Technical Information

Terminology and Symbols in Control Engineering

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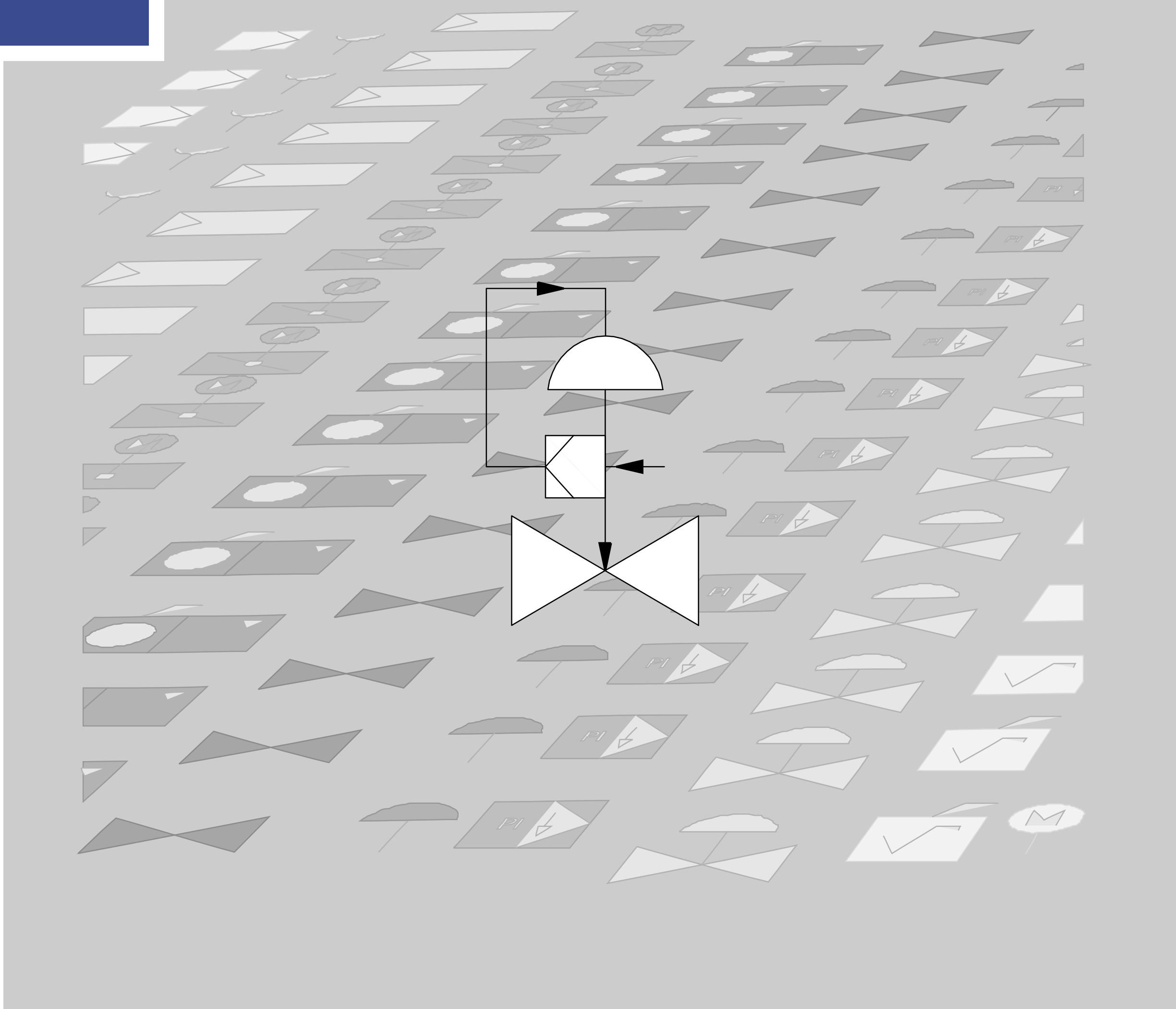

Part 1 Fundamentals

Technical Information

Should you have any further questions or suggestions, please do not hesitate to contact us:

SAMSON AG
V74 / Schulung
Weismüllerstraße 3
D-60314 Frankfurt

Phone (+49 69) 4 00 94 67
Telefax (+49 69) 4 00 97 16
E-Mail: schulung@samson.de
Internet: http://www.samson.de

Terminology and Symbols in Control Engineering

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Preface

The technical informations presented in this document are based on definitions according to DIN, the German organization of standardization (Deutsches Institut für Normung). Continuous efforts are being made to determine international definitions in order to achieve an increasing similarity in the terminology used. Nevertheless, differences in designations and representations do exist in international use. Literature presented at the end of this document includes international standards and publications relating to DIN standards, or being derived from them.

Representations and text sections referring to DIN are often cited in short form, summarizing the contents. The precise facts must always be read - also because of possible extensions or amendments - in the current edition of the respective standard.

Introduction

Planning, design and start-up of process control systems require clear and unambiguous communication between all parts involved. To ensure this, we need a clear definition of the terms used and – as far as the documentation is concerned – standardized graphical symbols. These symbols help us represent control systems or measurement and control tasks as well as their device-related solution in a simple and clear manner.

Terminology in Control Engineering

To maintain a physical quantity, such as pressure, flow or temperature at a desired level during a technical process, this quantity can be controlled either by means of open loop control or closed loop control.

Open loop control

open action flow

In an open loop control system, one or more input variables of a system act on a process variable. The actual value of the process variable is not being checked, with the result that possible deviations – e.g. caused by disturbances– are not compensated for in the open loop control process. Thus, the characteristic feature of open loop control is an open action flow.

disturbances are not recognized

The task of the operator illustrated in Fig. 1 is to adjust the pressure (p_2) in a pipeline by means of a control valve. For this purpose, he utilizes an assignment specification that determines a certain control signal (y) issued by the remote adjuster for each set point (w). Since this method of control does not consider possible fluctuations in the flow, it is recommended to use open loop control only in systems where disturbances do not affect the controlled variable in an undesired way.

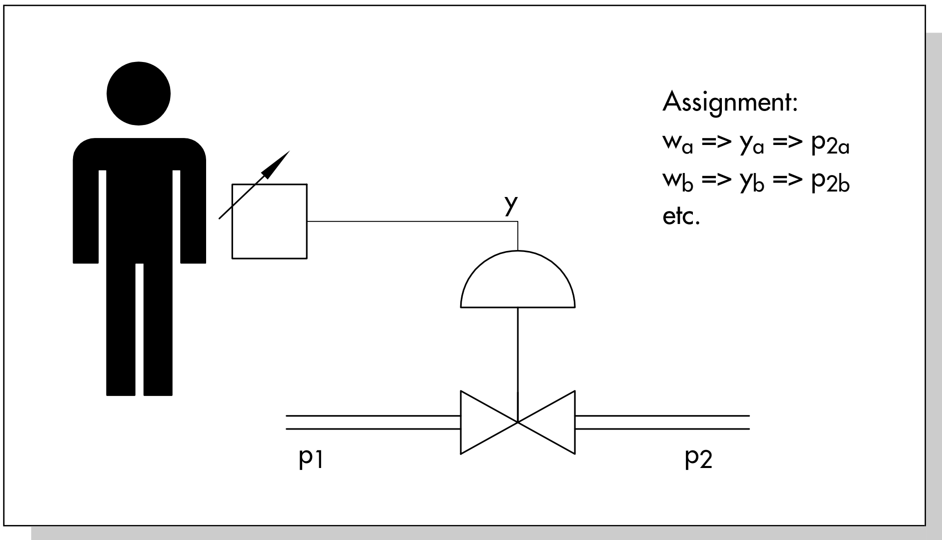

Fig. 1: Operator controls the process variable p_2 via remote adjuster

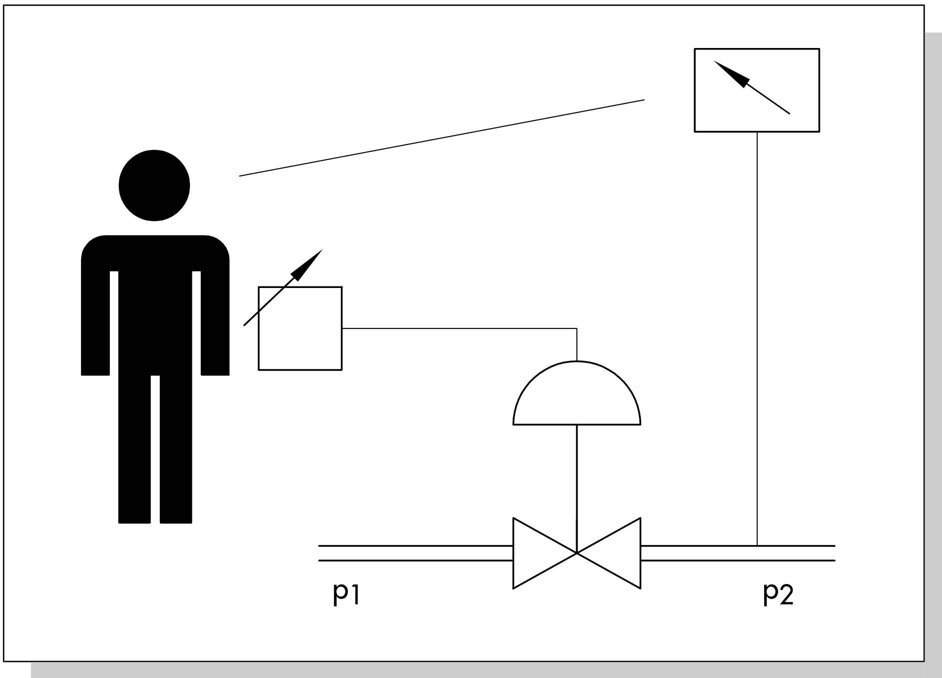

Fig. 2: Operator controls the process variable p_2 an a closed loop

Closed loop control

In a closed loop control system, the variable to be controlled (controlled variable x) is continuously measured and then compared with a predetermined value (reference variable w). If there is a difference between these two variables (error e or system deviation x_w), adjustments are being made until the measured difference is eliminated and the controlled variable equals the reference variable. Hence, the characteristic feature of closed loop control is a closed action flow.

closed action flow

The operator depicted in Fig. 2 monitors the pressure p_2 in the pipeline to which different consumers are connected. When the consumption increases, the pressure in the pipeline decreases. The operator recognizes the pressure drop and changes the control pressure of the pneumatic control valve until the desired pressure p_2 is indicated again. Through continuous monitoring of the pressure indicator and immediate reaction, the operator ensures that the pressure is maintained at the desired level. The visual feedback of the process variable p_2 from the pressure indicator to the operator characterizes the closed action flow.

disturbances are eliminated

The German standard DIN 19226 defines closed loop control as follows:

definition of closed loop control: DIN 19 226

Closed loop control is a process whereby one variable, namely the variable to be controlled (controlled variable) is continuously monitored, compared with another variable, namely the reference variable and, depending on the outcome of this comparison, influenced in such a manner as to bring about adaptation to the reference variable. The characteristic feature of closed loop control is the closed action flow in which the controlled variable continuously influences itself in the action path of the control loop.

A control process can also be regarded as 'continuous' if it is composed of a sufficiently frequent repetition of identical individual processes. The cyclic program sequence of digital sampling control would be such a process.

difficulties with the English term ´control´

Note: In English literature we only find one term, that is 'control', being used for actually two different concepts known as 'steuern' and 'regeln' in the German language. When translating into German, we therefore come across the problem whether 'control' means 'steuern' or 'regeln'. If both methods are involved, 'control' often is translated as 'automatisieren' or 'leiten' (control station). An exact distinction can be made if the German term 'Regelung' is made obvious by using the English term 'closed loop control'.

Process

A process comprises the totality of actions effecting each other in a system in which matter, energy, or information are converted, transported or stored. Adequate setting of boundaries helps determine sub-processes or complex processes.

- Examples:

- Generation of electricity in a power plant
- Distribution of energy in a building
- Production of pig iron in a blast furnace
- Transportation of goods

Control loop

The components of a control loop each have different tasks and are distingu-ished as follows:

components of the control loop

	Controlling system	Controller and acuator
+	**Controlled system**	Final control element, pump, pipeline, heating system etc.
+	**Measuring equipment**	Temperature sensor, pressure sensor, converter etc.
=	**Control loop**	

The components of the final control equipment are part of the controlling sy stem as well as part of the controlled system.

components of the final control equipment

	Actuator (controlling system)	Actuating drive
+	**Final control element** (controlled system)	Closure member
=	**Final control equipment**	Control valve

The distinction made above results directly from the distribution of tasks. The actuator processes and amplifies the output signal of the controller, whereas the final control element – as part of the controlled system – manipulates the mass and energy flow.

Abbreviations of variables relating to closed loop control

DIN or IEC

The abbreviation of variables allows the determination of standardized symbols. The symbols used in German-speaking countries and specified in DIN 19221 correspond with the international reserve symbols approved by the publication IEC 27-2A. Aside from that, IEC also determines so-called chief symbols which considerably differ from those used in DIN in some important cases.

controlled variable, actual value

x (IEC chief symbol: y)

In a control loop, the process variable to be controlled is represented by x. In process engineering, usually a physical (e.g. temperature, pressure, flow) or a chemical (e.g. pH value, hardness) quantity is controlled.

reference variable

w (IEC chief symbol: w)

This variable determines the value that must be reached (set point) by the process variable to be controlled. The physical value of the reference variable – this may be a mechanical or electric quantity (force, pressure, current, voltage, etc.) – is compared with the controlled variable x in the closed control loop.

feedback variable

r (IEC chief symbol: f)

This variable results from the measurement of the controlled variable and is fed back to the comparator.

error

e = w – x (IEC chief symbol: e)

The input variable e of the controlling element is the difference between reference variable and controlled variable, calculated by the comparator. When the influence of the measuring equipment is included, the equation e = w – r applies.

system deviation

$\mathbf{x_w = x - w}$

The equation above shows that the system deviation yields the same result as error, however, with an inverse sign. When the influence of the measuring equipment is included, $x_w = r - w$ applies.

manipulated variable

y (IEC chief symbol: m)

The manipulated variable is the output variable of the controlling equipment and the input variable of the controlled system. It is generated by the controller, or in case an actuator is being used, by the actuator. This variable depends on the setting of the control parameters as well as on the magnitude of error.

controller output variable

y_R

When dividing the controlling system into the controller and actuator, the variable y_R stands for the output variable of the controller or the input variable of the actuator.

disturbance variable

z (IEC chief symbol: v)

Disturbances act on the control loop and have an undesired effect on the controlled variable. Closed loop control is used to eliminate disturbance variables.

range of the manipulated variable

Y_h

The manipulated variable y can be determined by the controller within Y_h, the range of the manipulated variable :

$$y_{min} \leq y \leq y_{max}$$

Symbols in Control Engineering

Signal flow diagrams

A signal flow diagram is the symbolic representation of the functional interactions in a system. The essential components of control systems are represented by means of block diagrams. If required, the task represented by a block symbol can be further described by adding a written text.

However, block diagrams are not suitable for very detailed representations. The symbols described below are better suited to represent functional details clearly.

Blocks and lines of action

The functional relationship between an output signal and an input signal is symbolized by a rectangle (block). Input and output signals are represented by lines and their direction of action (input or output) is indicated by arrows.

- Example: Root-extracting a quantity (Fig. 3)
  (e.g. flow rate measurement via differential pressure sensors)

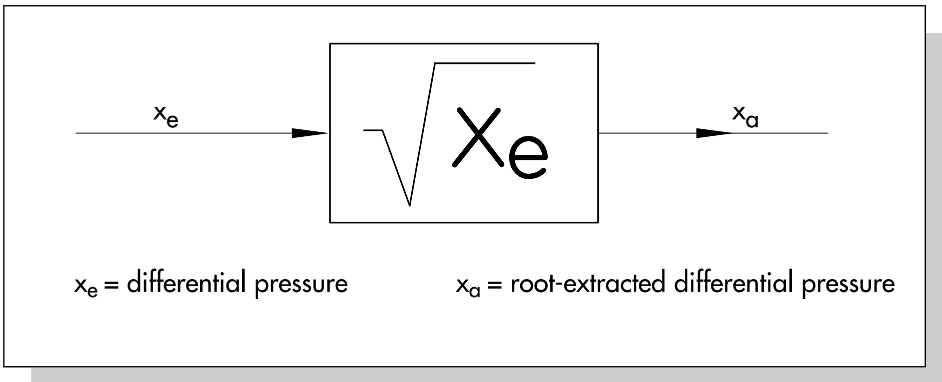

Fig. 3: Root-extracting a differential pressure signal

- Example: Representing dynamic behavior (Fig. 4)
  (e.g. liquid level in a tank with constant supply)

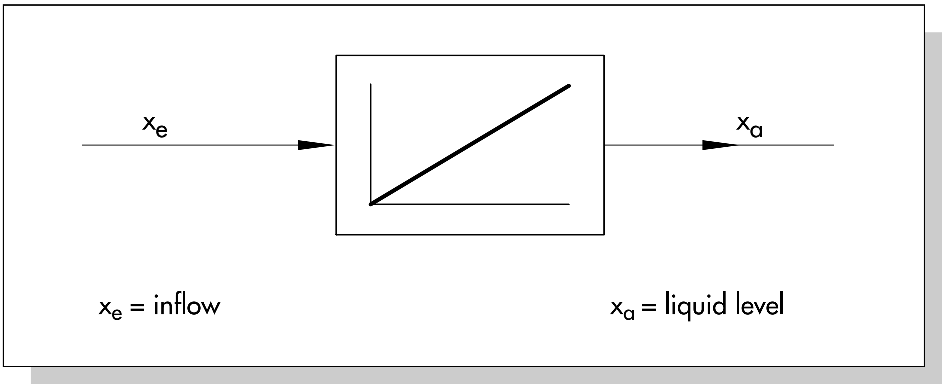

Fig. 4: Development of a liquid level over time

- Example: Summing point (Fig. 5)

The output signal is the algebraic sum of the input signals. This is symbolized by the summing point. Any number of inputs can be connected to one summing point which is represented by a circle. Depending on their sign, the inputs are added or subtracted.

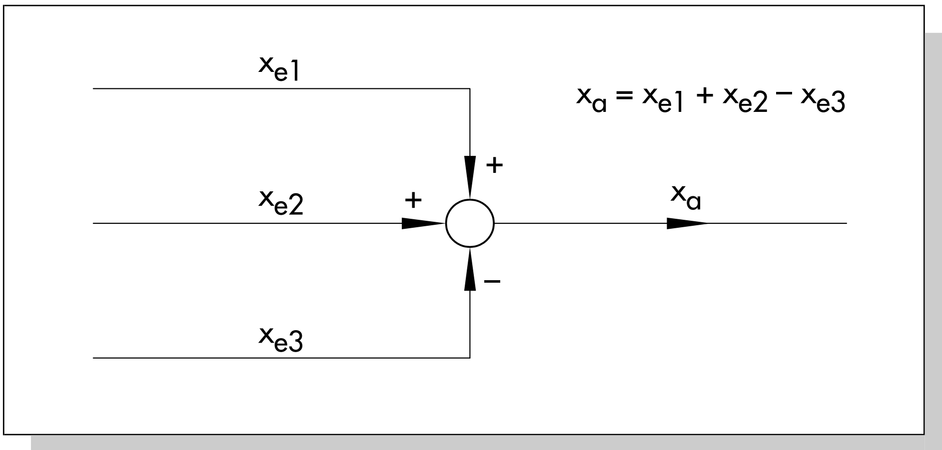

Fig. 5: Summing point

- Example: Branch point (Fig. 6)

A branch point is represented by a point. Here, a line of action splits up into two or more lines of action. The signal transmitted remains unchanged.

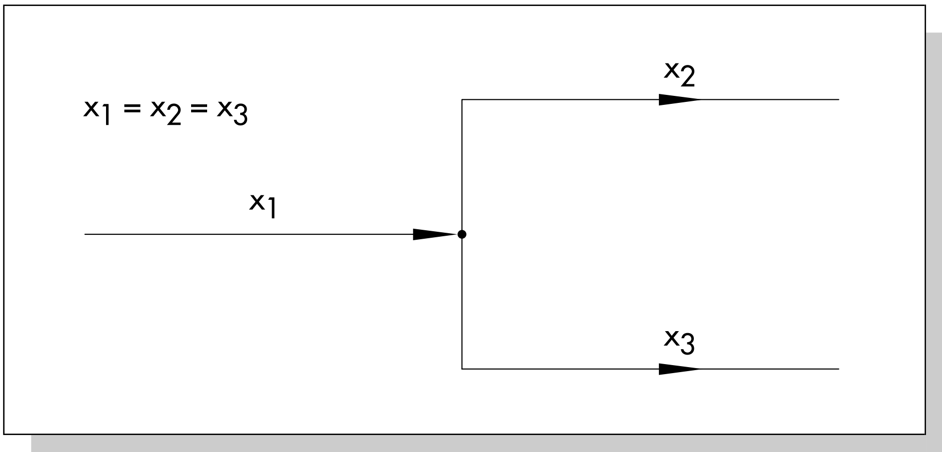

Fig. 6: Branch point

- Example: Signal flow diagram of open loop and closed loop control

The block diagram symbols described above help illustrate the difference between open loop and closed loop control processes clearly.

signal flow diagram of open loop control

In the open action flow of open loop control (Fig. 7), the operator positions the remote adjuster only with regard to the reference variable w. Adjustment is carried out according to an assignment specification (e.g. a table: set point w_1 = remote adjuster position v_1; $w_2 = v_2$; etc.) determined earlier.

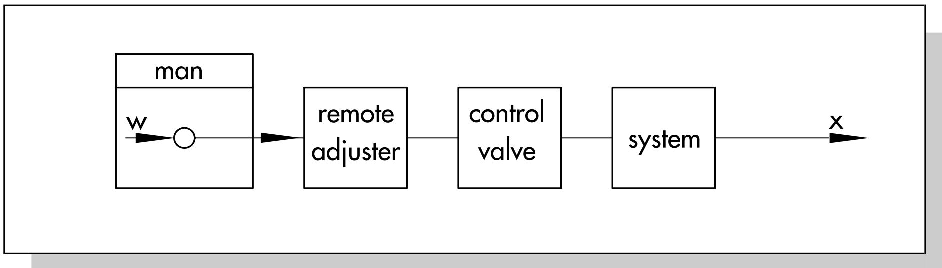

Fig. 7: Block diagram of manual open loop control

signal flow diagram of closed loop control

In the closed action flow of closed loop control (Fig. 8), the controlled variable x is measured and fed back to the controller, in this case man. The controller determines whether this variable assumes the desired value of the reference variable w. When x and w differ from each other, the remote adjuster is being adjusted until both variables are equal.

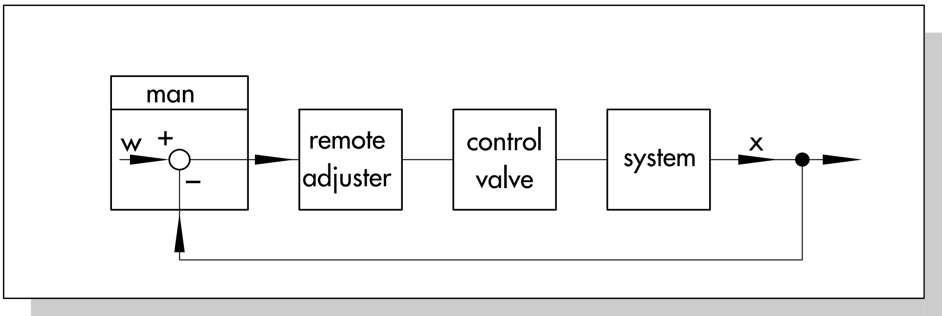

Fig. 8: Block diagram of manual closed loop control

Device-related representation

elements and signals of a control loop

Using the symbols and terminology defined above, Fig. 9 shows the typical action diagram of a closed loop control system (abbreviations see page 10).

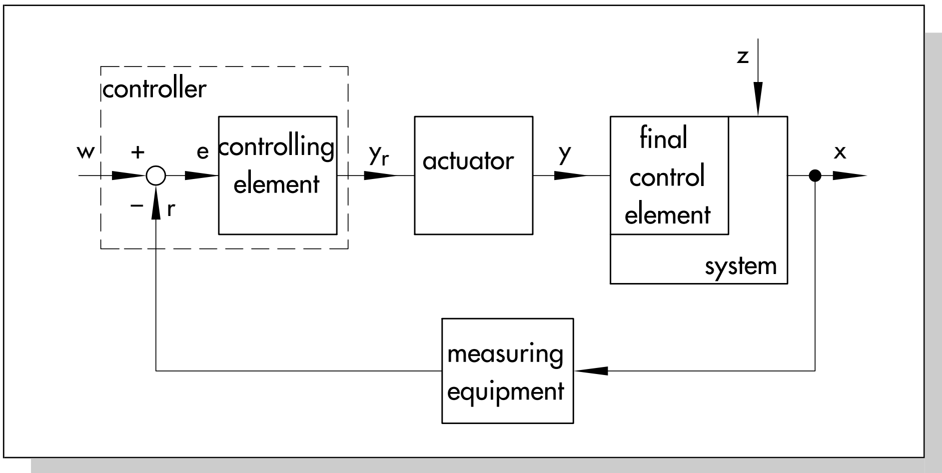

Fig. 9: Block diagram of a control loop

graphical symbols for detailed, solution-related representations

Whenever the technical solution of a process control system shall be pointed out, it is recommended to use graphical symbols in the signal flow diagram (Fig. 10). As this representation method concentrates on the devices used to perform certain tasks in a process control system, it is referred to as solution-related representation. Such graphical representations make up an essential part of the documentation when it comes to planning, assembling, testing, start-up and maintenance.

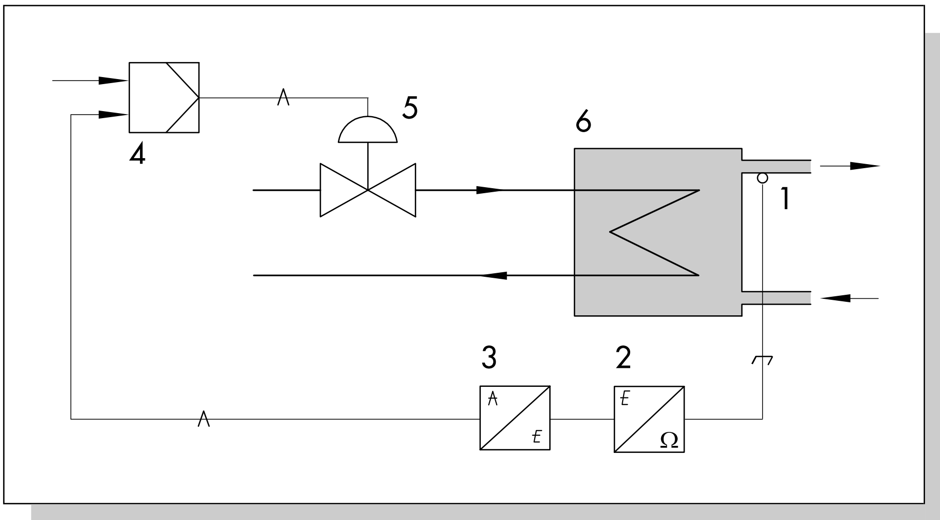

Fig. 10: Graphical symbols for describing temperature control of a heat exchanger system

1	*Sensor (temp.)*	*2*	*Transmitter*
3	*Signal converter*	*4*	*Controller*
5	*Pneumatic linear valve*	*6*	*Heat exchanger*

Each unit has its own graphical symbol that is usually standardized. Equipment consisting of various units is often represented by several lined-up symbols.

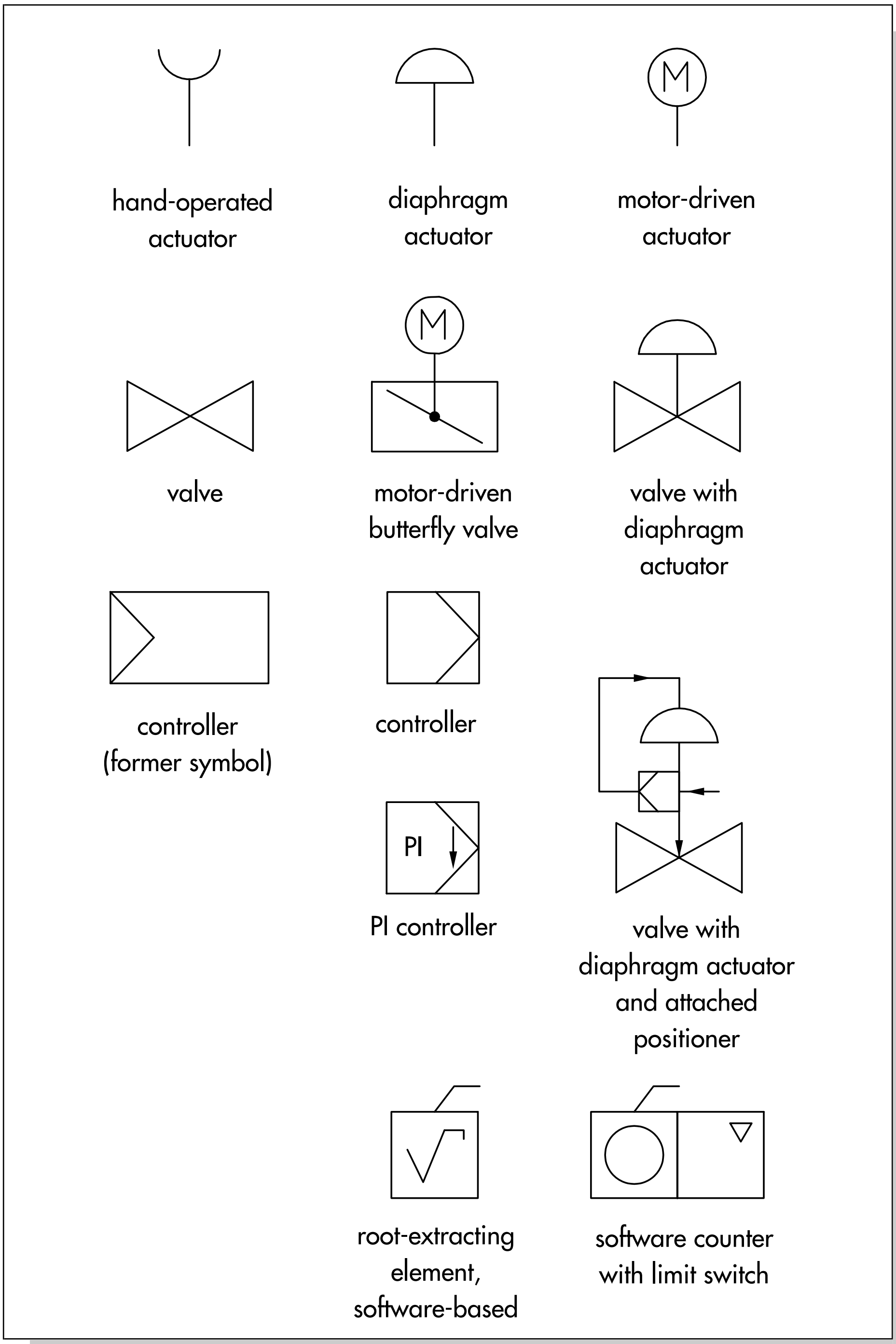

Fig. 11: *Graphical symbols for controllers, control valves and software-based functions according to DIN 19227 Part 2*

functions performed by software are marked with a flag

graphical symbols for process control

Graphical symbols used for process control are specified in DIN 19227, including symbols for sensors, adapters, controllers, control valves, operating equipment, generators, conduits and accessories (Figs. 11 and 12). However, there are a number of other DIN standards covering graphical symbols, such as DIN 1946, DIN 2429, DIN2481, DIN 19239 and DIN 30600 (main standard containing approximately 3500 graphical symbols).

It is recommended to always use standardized graphical symbols. In case a standardized symbol does not exist, you may use your own.

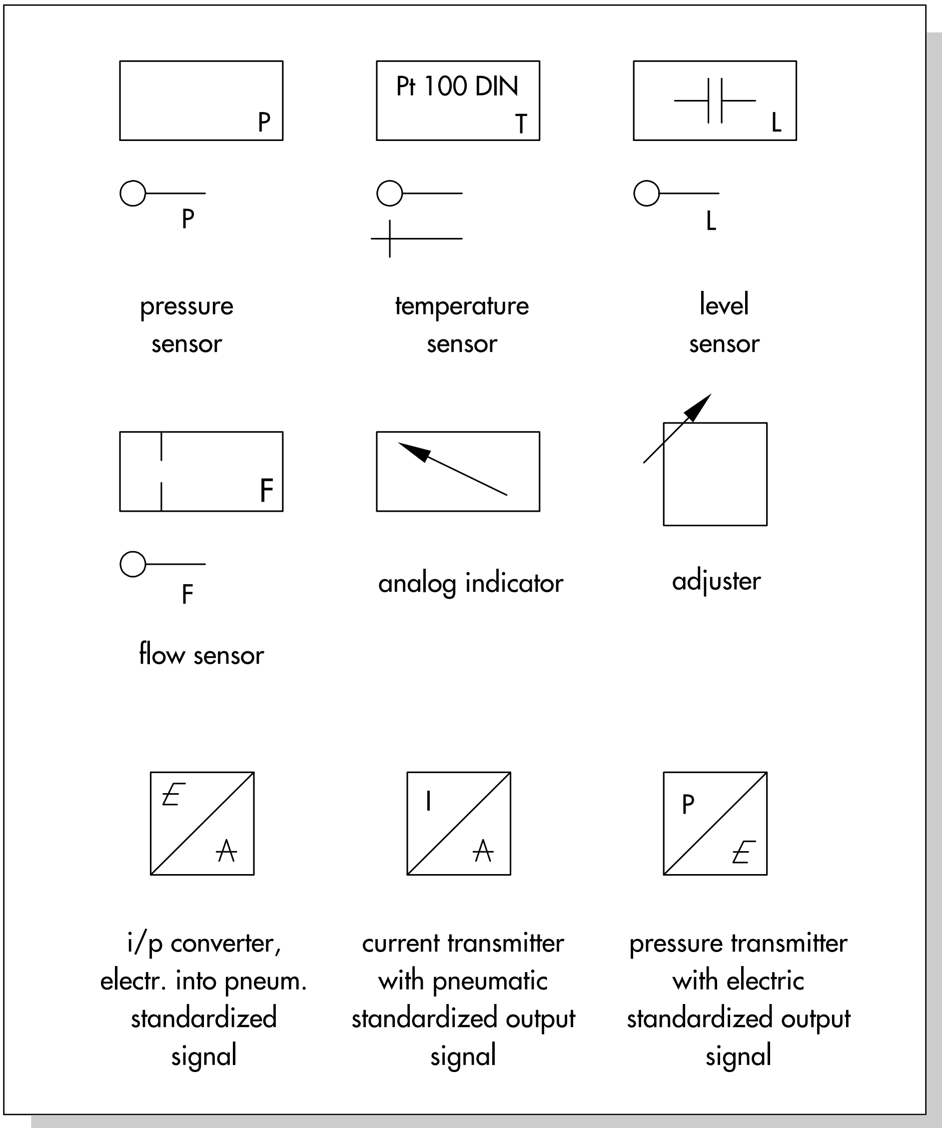

Fig. 12: Graphical symbols for sensors, transmitters, adjusters and indicators according to DIN 19227 Part 2

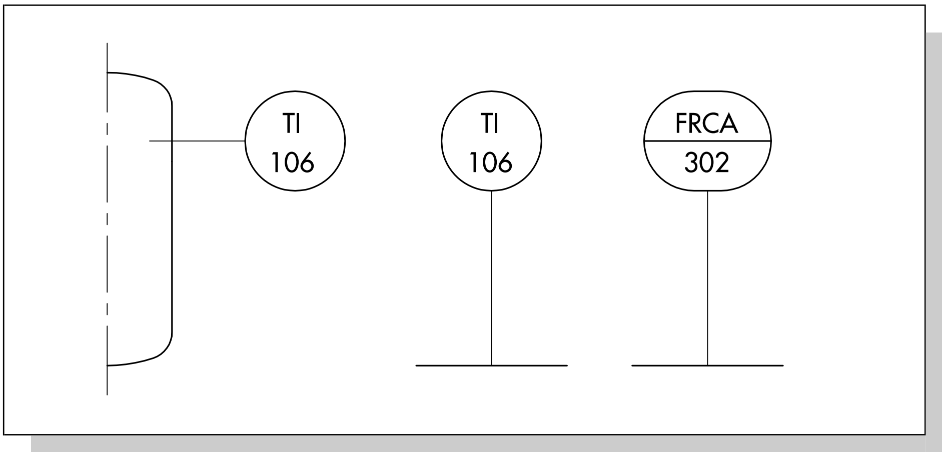

Fig. 13: Instrumentation and control tags disignated according to DIN 19227 Part 1

Instrumentation and control tags

Apart from the solution-related representation, process control systems can also be represented by means of instrumentation and control tags (DIN 19227 Part 1) which describe the task to be done.

instrumentation and control tags

An instrumentation and control tag is represented by a circle. When the circle is divided by an additional line, editing and operating procedures are not carried out on site, but in a centralized control station. In the bottom half of the circle, you will find the instrumentation and control tag number. The identifying letters in the top half specify the measuring or input variable as well as the type of signal processing, organizational information and the signal flow path. If additional space is needed, the circle is elongated to form an oval (Fig. 13).

The typical use of identifying letters in an instrumentation and control tag is shown below:

Example: **P D I C**

First letter (pressure)
Supplementary letter (differential)
1st succeeding letter (indication)
2nd succeeding letter (control)

The meaning and the order of the identifying letters are listed in the following table.

for further details, see DIN 19227

	Group 1: Measuring or input variable		Group 2: Processing
	First letter	**Supplementary letter**	**Succeeding letter** (order: I, R, C, ...any)
A			Fault message, alarm
C			Automatic control
D	Density	Differential	
E	Electric quantities		Sensing function
F	Flow rate, troughput	Ratio	
G	Distance, length, position		
H	Hand (manually initiated)		High limit
I			Indication
K	Time		
L	Level		Low limit
O			Visual signal, yes/no indication
P	Pressure		
Q	Material properties	Integral, sum	
R	Radiation		Record or print
S	Speed, rotational speed, frequency		Circuit arrangement, sequence control
T	Temperature		Transmitter function
U	Multivariable		
V	Viscosity		Control valve function
W	Velocity, mass		
Y			Calculating function
Z			Emergency interruption, safety device

The two possible methods of graphical representation are compared with each other in the Figs. 14 and 15. The device-related representation according to DIN19227 Part 2 (Fig. 15) is in general easily understood. Whereas instrumentation and control tags according to DIN19227 Part 1 (Fig. 14) are more suitable for plotting complex systems.

instrumentation and control tags

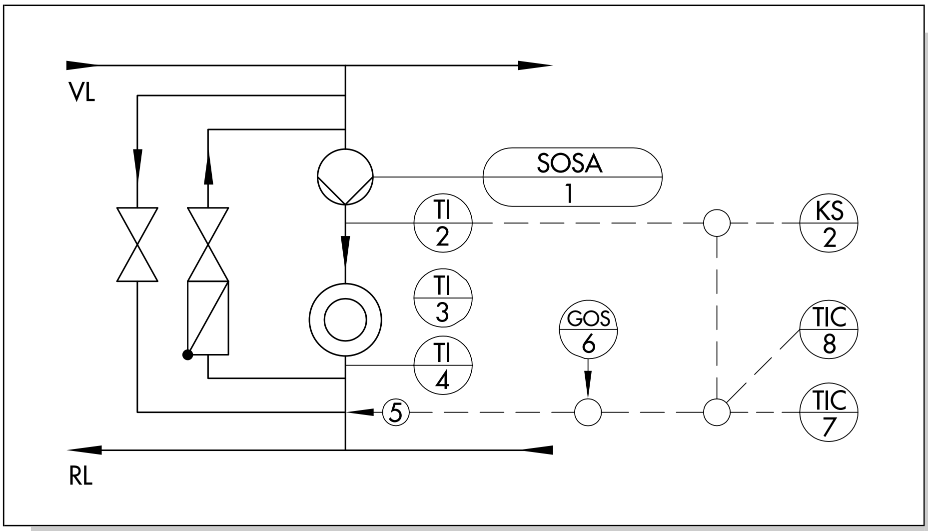

Fig. 14: Representation of a control loop according to DIN 19227 Part 1

device-related symbols

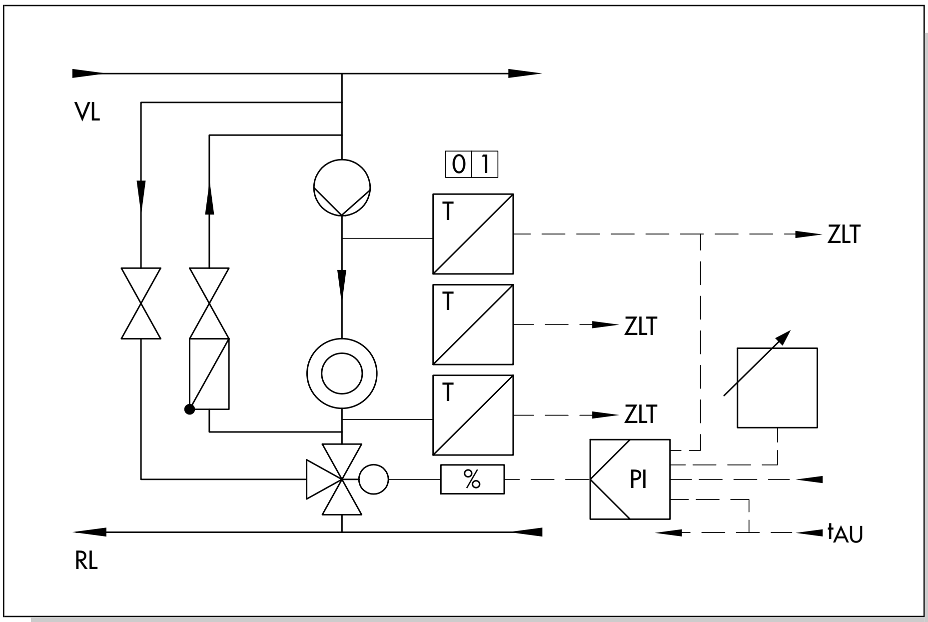

Fig. 15: Representation of a control loop according to DIN 19227 Part 2

Control Systems and Structures

designed for good disturbance reaction or reference action

Depending on the job to be done, many different structures of control can be used. The main criterion of difference is the way the reference variable w is generated for a certain control loop. In setting the controller, it is also important to know whether the reference variable is principally subject to changes or disturbance variables need to be compensated for.

- To attain good disturbance reaction, the controller must restore the original equilibrium as soon as possible (Fig. 16).
- To attain good reference action, the controlled variable must reach a newly determined equilibrium fast and accurately (Fig. 17).

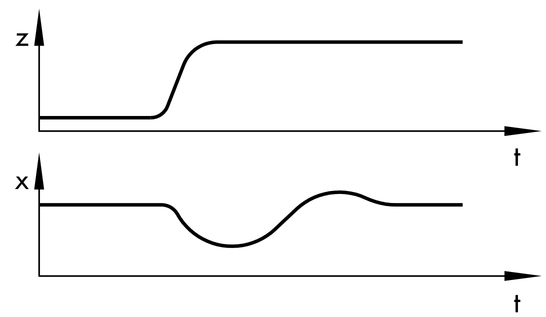

Fig. 16: Disturbance reaction

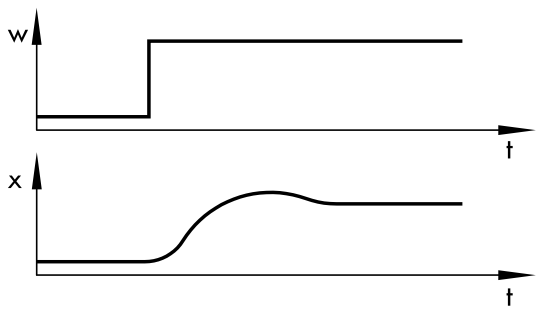

Fig. 17: Reference action

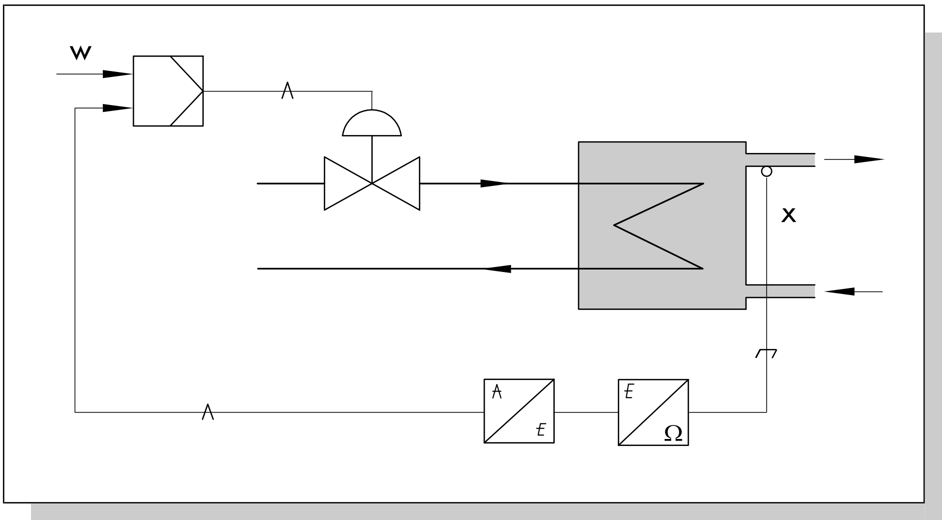

Fig. 18: Temperature control by means of fixed set point control

Fixed set point control

fixed reference variable

In fixed set point control, the reference variable w is set to a fixed value. Fixed set point controllers are used to eliminate disturbances and are therefore designed to show good disturbance reaction.

The temperature control system in Fig. 18 will serve as an example for fixed set point control. The temperature of the medium flowing out of the tank is to be kept at a constant level by controlling the heating circuit. This will provide satisfactory results as long as high fluctuations in pressure caused by disturbances do not occur in the heating circuit.

Follow-up control

follow-up controllers require good reference action

In contrast to fixed set point control, the reference variable in follow-up control systems does not remain constant but changes over time. Usually, the reference variable is predetermined by the plant operator or by external equipment. A reference variable that changes fast requires a control loop with good reference action. If, additionally, considerable disturbances need to be eliminated, the disturbance reaction must also be taken into account when designing the controller.

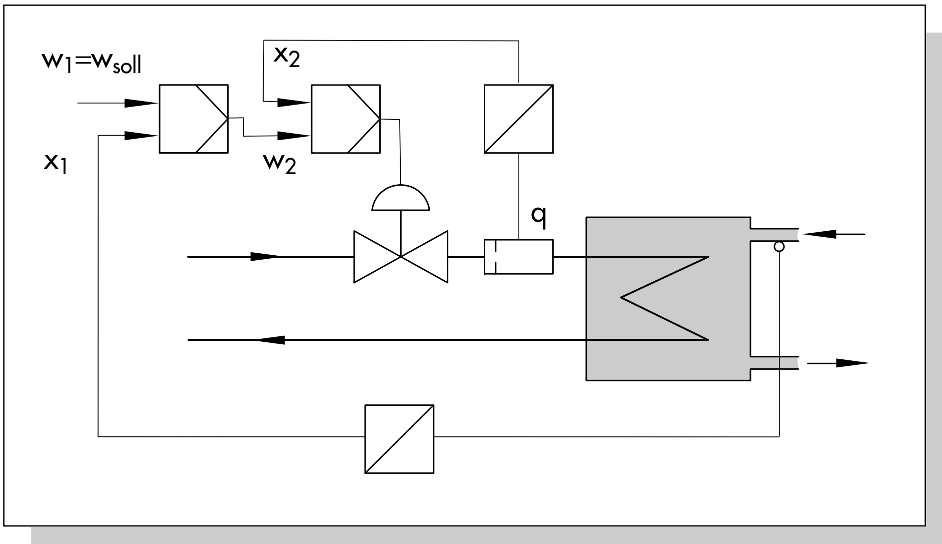

Fig. 19: Temperature control by means of cascade control

Cascade control

Cascade control systems require a minimum of two controllers, these are the master or primary and the follower or secondary controller. The characteristic feature of this control system is that the output variable of the master controller is the reference variable for the follower controller.

master and follower controller for high-quality control

Employing cascade control, the temperature control of the heat exchanger (Fig. 19) provides good results also when several consumers are connected to the heating circuit. The fluctuations in pressure and flow are compensated for by the secondary flow controller (w_2, x_2) which acts as final control element to be positioned by the primary temperature controller.

In our example the outer (primary) control loop (w_1, x_1) must be designed to have good disturbance reaction, whereas the inner –secondary– control loop requires good reference action.

Ratio control

Ratio control is a special type of follow-up control and is used to maintain a fixed ratio between two quantities. This requires an arithmetic element (V). Its input variable is the measured value of the process variable 1 and its output variable manipulates the process variable 2 in the control loop.

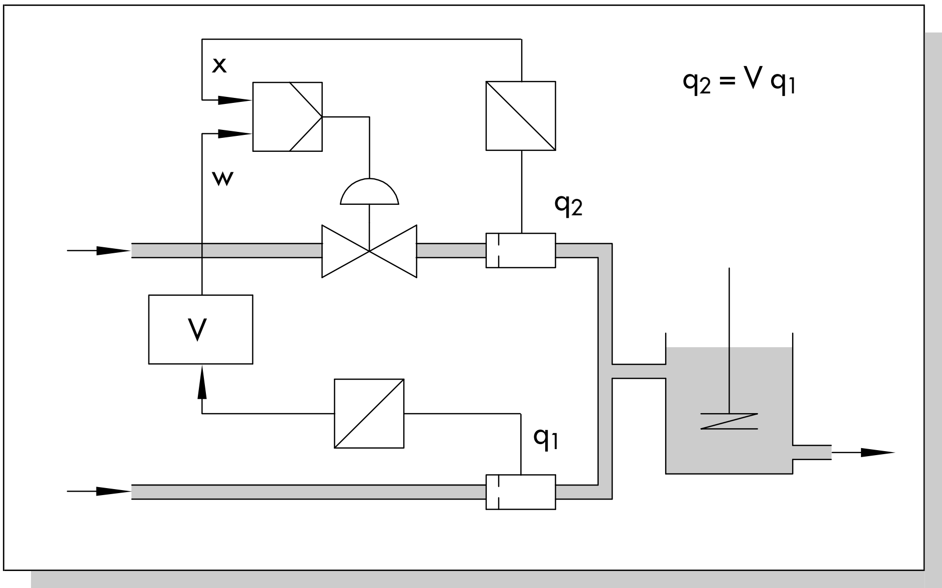

Fig. 20: Ratio control

Fig. 20 illustrates a mixer in which the flow rate q_2 of one material is controlled in proportion to the flow rate q_1 of another material.

Appendix A1: Additional Literature

[1] Controllers and Control Systems
Technical Information L102EN; SAMSON AG

[2] DIN 19226: Control technology

[3] DIN 19227: Graphical symbols and identifying letters for process control engineering

Figures

SAMSON AG · MESS- UND REGELTECHNIK · Weismüllerstraße 3 · D-60314 Frankfurt am Main
Phone (+49 69) 4 00 90 · Telefax (+49 69) 4 00 95 07 · Internet: http://www.samson.de

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