Over 5 to 9, incl.	1/8 to 0.008, incl.	0.010
No. 5	Over 9 to 20, incl.	0.105 to 0.015	0.010
No. 5	Over 20 to 23 15/16, incl.	0.099 to 0.023	0.015

TABLE 26-[illegible] MECHANICAL AND FABRICATION PROPERTIES OF STAINLESS STEELS SUITABLE FOR STAMPING OPERATIONS†

Group*	AISI type No.	Adaptable for deep drawing	Yield strength, 1,000 psi	Ultimate strength, 1,000 psi	Elongation, % in 2 in., min	Hardness: Brinell (max)	Hardness: Rockwell (max)	Impact, ft-lb, Izod	Reduction in area, %, min	Heat treatment: Annealing temp, deg F	Heat treatment: Hardening temp, deg F
A	301	x	35	100	50	180	B90	85 min	60	1950-2050	Hardenable by cold working [illegible]
A	302	x	30	80	50	180	B90	85 min	60	1850-2050	Hardenable by cold working [illegible]
A	304	x	30	80	50	180	B90	85 min	60	1850-1950	Hardenable by cold working [illegible]
A	305	x	25	75	50	180	B90	85 min	60	1850-1950	Hardenable by cold working [illegible]
A	308	x	30	80	40	200	B95	70 min	50	1850-2050	Hardenable by cold working [illegible]
A	310	x	30	75	40	180	B90	80 min	50	2050-2150	Hardenable by cold working [illegible]
A	316	x	30	75	40	200	B95	70 min	50	1975-2150	Hardenable by cold working [illegible]
A	317	x	30	75	40	200	B95	70 min	50	1975-2150	Hardenable by cold working [illegible]
A	321	No	30	75	40	200	B95	80 min	50	1800-2000	Hardenable by cold working [illegible]
A	347	No	30	80	40	200	B95	80 min	50	1800-2000	Hardenable by cold working [illegible]
M	403	No	32	60	20	200	B95	85 min	50	1500-1650	1700-1850
M	410	x	32	60	20	200	B95	85 min	50	1500-1650	1700-1850
F	430	x	35	60	20	200	B95	3-85	40	1400-1500	Not hardenable
F	442	No	45	80	20	200	B95	Low	40	1500	Not hardenable
F	446	No	45	75	20	200	B95	Low	40	1450-1600	Not hardenable

* A, chromium-nickel austenitic, hardenable by cold working; M, chromium martensitic, hardenable; F, chromium ferritic, nonhardenable.
† All types are readily formable by bending.

TABLE 26-[illegible]. WIDTH TOLERANCES FOR COLD-ROLLED STAINLESS-STEEL STRIP, NO. 1 EDGE

All tolerances are plus or minus

Specified thickness, in.	Width ranges, in., incl.					
	Under ½ to [illegible]	½ to 6	Over 6 to 9	Over 9 to 12	Over 12 to 20	Over 20 to [illegible]
[illegible] to [illegible], incl.		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] to [illegible], incl.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] to [illegible], incl.	0.008	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] and under	0.005	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TIN MILL PRODUCTS

Low-carbon steels coated with tin or terne metal (a lead-tin alloy), and uncoated black plate, are produced mainly for the canmaking and roofing industries.

Black plate is produced in thicknesses varying from [illegible] to [illegible] in., in various qualities and finishes.

Tin plate is produced in thicknesses varying from [illegible] to [illegible] in., with tin coatings applied by various methods.

Short terneplate is processed black plate coated with terne metal of various thicknesses. For manufacturing purposes, terneplate is supplied with coating weights of [illegible], 8, 15, 20, and 40 lb per double-base box. A double-base box is 224 sheets of 14- by 20-in. short terneplate sheets. Coating weight is the amount of tin or tin alloy (terne) used in the coating operation, not the amount of tin adhering to the sheets.

References

1. "Steel Products Manual," American Iron & Steel Institute.
2. "Stainless Steel Handbook," Allegheny Ludlum Steel Corp., [illegible].
3. "Steel Data Book," Joseph T. Ryerson & Son, Inc., [illegible].

SECTION 27

NONFERROUS STAMPING MATERIALS

WROUGHT ALUMINUM ALLOYS*

These alloys are essentially of two distinct classes: (1) non-heat-treatable, in which the harder tempers are produced by cold working, and (2) heat-treatable, in which the properties of strength and hardness are increased by thermal treatments.

Wrought Alloy Designations. Most wrought alloys are designated by a number followed by the letter S. The principal alloying element determines the numerical range in which various wrought alloys are placed. Some wrought alloys have designations assigned by the producers which do not conform to the above system. The Reynolds R300 series and the Kaiser K100 series are examples.

New alloys have been developed, and in the absence of standard alloy designations, a number of unrelated alloy-designation systems were created. Their use has been generally unsatisfactory and has led to frequent confusion and misunderstanding.

The Aluminum Association developed and put into use on October 1, 1954, a new alloy-designation system using a four-digit index system. The first digit indicates the alloy group. The second digit indicates modifications of the original alloy or impurity limits. The last two digits indicate the aluminum purity in the 1xxx group. In the 2xxx through the 8xxx alloy groups, the last two of the four digits have no special significance but serve only to identify the different alloys in the group. Generally, these digits are the same as those formerly used to designate the same alloy. Thus, 2014 was formerly 14S, and 3003 was 3S. For new alloys, these last two digits are assigned consecutively beginning with xx01. Table 27-1 lists the designations for aluminum alloy groups by both the commercial designation and the Aluminum Association system.

TABLE 27-1. DESIGNATIONS FOR WROUGHT ALUMINUM ALLOY GROUPS

Old commercial designation	New AA designation	*Major alloying element*
2S	1xxx	Aluminum, 99.00% min and greater
3S–9S	3xxx	Manganese
10S–29S	2xxx	Copper
30S–49S	4xxx	Silicon
50S–59S	5xxx	Magnesium
60S–69S	6xxx	Magnesium and silicon
70S–79S	7xxx	Zinc
	8xxx	Other elements
	9xxx	Unused series

Temper Designations. The temper designation follows the alloy designation as a suffix, *e.g.*, 24SO. The temper is indicated by a letter which may have a suffix of one

* Reviewed by R. B. Smith, Director, Engineering Standards & Data, Products and Application Department, Reynolds Metals Co.

TABLE 27-2. NOMINAL COMPOSITION OF ALUMINUM SHEET ALLOYS

Alloy		Per cent of alloying elements (aluminum and normal impurities constitute remainder)					
AA designation	Commercial designation	Silicon	Copper	Manganese	Magnesium	Chromium	Zinc
1100	2S		99.0 minimum aluminum				
3003	3S*		...	1.2			
3004	4S*		...	1.2	1.0		
2014	14S*,†	0.8	4.5	0.8	0.4		
2024	24S*		4.5	0.6	1.5		
5050	50S*			...	1.3		
5052	52S			...	2.5	0.25	
6061	61S*	0.6	0.25	...	1.0	0.25	
7075	75S*		1.6	...	2.5	0.30	5.6

* These alloys are also produced as Alclad sheet, which has a cladding of pure aluminum or a suitable aluminum alloy metallurgically bonded to both sides of the core alloy. The cladding electrolytically protects the core alloy wherever it is exposed at cut surfaces. Cladding is indicated by adding the prefix "Alclad."

† Alclad 14S is also designated R301.

or more digits to designate the temper treatment more completely, *e.g.*, –H14. Designations applicable to aluminum sheet are as follows:

F	As fabricated. Applies to products which acquire some temper qualities in the shaping process but are not subsequently thermally treated or intentionally strain hardened	
O	Annealed, recrystallized. Applies to the softest temper	
H1	Strain hardened only	An additional digit indicates the final degree of strain hardening
H2	Strain hardened and then partially annealed	
H3	Strain hardened and then stabilized	
W	Solution heat-treated. An unstable temper	
T3	Solution heat-treated and then cold-worked	
T4	Solution heat-treated and naturally aged to a substantially stable condition	
T6	Solution heat-treated and then artificially aged	

The Aluminum Association temper designations are the same as in the old commercial designations, and are separated from the alloy designation by a dash, thus: 1100-H12.

TABLE 27-3. STANDARD TEMPERS OF ALUMINUM SHEET

Alloy	Standard tempers*		Alloy	Standard tempers*
	Flat sheet	Coiled sheet		
Heat-treatable Alloys			Non-heat-treatable Alloys‡	
R301 or Alclad 14S	O	O		O
	T3†	T4	2S	H12 (¼ hard)
	T6	T6	3S	H14 (½ hard)
			Alclad 3S	H16 (¾ hard)
24S	O	O		H18 (full hard)
Alclad 24S	T3†	T4		
			4S	O
61S	O	O	Alclad 4S	H32 (¼ hard)
Alclad 61S	T4	T4	50S	H34 (½ hard)
	T6	T6	Alclad 50S	H36 (¾ hard)
			52S	H38 (full hard)
75S	O	O		
Alclad 75S	T6	T6		

* See Temper Designations for explanation of tempers.

† If heat-treated by the user, the temper will be T4.

‡ Also produced in equivalent tempers by strain hardening and then partial annealing (H2 series of tempers).

TABLE 27-4. TYPICAL MECHANICAL PROPERTIES OF ALUMINUM SHEET ALLOYS

Alloy	Temper	Tension: Strength, psi: Ultimate	Tension: Strength, psi: Yield	Tension: Elongation,* %	Shear: Shearing strength, psi
2S	O	13,000	5,000	35	9,000
	H12	16,000	15,000	12	10,000
	H14	18,000	17,000	9	11,000
	H16	21,000	20,000	6	12,000
	H18	24,000	22,000	5	13,000
3S Alclad 3S	O	16,000	6,000	30	11,000
	H12	19,000	18,000	10	12,000
	H14	22,000	21,000	8	14,000
	H16	26,000	25,000	5	15,000
	H18	29,000	27,000	4	16,000
4S Alclad 4S	O	26,000	10,000	20	16,000
	H32	31,000	25,000	10	17,000
	H34	35,000	29,000	9	18,000
	H36	38,000	33,000	5	20,000
	H38	41,000	36,000	5	21,000
R301 or Alclad 14S	O	25,000	10,000	21	18,000
	T3	63,000	40,000	20	37,000
	T4	61,000	37,000	22	37,000
	T6	68,000	60,000	10	41,000
24S	O	27,000	11,000	20	18,000
	T3	70,000	50,000	18	41,000
	T4	68,000	47,000	20	41,000
Alclad 24S	O	26,000	11,000	20	18,000
	T3	65,000	45,000	18	40,000
	T4	64,000	42,000	19	40,000
Alclad 50S	O	21,000	8,000	24	15,000
	H32	25,000	21,000	9	17,000
	H34	28,000	24,000	8	18,000
	H36	30,000	26,000	7	19,000
	H38	32,000	29,000	6	20,000
52S	O	28,000	13,000	25	18,000
	H32	35,000	25,000	12	20,000
	H34	38,000	31,000	10	21,000
	H36	40,000	35,000	8	23,000
	H38	42,000	37,000	7	24,000
61S	O	18,000	8,000	25	12,000
	T4	35,000	21,000	22	24,000
	T6	45,000	40,000	12	30,000
Alclad 61S	O	17,000	7,000	25	11,000
	T4	33,000	19,000	22	22,000
	T6	42,000	37,000	12	27,000
75S	O	33,000	15,000	17	22,000
	T6	83,000	73,000	11	48,000
Alclad 75S	O	32,000	14,000	17	22,000
	T6	76,000	67,000	11	46,000

* Elongation values are for 1/16-in.-thick specimens with a 2-in. gage length.

TABLE 27-5. STANDARD ALUMINUM SHEET THICKNESSES, INCHES

0.012	0.040	0.091
0.016	0.051	0.102
0.020	0.064	0.125
0.025	0.072	0.156
0.032	0.081	0.188

0.250 in. and thicker is plate

TABLE 27-6. THICKNESS TOLERANCES, INCHES, FOR ALUMINUM SHEET
All tolerances are plus or minus*

Specified thickness, in., incl.	Width ranges, in., over and through						
	Up to 18	18 through 36	36 through 54	54 through 72	72 through 90	90 through 102	102 through 132
Alloys 2S, 3S, and 50S							
0.006-0.007	0.001	0.001					
0.008-0.010	0.001	0.0015					
0.011-0.017	0.0015	0.0015	0.002				
0.018-0.028	0.0015	0.002	0.0025				
0.029-0.036	0.002	0.002	0.0025	0.0035			
0.037-0.045	0.002	0.0025	0.003	0.004			
0.046-0.068	0.0025	0.003	0.004	0.005	0.007		
0.069-0.076	0.0025	0.003	0.004	0.006	0.008		
0.077-0.096	0.003	0.003	0.004	0.006	0.008		
0.097-0.108	0.0035	0.004	0.005	0.007	0.009	0.010	
0.109-0.140	0.0045	0.0045	0.005	0.007	0.009	0.010	
0.141-0.172	0.005	0.006	0.008	0.009	0.011	0.012	
0.173-0.203	0.007	0.007	0.009	0.011	0.013	0.015	
0.204-0.249	0.009	0.009	0.011	0.013	0.015	0.017	

Specified thickness, in., incl.	Width ranges, in., over and through											
	Up to 18	18 through 36	36 through 48	48 through 54	54 through 60	60 through 66	66 through 72	72 through 78	78 through 84	84 through 90	90 through 96	96 through 102
Alloys 4S, 14S, 24S, 52S, 61S, and 75S												
0.006-0.007	0.001	0.0015										
0.008-0.010	0.001	0.0015										
0.011-0.017	0.0015	0.0015										
0.018-0.028	0.0015	0.002	0.0025									
0.029-0.036	0.002	0.002	0.0025									
0.037-0.045	0.002	0.0025	0.003	0.004	0.005							
0.046-0.068	0.0025	0.003	0.004	0.005	0.005	0.006	0.007	0.008	0.009			
0.069-0.076	0.003	0.003	0.004	0.005	0.006	0.008	0.010	0.010	0.011	0.012		
0.077-0.096	0.0035	0.0035	0.004	0.005	0.006	0.008	0.010	0.010	0.011	0.012		
0.097-0.108	0.004	0.004	0.005	0.005	0.007	0.010	0.012	0.013	0.014	0.016	0.018	0.020
0.109-0.140	0.0045	0.0045	0.005	0.005	0.007	0.010	0.012	0.013	0.014	0.015	[illegible]	[illegible]
0.141-0.172	0.006	0.006	0.008	0.008	0.009	0.012	0.014	0.015	0.016	0.017	0.019	[illegible]
0.173-0.203	0.007	0.007	0.010	0.010	0.011	0.014	0.016	0.017	0.017	0.017	0.022	[illegible]
0.204-0.249	0.009	0.009	0.011	0.011	0.013	0.016	0.018	0.018	0.018	0.023	0.024	[illegible]

* When a dimensional tolerance is specified other than as an equal bilateral tolerance, the value of the standard tolerance is that which would apply to the mean of the maximum and minimum dimensions permissible under the tolerance.

TABLE 27-7. WIDTH TOLERANCES, INCHES, FOR ALUMINUM SHEET
Sheets not resquared; all tolerances are plus or minus

Flat sheet and plate sheared			Coiled sheet (slit)	
Specified width, in., over-through	Thickness range, in., incl. 0.006–0.162	Thickness range, in., incl. 0.163–0.249	Specified width, in., over-through	Thickness range, 0.006–0.162 in.
Up to 4	1/32	...	Up to 6	0.010
4–18	1/16	3/32	6–12	0.016
18–36	3/32	1/8	12–24	1/32
36–54	1/8	5/16	24–48	3/16
54–72	5/32	3/16		
72–102	3/16	1/4		

Data courtesy of Reynolds Metals Co.

TABLE 27-8. LENGTH TOLERANCES FOR ALUMINUM FLAT SHEET
For all specified thicknesses from 0.006 to 0.249 in., incl.

Specified Length, In.	*Tolerance, In., Plus or Minus*
Through 18	1/16
Over 18 through 48	3/32
Over 48 through 120	1/8
Over 120 through 180	5/32
Over 180 through 240	1/4

Courtesy of Reynolds Metals Co.

COPPER AND WROUGHT COPPER ALLOYS*

In thicknesses up to and including 0.188 in., these materials are classed as strip up to and including 20-in. width, and as sheet in wider widths. Over 0.188 in. thick, they are classed as bars up to and including 12-in. width, and as plate for widths over 12 in.

Table 27-9 lists properties of nine types of coppers and brasses most often encountered in pressworking. SAE 71 covers materials of maximum copper content, characterized by high electrical and thermal conductivities and corrosion resistance, with excellent workability.

The rest are straight brasses or copper-zinc alloys, characterized by greater strength and hardness than for the coppers. They have wide application for fabricated parts, particularly where machinability is not a prime requisite.

For annealed materials (see Table 27-9), present practice is almost invariably to indicate degree of anneal in terms of grain size (Table 27-13).

It is beyond the scope of this handbook to list copper and its numerous alloys as available in strip and sheet of various thicknesses. Basic sizes and tolerances are given in Tables 27-10 and 27-11.

Copper alloys are classified as either refractory or nonrefractory (see Table 27-11). Alloys are defined as "refractory" which contain less than nominally 61 per cent copper, also all alloys containing more than one of the following elements and any alloy nominally containing the following amounts or more: aluminum 2 per cent, beryllium 1.50 per cent.

Cold-worked brasses are available in the rolled tempers listed in Table 27-12. It is strongly recommended that reference be made directly to the degree of reduction in per cent. Copper alloys are cold-worked to increase their hardness or temper instead of being heated and quenched as required by most other metals. The various tempers are obtained by reducing the thickness of the sheet or area of the wire by rolling. The approximate percentage of reduction from the soft state to the desired temper is included in the table.

* Reviewed by A. L. Hein, Research Engineer, Copper & Brass Research Association.

TABLE 27-9. TYPICAL PROPERTIES OF WROUGHT COPPERS AND PLAIN BRASS SHEETS AND STRIP

SAE No.	71	71 (sheet), 75 (tube)			79A, 74D	79B	70B, 70A, 74C, 80A	74B, 70C, 80B	74A
Type	Electrolytic tough-pitch copper	Deoxidized copper	Gilding, 95%	Commercial bronze, 90%	Red brass, 85%	Low brass, 80%	Cartridge brass, 70%	Yellow brass	Muntz metal
Composition, % (excluding impurities)	Cu, 99.90 min, oxy. about 0.04	Cu, 99.90 min, P, 0.015-0.040	Cu, 94.0-96.0, Zn, remainder	Cu, 89.0-91.0, Zn, remainder	Cu, 84.0-86.0, Zn, remainder	Cu, 78.5-81.5, Zn, remainder	Cu, 68.5-71.5, Zn, remainder	Cu, 64.0-68.5, Zn, remainder	Cu, 59.0-63.0, Zn, remainder
Mechanical properties:									
Modulus of elasticity in tension, 10^6 psi	17.0	17.0	17.0	17.0	17.0	16.0	16.0	15.0	15.0
Tensile strength, 1,000 psi:									
Annealed*	32.0	32.0	34.0	37.0	39.0	44.0	47.0	47.0	54.0
Half hard	42.0		48.0	52.0	57.0	61.0	62.0	61.0	70.0
Hard	50.0	55.0‡	56.0	61.0	70.0	74.0	76.0	74.0	74.0‡
Yield strength, 10^3 psi†									
Annealed*	10.0	10.0	10.0	10.0	10.0	14.0	15.0	15.0	21.0
Half hard	36.0		40.0	45.0	49.0	50.0	52.0	50.0	[illegible]
Hard	45.0	50.0‡	50.0	54.0	57.0	59.0	63.0	60.0	[illegible]‡
Elongation in 2 in., %									
Annealed*	45	45	45	45	48	50	62	62	45
Half hard	14		12	11	12	18	23	23	10.0
Hard	6	8‡	5	5	5	7	8	8	[illegible]‡
Hardness, Rockwell:									
Annealed*	F40	F40	F46	F53	F56	F61	F64	F64	F80
Half hard	B40		B52	B58	B65	B70	B70	B70	B75
Hard	B50	B60‡	B64	B70	B77	B82	B82	B80	B80‡
Shear strength, 10^3 psi:									
Annealed*	22.0	22.0	26.0	28.0	34.0	32.0	33.0	33.0	40.0
Half hard	26.0		34.0	35.0	37.0	39.0	40.0	40.0	44.0
Hard	28.0	29.0‡	37.0	38.0	42.0	44.0	44.0	43.0	
Endurance strength, 10^3 psi (100 million cycles):									
Annealed*	11.0‡						14.0		
Half hard	17.0						18.0		
Hard	13.0	19.0‡					21.0	14.0	

Fabricating properties									
Capacity for being cold-worked	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent	Fair
Capacity for being hot-worked	Excellent	Excellent	Good	Good	Good	Fair	Fair	Poor	Excellent
Hot-working temp, deg F	1400–1600	1400–1600	1400–1600	1400–1600	1450–1650	1500–1650	1350–1550	...	1150–1450
Annealing temp, deg F	700–1200	700–1200	800–1150	800–1150	800–1350	800–1300	800–1400	800–1300	800–1100
Machinability (free-cutting brass = 100)	20	20	20	20	30	30	30	30	40
Common pressworking fabrication processes	Blanking, coining, drawing, piercing and punching, shearing, squeezing and swaging, stamping					Blanking, drawing, forming and bending, heading and upsetting, piercing and punching, shearing, squeezing and swaging, stamping			Blanking, forming and bending, hot forming and pressing, hot heading and upsetting, shearing
	Heading and upsetting, hot forging and pressing, impact extrusion	Forming and bending, hot forging and pressing	Forming and bending	Forming and bending, heading and upsetting, hot forging and pressing	Forming and bending, heading and upsetting				
Available forms	Flat products, rod, wire, tube, pipe, shapes	Tube, pipe, rod, rolled strip	Rolled strip	Rolled strip, sheet, plate, rod, wire, tube	Rolled strip, sheet, wire, tube, pipe	Wire, rolled strip and flat wire	Rolled strip and flat wire, drawn flat wire, rolled bar, sheet, rod, wire tube	Rolled strip and flat wire, drawn flat wire, sheet, plate rod, wire	Rolled strip and bar sheet, plate, rod, tube
Typical uses	Architectural trim; automobile radiators; electrical contacts, ball floats	Air, water, gasoline, and oil lines; rotating bands	Coins; bullet jackets; fuse caps; primers; jewelry; base for gold or vitreous enamel	Grillwork; cosmetic compacts; primer caps; costume jewelry; vitreous enamel base	Weatherstrip; electrical sockets; fasteners; heat-exchanger tubes; jewelry	Ornamental metalwork; battery caps; musical instruments; clock dials; pump lines	Lamp fixtures, fasteners; ammunition components	Grillwork; reflectors; lamp fixtures; fasteners; stencils	Architectural trimmings; condenser plates; hot forgings

Adapted from data supplied by Copper & Brass Research Association.
* 0.030 mm nominal grain size.
† ½ % extension under load.
‡ 0.025 mm nominal grain size.
§ Tube.
‖ Soft anneal.

TABLE 27-16 WIDTH TOLERANCES, INCHES, FOR FLAT COPPER PRODUCTS

[illegible]

[illegible]

Slit Metal and Slit Metal with Rolled Edges				
Width, in.	Thickness, 0.004 to 0.032 in., incl.	Thickness, over 0.032 to 0.125 in., incl.	Thickness, over 0.125 to 0.188 in., incl.	Thickness, over 0.188 to 0.375 in., incl.
[illegible] to 2, incl.	0.005	0.010	0.012	0.015
Over 2 to 8, incl.	0.008	0.013	0.015	0.015
Over 8 to 24, incl.	1/64	1/64	1/64	1/32

Rolled Edge Metal Not Previously Slit (for Rectangles Only, Not Including Squares)		
Width, in.	Copper and nonrefractory alloys	Refractory alloys
Up to 0.050, incl.	0.0013	0.0015
Over 0.050 to 0.060, incl.	0.0015	0.002
Over 0.060 to 0.130, incl.	0.002	0.003
Over 0.130 to 0.188, incl.	0.003	0.004
Over 0.188 to 0.500, incl.	0.0035	0.005
Over 0.500 to 1.25, incl.	0.005	0.007
Over 1.25 to 2.00, incl.	0.008	0.010
Over 2.00 to 4.00, incl.	0.012	0.015
Over 4.00 to 12.00, incl.	0.30%*	0.30%

Square Sheared Metal (All Lengths to 10 Ft, Incl.)			
Width, in.	Thickness, up to 1/16 in., incl.	Thickness, over 1/16 to 1/8 in., incl.	Thickness, over 1/8 in.
Up to 20, incl.	1/32	3/64	1/16
Over 20 to 36, incl.	3/64	3/64	1/16
Over 36 to 120, incl.	1/16	1/16	1/16

Sawed Metal (for Specific and Stock Lengths)			
Width, in.	Lengths to 10 ft, incl.		Lengths over 10 ft
	Thickness, up to 1½ in., incl.	Thickness, over 1½ in.	All thicknesses
Up to 12, incl.	1/32	1/16	1/16
Over 12 to 120, incl.	1/16	1/16	1/16

Data courtesy of Copper & Brass Research Association.

* Expressed to the nearest 0.001 in.

TABLE 27-11. THICKNESS TOLERANCES, INCHES, COLD-ROLLED COPPER ALLOY PRODUCTS (SLIT, SLIT AND EDGE ROLLED, SHEARED, SAWED OR MACHINED EDGES)

Tolerances are plus and minus; if all plus or all minus tolerances are desired, double the listed values

Thickness, in.	Width, in. Up to 8, incl.	Over 8 to 12, incl.	Over 12 to 14, incl.	Over 14 to 20, incl.	Over 20 to 28, incl.	Over 28 to 36, incl.	Over 36 to 48, incl.	Over 48 to 60, incl.
	Strip				Sheet			
Up to 0.004, incl.	0.0003	0.0006	0.0008					
Over 0.004 to 0.006, incl.	0.0004	0.0008	0.0008	0.0013				
Over 0.006 to 0.009, incl.	0.0006	0.0010	0.0010	0.0015				
Over 0.009 to 0.013, incl.	0.0008	0.0010	0.0013	0.0018	0.0025	0.003	0.0035	0.004
Over 0.013 to 0.017, incl.	0.0010	0.0013	0.0015	0.002	0.0025	0.003	0.0035	0.0045
Over 0.017 to 0.021, incl.	0.0013	0.0015	0.0018	0.002	0.003	0.0035	0.004	0.005
Over 0.021 to 0.026, incl.	0.0015	0.002	0.002	0.0025	0.003	0.0035	0.004	0.005
Over 0.026 to 0.037, incl.	0.002	0.002	0.002	0.0025	0.0035	0.004	0.005	0.006
Over 0.037 to 0.050, incl.	0.002	0.0025	0.0025	0.003	0.004	0.005	0.006	0.007
Over 0.050 to 0.073, incl.	0.0025	0.003	0.003	0.0035	0.005	0.006	0.007	0.008
Over 0.073 to 0.130, incl.	0.003	0.0035	0.0035	0.004	0.006	0.007	0.008	0.010
Over 0.130 to 0.188, incl.	0.0035	0.004	0.004	0.0045	0.007	0.008	0.010	0.012
	Bar				Plate			
Over 0.188 to 0.205, incl.	0.0035	0.004	0.004	0.0045	0.007	0.009	0.010	0.012
Over 0.205 to 0.300, incl.	0.004	0.0045	0.0045	0.005	0.009	0.010	0.012	0.014
Over 0.300 to 0.500, incl.	0.0045	0.005	0.005	0.006	0.012	0.013	0.015	0.018
Over 0.500 to 0.750, incl.	0.0055	0.007	0.007	0.008	0.015			
Over 0.750 to 1.00, incl.	0.007	0.009	0.009	0.011	0.018			
	Refractory Alloys							
	Strip				Sheet			
Up to 0.004, incl.	0.0004	0.0008	0.0008					
Over 0.004 to 0.006, incl.	0.0006	0.0010	0.0010	0.0015				
Over 0.006 to 0.009, incl.	0.0008	0.0013	0.0013	0.002				
Over 0.009 to 0.013, incl.	0.0010	0.0015	0.0015	0.0025				
Over 0.013 to 0.017, incl.	0.0013	0.002	0.002	0.0025				
Over 0.017 to 0.021, incl.	0.0015	0.0025	0.0025	0.003				
Over 0.021 to 0.026, incl.	0.002	0.0025	0.0025	0.003	0.004	0.005	0.006	0.007
Over 0.026 to 0.037, incl.	0.0025	0.003	0.003	0.0035	0.005	0.006	0.007	0.008
Over 0.037 to 0.050, incl.	0.003	0.0035	0.0035	0.004	0.006	0.007	0.008	0.010
Over 0.050 to 0.073, incl.	0.0035	0.004	0.004	0.0045	0.007	0.008	0.010	0.012
Over 0.073 to 0.130, incl.	0.004	0.0045	0.0045	0.005	0.008	0.010	0.012	0.014
Over 0.130 to 0.188, incl.	0.0045	0.005	0.005	0.006	0.010	0.012	0.014	0.016
	Bar				Plate			
Over 0.188 to 0.205, incl.	0.0045	0.005	0.005	0.006	0.010	0.012	0.014	0.016
Over 0.205 to 0.300, incl.	0.005	0.006	0.006	0.007	0.012	0.014	0.016	0.018
Over 0.300 to 0.500, incl.	0.006	0.007	0.007	0.008	0.015	0.017	0.019	0.023
Over 0.500 to 0.750, incl.	0.008	0.010	0.010	0.012	0.019			
Over 0.750 to 1.00, incl.	0.010	0.012	0.012	0.015	0.023			

Data courtesy of Copper & Brass Research Association.

TABLE 27-12. COMMERCIAL TEMPERS FOR WROUGHT COPPER ALLOYS

Commercial temper designation [illegible]	Standard abbreviation	B & S numbers hard	Per cent reduction: [illegible]	Per cent reduction: Wire [illegible]
Eighth hard	1/8 H	1/2	6	11
Quarter hard	1/4 H	1	11	21
Half hard	1/2 H	2	21	37
Three-quarters hard	3/4 H	3	29	50
Hard	H	4	37	60
Extra hard		6	50	75
Spring		8	61	84
Extra spring		10	69	90

Data courtesy of Chase Brass and Copper Co.

TABLE 27-13. GRAIN SIZE OF COPPER ALLOYS

ASTM standard temper nominal grain size, mm	Temper name	Typical use
0.015	Light anneal	Slight forming operations
0.025	Light anneal	Shallow drawing
0.035	Drawing or rod anneal	For best average surface
0.050	Intermediate anneal	Deep drawing
0.070	Soft anneal	Deep drawing
0.120	Dead-soft anneal	Heavy drawing on thick gages

Adapted from "Metals Handbook."[10]

Beryllium Copper. Mechanical properties of beryllium copper, the strongest of the copper alloys, are given in Table 27-14. The nominal composition of the wrought alloy is: beryllium, 2.0 per cent, cobalt 0.3 per cent, copper, 97.7 per cent.

Beryllium copper sheet or strip in the softer tempers does not have a pronounced directionality of its grain structure.

TABLE 27-14. TYPICAL MECHANICAL PROPERTIES OF BERYLLIUM COPPER STRIP

Temper	Tensile strength, psi	Elongation in 2 in., %
Annealed	60,000- 80,000	35-50
Annealed, heat-treated	165,000-180,000	5-10
No. 1 hard	73,000- 78,000	10-35
No. 1 hard, heat-treated	175,000-190,000	4-7
No. 2 hard	80,000-100,000	5-15
No. 2 hard, heat-treated	185,000-200,000	2-5
No. 4 hard	95,000-120,000	2-6
No. 4 hard, heat-treated	190,000-205,000	1-3

Data courtesy of Beryllium Corp.

* Superior numbers relate to References at the end of this section.

WROUGHT MAGNESIUM ALLOYS*

Only a limited amount of magnesium forming can be done at room temperature; the bulk of the work is done between 400 and 600°F.

For this reason, iron or steel dies must be made somewhat oversize. All die dimensions should be multiplied by a factor of 1.004 if the drawing temperature is to be

TABLE 27-15. COMMERCIAL TOLERANCES FOR WROUGHT MAGNESIUM ALLOY SHEET

All tolerances are plus or minus

Thickness, in.	Tolerance, in.		
	Thickness Tolerances		
	Up to 36-in. width	36 in. wide and over	
0.016–0.036	0.002	0.0025	
0.037–0.050	0.0025	0.003	
0.051–0.080	0.003	0.004	
0.081–0.250	5% of thickness	5% of thickness	
	Width Tolerances		
	Up to 18 in. wide	Over 18 to 30 in. wide	Over 30 in. wide
0.016–0.102	1/16	3/32	1/8
0.103–0.250	3/32	1/8	5/32

Data courtesy of Magnesium Association.

TABLE 27-16. PROPERTIES AND CHARACTERISTICS OF WROUGHT MAGNESIUM ALLOYS

ASTM grade	M1	AZ31X
Alcoa grade	AMC3S	AMC52S
Dow Chemical Co. grade	M	FS1
Nominal composition, % (remainder is magnesium)	Mn, 1.20 min	
	....	Al, 3.0
	....	Zn, 1.0
Mechanical properties:		
Ultimate strength, 1,000 psi*	25–37	32–42
Yield strength, 1,000 psi*	15–25	15–32
Shear strength, 1,000 psi	16–18	21–23
Elongation, % in 2 in.*	4–16	4–21
Hardness, Brinell	45–56	56–58
Fabricating properties:		
Hot-work temp, deg F (annealed)	600 ± 50	500 ± 50
Hot-work temp, deg F (hard rolled)	400 ± 50	350 ± 50
Min 90° bend radius (approx) at 70°F†		
Annealed	5T	4T
Hard-rolled	12T	12T
Max reduction per draw, %, at 70°F‡	20	25

* Values in tension.

† Values apply to sheets 0.040 to 0.072 in. thick; values decrease for thinner stock and increase for thicker stock.

$$‡\ \%\ \text{reduction} = \frac{\text{blank diam.} - \text{punch diam.}}{\text{blank diam.}} \times 100.$$

* Reviewed by J. S. Kirkpatrick, Vice President, Brooks & Perkins, Inc.

[illegible] Clearance between the punch and the die should never be less than the metal thickness. For deep draws clearance should equal about 1.3 times the thickness of the metal being drawn.

Sheet tolerances for magnesium are given in Table 27-15, and general properties and characteristics in Table 27-16.

ZINC AND ZINC ALLOYS*

Wrought zinc characteristically flows under constant loads substantially below their ultimate strengths. Strip is produced in widths up to 20 in., and in thicknesses as small as 0.004 in. Table 27-17 lists properties of types most commonly press-worked.

TABLE 27-17. TYPICAL PROPERTIES OF WROUGHT ZINC ALLOYS

Type	Commercial rolled zinc (deep-drawing zinc)	Commercial rolled zinc	Commercial rolled zinc	Copper hardened rolled zinc alloy	Rolled zinc alloy
Composition, %	Pb 0.10 max, Zn, remainder	Pb, 0.05-0.10, Cd, 0.05-0.08, Zn, remainder	Pb, 0.25-0.50, Cd, 0.25-0.45, Zn, remainder	Cu, 0.85-1.25, Zn, remainder	Cu, 0.85-1.25, Mg 0.006-0.016, Zn remainder
Mechanical properties:					
Tensile strength, 1,000 psi:†					
Hot-rolled	19.5, 23.0	21.0, 25.0	23.0, 29.0	24.0, 32.0	25.0, 36.0
Cold-rolled	21.0, 27.0	22.0, 29.0	25.0, 31.0	32.0, 40.0	37.0, 48.0
Elongation in 2 in., %:†					
Hot-rolled	65, 50	52, 30	50, 32	20, 15	20, 10
Cold-rolled	50, 40	40, 30	45, 28	5, 3	20, 2
Hardness, Brinell:					
Hot-rolled	38	43	47	52	61
Cold-rolled			.....	60	80
Fatigue strength (endurance limit), 1,000 psi, hot-rolled	2.5	3.8	4.1	6.1	6.8
Common fabrication processes	Drawing, bending, roll forming				
	Spinning, swaging, impact extrusion		Swaging, impact extrusion	Spinning, swaging	
Commonly available forms	Rolled strip and sheet, extruded rod and shapes, drawn rod and wire				
Typical uses	Generally any drawn, formed, or spun article not requiring stiffness	Generally any drawn, formed, or spun article requiring some rigidity	Plates and strip for soldered battery cans	Drawn, formed or spun articles requiring stiffness	

Data courtesy of New Jersey Zinc Co.

† Where two figures separated by a comma are given, the first represents strength in direction parallel to the grain, the second, perpendicular to grain.

* Reviewed by E. W. Horvick, Staff Engineer, American Zinc Institute, Inc.

Sheet and strip (ribbon) rolled zinc of commercial quality contains a totality of lead, iron, and cadmium of less than 2 per cent. Available commercial sizes are listed in Table 27-18.

TABLE 27-18. AVAILABLE SIZES, THICKNESSES, AND TOLERANCES, ZINC SHEET AND STRIP

Commercial sizes

	Widths, in.	Lengths, in.	Thicknesses, in.	Thickness tolerances, in.
Sheet....	3–60	3–120	0.006–0.375	Up to and including 0.032, ±0.002; over 0.032, ±6%
Strip.	3/16–20	Varying	0.004 and 0.006–0.375	Up to and including 0.020, ±0.001; over 0.020, ±5%

Width tolerances, in., sheet and strip

Thickness, in.	Widths up to and including 18 in.	Widths over 18 in.
Up to 0.125........	±0.031	±0.063
0.126–0.250..........	±0.063	±0.063
0.251–0.375..........	±0.125	±0.125

Data courtesy of the American Zinc Institute.

Zinc sheet is furnished with a bright rolled finish, a mill finish between bright and dull, a bright polish finish, and a satin finish. Strip is furnished in the same finishes except the bright polish finish, but is available in a frosted finish on one side. Pure zinc is available in a dead-soft condition, the alloys in various degrees of hardness and stiffness.

TITANIUM AND ITS ALLOYS

Commercial titanium sheet is formable by bending, drawing, and similar operations, being comparable with quarter- to half-hard 18-8 stainless steel.

Commercially pure annealed titanium (containing no more than 0.03 per cent each of oxygen, nitrogen, and carbon) as supplied in the annealed state has an ultimate tensile strength in the range of 70,000 to 90,000 psi, a yield strength of 55,000 to 80,000 psi, and elongates (in 2 in.) from 20 to 30 per cent. Available annealed titanium alloys exhibit ultimate tensile-strength ranges of 100,000 to 175,000 psi and yield-strength ranges of 75,000 to 160,000 psi. The principal alloying elements, chromium, manganese, molybdenum and iron (including quantities of oxygen, carbon, and nitrogen over 0.03 per cent) reduce ductility, since the elongation range in 2 in. is 10 to 25 per cent.

TABLE 27-19. DIMENSIONS AND TOLERANCES FOR THE COMMERCIALLY PURE AND ALLOY GRADES OF HOT-ROLLED AND COLD-ROLLED TITANIUM SHEETS

Finish ordering thickness, in.	Max sheet sizes, in.	Thickness tolerance, plus or minus, %	Width tolerances
0.020 min. cold-rolled..	24 by 72	15	Nothing undersize specified; plus 1/16 in. on widths up to 42 in.; plus 1/8 in. on widths over 42 in.
0.025 min. cold-rolled..	36 by 96	10	
0.031 min. cold-rolled..	45 by 96		
0.031 to 0.125........	45 by 120		
Over 0.125...........	36 by 96	8	

Data courtesy of Titanium Metals Corp.

Widths under 24 in. fall within strip classification.

Thicknesses over 0.1875 in. are classified as plate.

[illegible] COMMERCIALLY PURE AND ALLOY GRADES OF [illegible] TITANIUM STRIP

[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

RARER METALS AND THEIR ALLOYS

[illegible]. [illegible] is fabricated by essentially the same methods as used for [illegible]. It has better forming, bending and deep-drawing properties at room temperature than magnesium. [illegible] alloys, now in the developmental stage, are [illegible] useful in [illegible] applications.

Tantalum. The ductility and workability of tantalum are similar to those for [illegible] except that it has no directional properties, and complicated forms can be produced.

Columbium. Fabricating procedures are similar to those for tantalum.

Vanadium. At slightly elevated temperatures, vanadium has relatively good workability in bending and moderately deep drawing.

Tungsten. Because of its rather low ductility, tungsten sheets up to 0.010 in. thick are generally formed at 200 F, with temperature increasing as sheet thickness increases. For sheets thicker than 0.010 in., forming should be done at 2100 to [illegible] F.

Molybdenum. Customary forming procedures can be followed for molybdenum. It should never be formed colder than 70 F. Thicknesses from 0.020 to 0.040 in. should be worked at 200 to 300 F, and thicker sheets at 900 to 1000 F.

PAPER-THIN METALS

Precision Steel. Low-carbon (AISI C1010) steel is available in widths up to [illegible] in thicknesses of 0.010 to [illegible] ± 0.0002 in., and down to 0.0005 ± 0.0001 in. Other metals rolled to these same thicknesses and widths are:

- Aluminum alloys
- Copper-base alloys: brass, bronze, beryllium copper, phosphor bronze, nickel [illegible]
- Ferrous metals: low- and high-carbon steels, stainless steels, chrome-iron alloys, silicon alloys, chrome-molybdenum-iron alloys, cobalt-nickel-iron alloys
- Nickel-base alloys: nickel, monel, Inconel, high-nickel permanent-magnet alloys
- High-temperature alloys
- Molybdenum, tantalum, titanium, zirconium
- Precious metals

CLAD METALS

[illegible] sheet or strip is a composite of a core or backing metal layer and a [illegible] layer or layers of dissimilar metal. The covering metal thickness is usually [illegible] of the total composite thickness, and it is bonded to the core by [illegible] metallurgical bonding.

[illegible] cladding for steel are stainless steels, nickel and nickel alloys, [illegible]; for copper, stainless steels and platinum; for brass, gold, silver [illegible]; for aluminum, aluminum chemically different from the core [illegible].

THE PRECIOUS METALS

Gold, silver, platinum, and palladium and their alloys are available in sheets as well as foil. These metals are no longer used only for jewelry, dental alloys, laboratory equipment; new uses and alloys have been found which are readily formable; composite sheets clad with these metals are available.

HEAT TREATMENT OF NONFERROUS MATERIALS

TABLE 27-21. ANNEALING TEMPERATURES FOR THE PRECIOUS METALS AND THEIR ALLOYS

Gold	None
Silver (commercially pure)	527°F
Platinum	1022-1742°F
Palladium	1470-2012°F

TABLE 27-22. ANNEALING TEMPERATURES AND HARDNESS VALUES FOR COPPER AND ITS ALLOYS[2]

Name	Analysis	Full anneal	Full-hard Rockwell	Annealed Rockwell
Copper		700-1200°F	B50	F40
Commercial bronze, 90%	90% copper, 10% zinc	800-1450°F	B70	F53
Red brass, 85%	85% copper, 15% zinc	800-1350°F	B77	F59
Cartridge brass, 70%	70% copper, 30% zinc	800-1400°F	B82	F64
Muntz metal	60% copper, 40% zinc	800-1100°F	B85	F80
Yellow brass	65% copper, 35% zinc	800-1300°F	B80	F64
Admiralty bronze	70% copper, 28% zinc, 0.05% arsenic, 1% tin	800-1100°F	B90	B25
Roman bronze	60% copper, 39.25% zinc, 0.75% tin	800-1100°F	B80	B50
Naval brass	60% copper, 39.25% zinc, 0.75% tin	800-1100°F	B90	B45
Manganese bronze	58.5% copper, 39.2% zinc, 1.0% iron, 0.03% manganese, 1% tin	800-1100°F	B90	B65
Phosphor bronze, 5% (A)	95% copper, 5% tin	900-1250°F	B87	F73
Nickel silver, 18% (A)	65.0% copper, 18% nickel, 17.0% zinc	1100-1500°F	B87	F85
Nickel silver, 18% (B)	55% copper, 18% nickel, 27% zinc	1100-1500°F	B91	F90
Cupronickel, 30%	70% copper, 30% nickel	1200-1500°F	B85	B40
Herculoy or low-silicon bronze, (B)	98% copper, 1.5% silicon, 0.25% manganese	900-1250°F	B77	F60
Aluminum bronze, 5%	95% copper, 5% aluminum	900-1200°F	B85	B40
Aluminum-silicon bronze	91% copper, 7% aluminum, 2% silicon	900-1200°F	B82	B75

TABLE 27-23. ANNEALING TEMPERATURES FOR STAINLESS-CLAD COPPER[1]

Max furnace temp, deg F	Time, min	Thickness, in.
1750	10	0.078
1750	8	0.062
1750	7	0.050
1750	6	0.025

Annealing of stainless-clad copper, when stress relief is needed, should follow this schedule. Induction annealing is not recommended.

References

1. Stocker, W. M., Jr.: How to Work Clad Materials, *Am. Machinist*, Feb. 6, 1950.
2. American Society of Tool Engineers: "Tool Engineers Handbook," McGraw-Hill Book Company, Inc., New York, 1949.
3. American Society for Metals: "Metals Handbook," Cleveland, Ohio, 1948.

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