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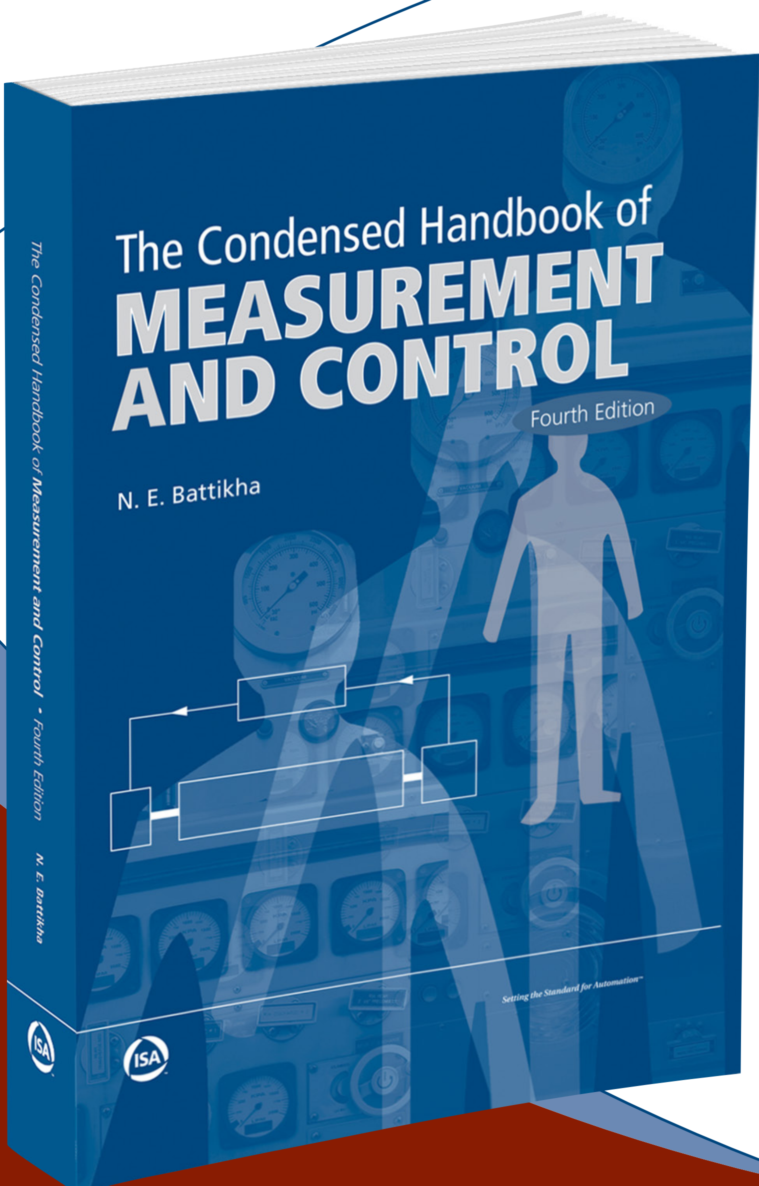

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Setting the Standard for Automation™

The Condensed Handbook

of Measurement and Control

Fourth Edition

N. E. Battikha

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ISA
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Dedication

This book is dedicated to the pioneers of measurement and control. This technology took its first steps along the Nile Valley about 2550 B.C., when Egyptian engineers began using precise, yet simple, measuring devices to level the foundation for building the Great Pyramid and employing weirs to measure and distribute irrigation water across the fertile delta. Much more recently, hundreds of dedicated people tinkering in their homes and labs, working late at night, and overcoming failures and frustrations, created the powerful computer technology we now rely on.

Without these pioneers, whose first tentative steps thousands of years ago have accelerated into today's full-speed sprint toward ongoing advances, the world of measurement and control would not exist and this book would never have been written. And instead of being a process control engineer, I would have probably devoted the past decades to a profession far less interesting and rewarding.

N. E. B.

About the Author

Nabil (Bill) E. Battikha, PE, has a BS in mechanical engineering with many decades of hands-on engineering experience in process control. He is the president of BergoTech Inc., a firm specializing in process control education at universities across North America. Over the course of his career, he has worked for suppliers of control equipment, consultants, and end users and developed experience mainly in engineering, management, and training. He has published three other books with ISA: *The Management of Control Systems* (1992), *Developing Guidelines for Instrumentation & Control* (1994), and *Managing Industrial Controls* (2014). He has participated in the creation of several ISA standards, has written numerous technical articles, and has co-authored a patent and a commercial software package.

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PREFACE

This is the fourth edition of *The Condensed Handbook of Measurement and Control*. Thanks to its readers, the previous three editions were a huge success. In 1998, in its first year of publication, the book was awarded ISA's Raymond D. Molloy award as the best-selling ISA book in that year. I sincerely hope that the book's success will continue—an indication that it is well received.

This book is directed toward all practitioners in process measurement and control (from beginners to specialists) as well as other technical personnel such as engineers from other disciplines, project managers, and maintenance personnel. Readers can find additional detailed information beyond the level of this book in specialized publications and with major vendors (whose valuable experience and knowledge is readily available to users).

I wrote this book because I wanted to concentrate the knowledge I acquired over many decades in a book format. I also thought that a condensed source presenting information on process measurement and control would be ideal for everyday use.

To the best of my knowledge, there is no other book quite like this one. One of the main difficulties I faced in writing it was deciding how much detail is required—a task I hope I accomplished successfully.

This book can be used as a reference book to be consulted whenever information is required on a topic related to process measurement and control. I have also used it as the basis for teaching courses at universities across North America.

I hope that this fourth edition, like the first three, will guide the reader in successfully selecting and implementing process measurement and control systems. The fourth edition updates most of the chapters of the third edition and adds a chapter on "Check-Out, Commissioning and Start-Up."

I have made every effort to ensure the accuracy of this book. I would appreciate hearing your comments and suggestions for improving it. Any such comments and suggestions should be directed to ISA who will forward them to me, thanks.

N. E. Battikha
2017

CHAPTER 1

INTRODUCTION

What Is Measurement and Control?

Measurement and control are the nervous system and brain of any modern plant. Measurement and control systems monitor and regulate processes that otherwise would be difficult to operate efficiently and safely while meeting the requirements for high quality and low cost.

Process measurement and control (also known as *process automation*, *process instrumentation and control*, *process control*, or just *instrumentation*) is needed in modern industrial processes for a business to remain profitable. It improves product quality, reduces plant emissions, minimizes human error, and reduces operating costs among many other benefits.

The production type, quantities, and requirements define the type of process required to make a certain product. In the process industries, two types are commonly used: continuous process and batch process. Often, a combination of the two processes exists in a typical plant.

The continuous process consists of raw materials entering the process and following a number of operations, such as treatment and blending, thus emerging as a new product. The material throughout the process is in constant movement and each operation performs a specific function. Continuous process is used in many industries such as oil refineries and bulk chemicals.

The batch process consists of raw materials transformed into a new product according to a batch recipe and a sequence. The raw materials typically are fed into reactors or tanks where the reactions occur to produce a new product. Batch process is used in many industries, such as specialty chemicals, pharmaceuticals, and foods.

Both the continuous and batch processes use two types of controls: *discrete* and *modulating*. Discrete control is basically on/off control. That is, control that is either on or off (i.e., either activated or deactivated). A good example would be a wall mounted thermostat that would turn a heater (or a heating system) on or off depending on the room temperature. A good example in industry would be on/off switches that sense the level in a tank connected to an on/off control valve, filling the tank when it is empty and stopping the filling (i.e., closing the valve) when the tank fills up.

Modulating control could be manual or automatic. Figures 1-1 and 1-2 give a good example of both conditions. Industrial control is mainly based on automatic operations (see Figure 1-2) using “controllers” to maintain the process within established set points.

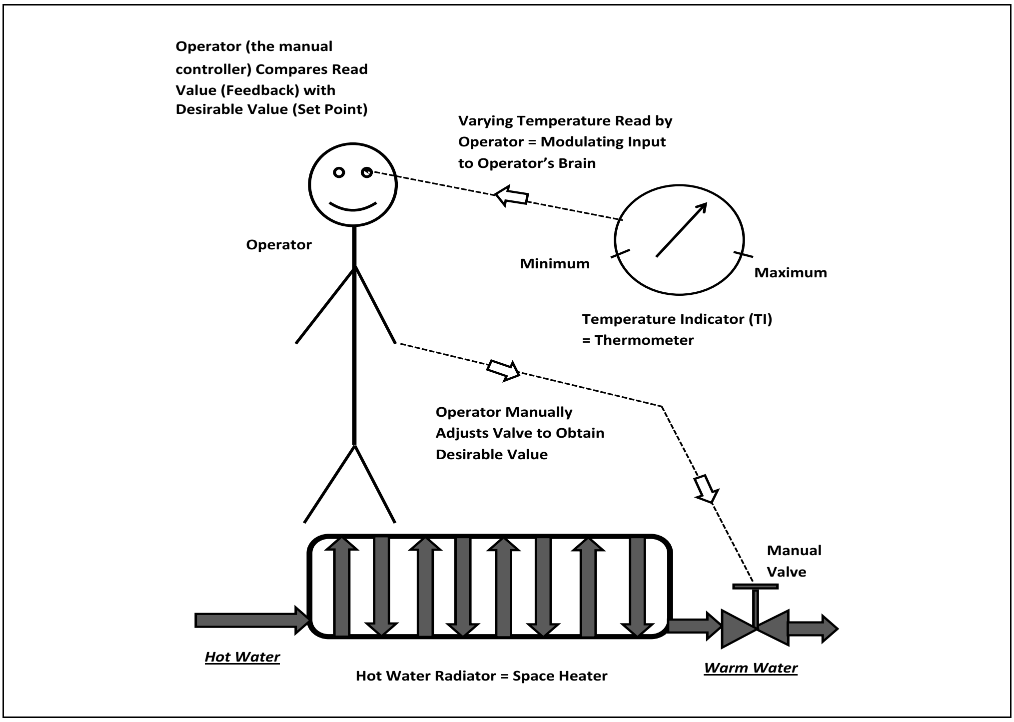

Figure 1-1. Modulating Signals—Manual Control

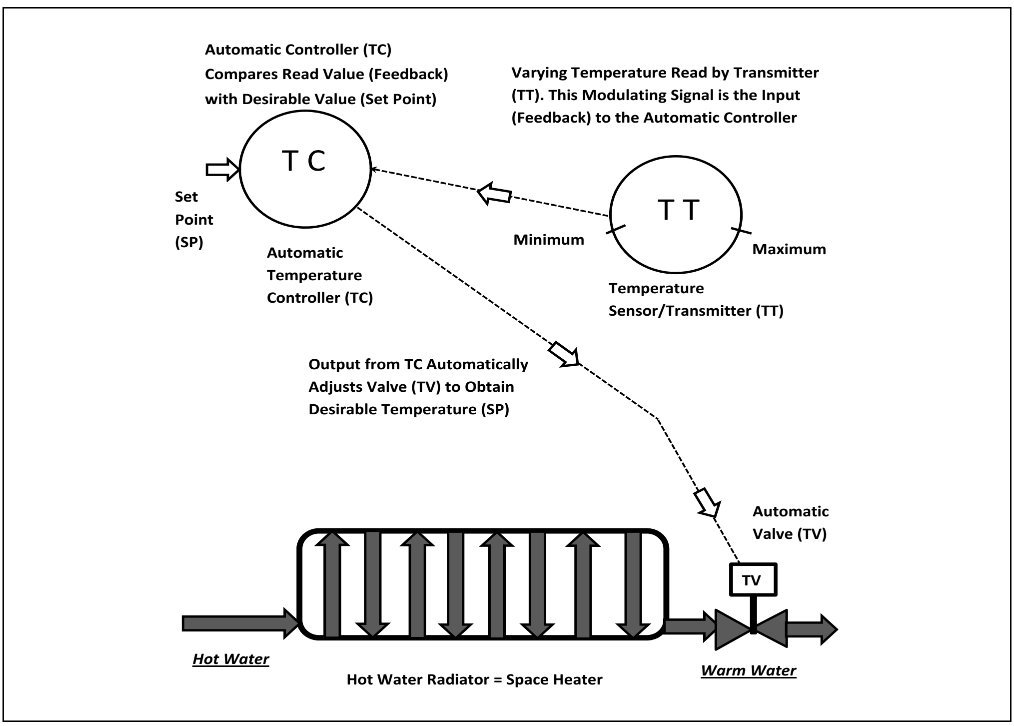

Figure 1-2. Modulating Signals—Automatic Control

In this illustration, three items in Figure 1-1 (the manual control diagram) have been replaced: The gage has been replaced with a transmitter (TT); the operator has been replaced with an automatic controller (TC); and the manual valve has been replaced with an automatic valve (TV).

Another type of measurement and control, not described in this book is used in manufacturing industries. It is called *manufacturing automation* or *discrete automation*. In such industries, components are manufactured in units typically by machinery such as presses and molding machines. Manufacturing is used for making auto parts and plastic components, as well as for assembling cars, packaging, and bottling operations. The sensors for this type of automation include limit switches and position sensors, while final controlled components include motors and industrial robots. Manufacturing automation is a parallel specialty of process measurement and control with its own components, specialists, knowledge, and expertise.

Definitions

- **Automation** – A system or method in which many or all of the processes of production, movement, and inspection of parts and materials are automatically performed or controlled by self-operating equipment, electronic devices, and so on.
- **Instrument** – Any of the various devices for indicating or measuring conditions, performance, position, direction, and the like. They are sometimes used for controlling operations.
- **Measurement** – Extent, quantity, or size as determined by measuring.

Note: Additional information on the terminology used in process control is available in the latest version of the ISA-51 standard.

Overview

Some measurement and control technologies have evolved rapidly over the past few years, while others have almost disappeared. Control equipment presently in use may become obsolete as newer and more efficient measurement techniques are introduced. The emergence of new techniques is driven by the ongoing need for better quality, by the increasing cost of materials, by continuous product changes, by tighter environmental requirements, by better accuracies, by improved plant performance, and by the evolution of microprocessor-based devices. These technical developments have made possible the measurement of variables judged impossible to measure only a few decades ago.

Effective measurement first requires a solid understanding of the process conditions. Selecting the correct measuring and control device is sometimes a challenge even for the most seasoned engineers, technicians, and sales personnel.

This handbook provides the tools to enable users to correctly implement measuring and control systems, which in many cases is an activity not well understood and therefore not successfully implemented. Given the ever-growing demand for measurement and control applications and the wide range of devices on the market, the user must be able to assess different methods of measurement and control and select the most appropriate one. It is not wise to consider only one type of measurement or control since each has its own advantages and disadvantages. The user must compare the different types in terms of which best fits the user's application since many techniques are available for measuring a parameter (such as flow, level, etc.). Making the optimum selection involves considering the requirements of the process, the desired degree of accuracy, the installation, dependability factors, maintenance, and economic factors. Since there is probably no one best method for measuring a specific variable, this guide should help the user decide which method is more appropriate for the application.

One final note: When describing process measurement and control functions, it is important to ensure that we are using uniform terminology. The latest version of ANSI/ISA-51.1, *Process Instrumentation Terminology*, includes definitions for many of the specialized terms used in the industrial process industries, such as *accuracy*, *dead band*, *drift*, *hysteresis*, *linearity*, *repeatability*, and *reproducibility*.

Historical Summary

A few decades ago, the scope of process measurement and control was much simpler to define than today. It was referred to simply as *instrumentation*. With the advent of software-based functionality and advances in technology in most fields, this specialty has begun to branch out into individual subspecialties.

Process measurement and control has evolved from a manual and mechanical technology to, successively, a pneumatic, electronic, and digital technology. This field's exponential growth and its progress towards digitally based systems and devices is still proceeding rapidly today.

We do not know with certainty who invented the field of measurement and control. However, about 2550 B.C., Egyptian engineers were surely using simple and yet accurate measuring devices to level the foundation and build the Great Pyramid, as well as cut its stones to precise dimensions. They also used weirs to measure and distribute irrigation water across the fertile Nile delta. Many centuries later, the Romans built their aqueducts and distributed water using elementary orifice plates.

The pitot tube was invented in the 1600s. The flyball governor for steam engines was invented in 1774 during the Industrial Revolution (with improved versions still in use today). The flyball governor is considered the first application of a feedback controller concept.

In the late 1800s, tin-case and wood-case thermometers and mercury barometers became commercially available. In the early 1900s, pen recorders, pneumatic controllers, and temperature controllers hit the market.

With the advent of World War I, the need for more efficient instruments helped improve and further develop the field of instrumentation. Control rooms were developed, and the concept of proportional, integral, and derivative (PID) control emerged. By the mid-1930s, analyzers, flowmeters, and electronic potentiometers were developed. At that time, there were more than 600 companies selling industrial instruments.

In the early 1940s, the Ziegler-Nichols tuning method (still in use today) was developed. World War II was a major influence in moving the field of measurement and control to a new plateau. Pressure transmitters, all-electronic instruments, and force-balance instruments were produced. In the late 1940s and through the 1950s, the process control industry was transformed by the introduction of the transistor. The following were introduced to the market during this period: pneumatic differential pressure transmitters, electronic controls, and the 4–20 mA DC signal range.

In the 1960s, computers were introduced along with the implementation of direct digital control (DDC) with CRT-based operator interfaces, the vortex meter, and improved control valves. The 1970s brought the microprocessor, programmable logic controllers (PLCs), distributed control systems (DCSs), fiber-optic transmission, in-situ oxygen analyzers, and the random access memory (RAM) chip.

The 1980s and 1990s saw the advent of the personal computer and the software era, which widened the application of DCSs and PLCs. Neural networks, expert systems, fuzzy logic, smart instruments, and self-tuning controllers were also introduced.

The future of measurement and control is unknown. However, based on present trends, it is expected that the line of demarcation between DCSs and PLCs will continue to disappear; auto-diagnostics and self-repair will increase; artificial intelligence will expand in acceptance and ease of use; and standard plantwide communication bus systems will become the rule. The age of the total integration of digital components—from the measurement to the control system to the final control element—is on the horizon.

Handbook Structure

This handbook is divided into chapters and appendices. Units of measurement are shown in customary U.S. units followed by the SI units in parentheses.

The book is divided into five major parts:

1. Chapters 1 to 14 are for design activities—typically these are the first steps in implementing process control systems.

2. Chapters 15 to 18 deal with the installation, start-up, maintenance, and calibration of control equipment—these activities typically follow Part 1 above.

3. Chapters 19 and 20 cover project management and decision-making tools—an activity that covers both Parts 1 and 2.

4. Chapter 21 describes the road to consulting—a subject of interest to experienced practitioners thinking of (or already) providing consulting services.

5. The appendices support all the above chapters.

The following is a further breakdown of each of these parts.

Identification and Symbols

Chapter 2 covers the naming of measurement and control functions using typical tag numbers. This chapter is based on ISA-5.1, *Instrumentation Symbols and Identification*.

Measurement

Chapters 3 through 7 focus on the measurement of analytical values, flow, level, pressure, and temperature, respectively. Each chapter consists of an overview and a comparison table. These tables provide, in a condensed form, the guidance the user needs to select a type of measuring device based on average parameters. For each type of device listed in the tables, a description follows that provides its principle of measurement and related application notes.

Control

Chapters 8 through 12 discuss the control portion of typical control systems. Chapter 8 provides an overview of the different types of control loops, a description of the three elements of a PID controller, and a description of controller settings (i.e., how to tune PID controllers). Chapters 9 through 12 describe, respectively, programmable electronic systems such as DCSs and PLCs, alarms and trip systems, control centers, and enclosures.

Control Valves

Chapter 13 provides an overview of control valves followed by a comparison table that lists the different types of control valves and each valve's different average parameters (such as service and rangeability). The chapter includes application notes related to control valves as well as information on valve trim and actuators.

Design and Documentation

Chapter 14 describes the different types of engineering drawings and documents found in a typical instrumentation and control job.

Installation

Chapter 15 covers the installation of instrumentation equipment.

Check-Up, Commissioning, and Start-Up

Chapter 16 explains the three main activities that follow the installation of control equipment.

Maintenance

Chapter 17 describes maintenance activities and their management.

Calibration

Chapter 18 covers instrument calibration and its requirements.

Project Implementation and Management

Chapter 19 explains the steps for implementing a project in process control.

Decision-Making Tools

Chapter 20 contains the tools and methods to facilitate a quantitative approach to the decision-making process.

Road to Consulting

This last chapter is geared toward practitioners of process control who are thinking of becoming independent contractors, or who are already working as consultants, and would like to know more about the world of consulting.

Appendices

Unit Conversion Tables

Appendix A provides tables for converting between commonly used SI units and commonly used U.S. units.

Corrosion Resistance Rating Guide

Appendix B will help the user determine the suitability of a particular material when it is in contact with a particular process. The table columns list materials normally encountered in instruments (e.g., Teflon, neoprene, Hastelloy C, titanium, stainless steel, etc.). The table rows list different fluids (e.g., acetic acid, aluminum chloride, beer, boric acid).

The Engineering Contractor

Appendix C describes the activities of an engineering contractor on a typical process control job.

Packaged Equipment

Appendix D describes the activities of a packaged equipment supplier from the point of view of instrumentation and control.

Typical Scope of Work

Appendix E lists the many engineering activities typically encountered in process control work.

Standard Development

Appendix F describes the steps required to develop a set of corporate standards or guidelines.

Typical Job Descriptions

Appendix G provides a set of typical job descriptions for personnel working in the field of process control.

Sample Audit Protocol and Sample Audit Report

Appendices H and I are related to the auditing activities described in Chapter 20.

Sample Control Panel Specification

Appendix J provides a sample specification for cabinets and control panels that can be adapted to a specific application when going out for bids.

Selecting Measurement and Control Devices

The process control designer must understand the process in order to be able to implement the required control system with the proper control equipment. The selection of control equipment typically involves considering the following:

1. Compliance with all code, statutory, safety, and environmental requirements in effect at the site.
2. Process and plant requirements, including the required accuracy and speed of response.
3. Good engineering practice, including acceptable cost, durability, and maintainability.

Implementing control systems entails several important aspects other than the specific technology. These include:

- Safety
- Performance
- Equipment location
- Air supply
- Electrical supply
- Grounding
- Installation and maintenance

Safety

Safety must be considered a top priority in the implementation of control systems. It is important to follow the codes and standards. It is also important to ensure that the equipment is manufactured from appropriate materials; incompatible materials may produce corrosion and material failure that may lead to leakage or major spills. For the same reasons, gasket and seal materials must also be compatible. All measurement and control equipment must be manufactured, installed, and maintained in compliance with the codes when they are located in hazardous areas or in the presence of flammable gases, vapors, liquids, or dusts. The latest version of ANSI/ISA-12 series of

CHAPTER 2

Identification and Symbols

Identification

Users of process measurement and control systems need some method for identifying control equipment and software functions so they can manage the engineering, purchasing, installation, and maintenance of such systems. Therefore, one of the key requirements of measurement and control systems is that every device have a unique tag number. Guidelines for tag numbers should either conform to a company standard or to the latest version of ISA standard 5.1. Either way, and to avoid misunderstandings and errors, these tag guidelines must be uniform throughout a plant and, in most cases, throughout a corporation. Older (or different) standards can be used provided they are clearly defined in the plant/corporate standards.

Identification of control equipment and functions must be done according to its purpose and not to its construction. Thus, a differential pressure transmitter across an orifice plate in a flow measuring application would be tagged as FT (flow transmitter), not PDT (pressure differential transmitter).

A typical tag number (e.g., TIC-103) consists of two parts (see Figure 2-1): a functional identification (e.g., TIC) and a loop number (e.g., 103). The functional identification consists of a first letter (designating the measured or initiating variable; for example, T for temperature) and one or more succeeding letters (identifying the functions performed; for example, I for indicator and C for controller). Therefore, a temperature indicating controller is identified as TIC, a temperature recorder as TR, and so on.

	TYPICAL TAG NUMBER
TIC-103	Tag Number (Instrument Identification)
T	Loop Identification
103	Loop Number
TIC	Functional Identification
T	First Letter
IC	Succeeding Letters
	EXPANDED TAG NUMBER
10-TIC-103-A	Tag Number
10	Optional Prefix
A	Optional Suffix

Note: Hyphens are optional as separators.

Figure 2-1. Tag Numbers

Table 2-1. Identification Letters

Note: Numbers in parentheses refer to following explanatory notes.

	First Letters (1)		Succeeding Letters (15)		
	Column 1	Column 2	Column 3	Column 4	Column 5
	Measured/ Initiating Variable	Variable Modifier (10)	Readout/ Passive Function	Output/Active Function	Function Modifier
A	Analysis (2)(3)(4)		Alarm		
B	Burner, Combustion (2)		User's Choice (5)	User's Choice (5)	User's Choice (5)
C	User's Choice (3a)(5)			Control (23a)(23e)	Close (27b)
D	User's Choice (3a)(5)	Difference, Differential, (11a)(12a)			Deviation (28)
E	Voltage (2)		Sensor, Primary Element		
F	Flow, Flow Rate (2)	Ratio (12b)			
G	User's Choice		Glass, Gage, Viewing Device (16)		
H	Hand (2)				High (27a)(28a)(29)
I	Current (2)		Indicate (17)		
J	Power (2)		Scan (18)		
K	Time, Schedule (2)	Time Rate of Change (12c)(13)		Control Station (24)	
L	Level (2)		Light (19)		Low (27b)(28)(29)
M	User's Choice (3a)(5)				Middle, Intermediate (27c)(28) (29)
N	User's Choice (5)		User's Choice (5)	User's Choice (5)	User's Choice (5)
O	User's Choice (5)		Orifice, Restriction		Open (27a)
P	Pressure (2)		Point (Test Connection)		
Q	Quantity (2)	Integrate, Totalize (11b)	Integrate, Totalize		
R	Radiation (2)		Record (20)		Run
S	Speed, Frequency (2)	Safety(14)		Switch (23b)	Stop
T	Temperature (2)			Transmit	
U	Multivariable (2)(6)		Multifunction (21)	Multifunction (21)	
V	Vibration, Mechanical Analysis (2)(4)(7)			Valve, Damper, Louver (23c)(23e)	
W	Weight, Force (2)		Well, Probe		
X	Unclassified (8)	*x*-axis (11c)	Accessory Devices (22), Unclassified (8)	Unclassified (8)	Unclassified (8)
Y	Event, State, Presence (2)(9)	*y*-axis (11c)		Auxiliary Devices (23d)(25)(26)	
Z	Position, Dimension (2)	*z*-axis (11c), Safety Instrumented System (30)		Driver, Actuator, Unclassified final control element	

CHAPTER 3

ANALYZERS

Overview

Analyzers are used to measure analytical values. The most frequently used analyzers in the process industries are pH and conductivity analyzers. Of all the typical measurements, such as flow, level, pressure, and so on, process analysis tends to be the most difficult to select, the least understood, the most troublesome, the most expensive, and the most difficult to maintain. It is therefore imperative that the user handles process analysis carefully and gives it the time (and money) required for a successful installation. Laboratory and portable analyzers will not be discussed in this handbook.

When selecting an analyzer, the user should preferably choose a time-proven off-the-shelf device. Custom-built analyzers tend to have debugging problems and lead to difficult and expensive maintenance.

The cost of implementing an analyzer system is typically much higher than the cost of the analyzer itself. An analyzer system may include a sample probe, a sample line, a shelter, sample disposal equipment, and calibration gases. In addition, ongoing maintenance costs includes the cost of maintenance personnel and their training, the replacement of calibration fluids, the cost of the calibrating equipment, and utilities.

Location

When deciding on the location of an analyzer, there are two possibilities: extractive and in-situ. Some analyzers are mounted remotely from the sample point; these are known as "extractive" analyzers. This approach is implemented when the process conditions are severe, when the sample point is practically inaccessible, or when the analyzer's capabilities require it (e.g., it is not built for an industrial environment). Extractive-type analyzer systems draw a sample from a remote location through a sample line to the analyzer. Such systems are also used where many analyzers are sampling a single process, and the sample can therefore be shared by more than one analyzer. Extractive systems typically require a probe, a sample line (sometimes heat traced), pumps, filters, sample line flushing, a means for calibration, and other miscellaneous equipment. The cost of extractive systems is much higher than in-situ systems. They also require more maintenance.

When extractive analyzer systems are implemented, they are typically assembled in a controlled environment by a specialized vendor in a specialized shop. This provides a better-quality final product. These preassembled systems are normally tested before being shipped to the site, minimizing start-up problems.

Analyzers that are mounted at the process are referred to as "in-situ" analyzers. With in-situ types, the instrument analyzing the sample is at the process and does not have to extract a sample. This eliminates all the sampling problems, and measurement can be achieved without the time delay created by sample lines.

Tagging

Tagging is required to identify all parts of an analyzer system, including all components of the sample system, valves, switches, circuit breakers, and all connection points. The tagging information is typically identified on nameplates that are attached with stainless steel screws or wire (refer to Chapter 2 for further details on tagging instruments). Attaching the nameplates with adhesive is an acceptable alternative only for temperature-controlled environments.

Implementation

It is important that the user prepares a technical specification that covers every component of an analyzer system. This specification should include the system's design, fabrication, supply, installation, and start-up. It is generally expected that the system vendor will furnish all the material needed for a complete and workable system.

The user needs to define the following in the technical specification to ensure a good match between the supplied analyzer system and the plant requirements:

- A description of the process and a tag number for the analyzer(s)
- The components to be measured, with the range of measurement and the required accuracy
- The concentration of all other components and contaminants in the sample stream (even if only traces), with their expected range
- The conditions of the process, that is, the minimum, normal, and maximum range for temperature and pressure
- The materials of construction in contact with the sample that can (or cannot) be used
- The physical state of the sample, that is, liquid, gas, and so on
- The hazards of the sample
- The electrical area classification of the area where the analyzer will be located
- The available power and utilities (such as instrument air)
- The environmental conditions (ambient temperature, corrosive environment, dusts, vibration/shock, etc.)

- The type of measurement, that is, continuous or intermittent, and at what interval?
- The analyzer response time versus the response time required by the process
- The warm-up time for the system following a restart, and the frequency that the analyzer is expected to shut down
- The requirements for the analyzer output signal (e.g., 4–20 mA and fieldbus) and display (analog or digital? local and/or remote?)
- The need for a sample probe and sample line (with the distance from the sample point to analyzer)
- The required analyzer(s) and the required accuracy
- The enclosure that will contain the sampling systems, the analyzers, and the exhaust system; will it consist of either a climate-controlled walk-in enclosure (known as the shelter) or a cabinet?
- The calibration system (such as gas cylinders with regulators) and whether it is manual or automatic
- When required, a strip-chart recorder or connection to a data collection system to continuously record the analyzed value(s)

For most analyzer applications, it is good practice for the user to discuss the requirements and implementation with one or more reputable suppliers. The plant and vendor must work closely to ensure a successful implementation.

The plant's responsibilities typically encompass the following:

- Specify the process data and system requirements by preparing the technical specification.
- Review all vendor designs. It should be noted here that unless plant personnel are very experienced in the application of analyzer systems, the system vendor must be made responsible for the design, implementation, and overall suitability of all components for performing the required analysis.
- Witness the testing at the system vendor's facilities.
- Install the enclosure and sample line. The system vendor may connect both ends of the sample line.
- Connect to the structure's grounding.
- Install and terminate all power and signal cables.
- Install and connect all utility piping.

CHAPTER 4

FLOW MEASUREMENT

Overview

Flow measurement is a key parameter used by plants for monitoring (including accounting needs) and for controlling processes. Of the most common process measurements—flow, level, temperature, and pressure—flow tends to be the most difficult to implement correctly and, therefore, the one for which incorrect devices are most likely to be selected.

The technology of flow measurement has evolved to the point where highly accurate and reliable devices are now on the market. Moreover, new measurement principles are being introduced, and existing principles are continuously improved upon. As a starting point, it should be mentioned that no single flowmeter can cover all flow measurement applications. This chapter provides some of the basic knowledge needed in order to select the correct flowmeter.

Classification

Flowmeters operate according to many different principles of measurement. However, they can be broadly classified into four categories:

1. Flowmeters that have wetted moving parts (such as positive displacement, turbine, and variable area). These meters utilize high-tolerance machined moving parts, which determine the meter's performance. These parts are subject to mechanical wear and thus are practical for clean fluids only.
2. Flowmeters that have wetted non-moving parts (such as vortex, differential pressure, target, and thermal). The lack of moving parts gives these meters an advantage. However, excessive wear, plugged impulse tubing, and dirty fluids may cause problems for these meters.
3. Obstructionless flowmeters (such as coriolis and magnetic). These meters allow the fluid to pass undisturbed and thus maintain their performance when handling dirty and abrasive fluids.
4. Flowmeters with sensors mounted externally (such as clamp-on ultrasonic). These meters offer no obstruction to the fluid and have no wetted parts. However, their limitations prevent them from being used in all applications.

Flowmeters can also be classified into four types:

1. Volumetric, such as positive displacement meters. They measure volume directly.

2. Velocity, such as magnetic, turbine, and ultrasonic meters. These meters determine total flow by multiplying the velocity by the area through which the fluid flows.
3. Inferential, such as differential pressure (dp), target, and variable-area meters. These meters infer the flow by some other physical property, such as differential pressure and then experimentally correlate it to flow.
4. Mass, such as coriolis mass flowmeters. These devices measure mass directly.

Measurement

Volumetric flow can be defined as a volume of fluid in a pipe passing a given point per unit of time. This can be expressed by

$$Q = A \times V$$

where Q is the volumetric flow, A is the cross-sectional area of the pipe, and V is the average fluid velocity. Therefore, the mass flow may then be defined as

$$\textit{volumetric flow} \times \textit{density}$$

Typically, flow measurements rely on empirical formulas and on test results. Therefore, a plant considering the application of any flowmeter should always bear in mind the limitations of the selected meter. For example, as temperature changes, the density of a fluid will change as well. That, in turn, may affect the accuracy of the reading unless compensation is implemented.

For gases, pressure and temperature must be compensated for if the measured values differ from the ones used for calculations. Unlike gases, liquids are incompressible but they may require temperature compensation since their density may vary significantly after a large change in temperature.

To standardize expressions of gas flow, process measurement professionals often express the gas flow at operating conditions to standard pressure and temperature conditions. Standard conditions are presumed to be 14.696 psia (101.325 kPa absolute) for pressure and 59°F (or 15°C) for temperature. However, such "standard" conditions may vary from industry to industry, so it is good practice to define these conditions to avoid errors. Gas flow expressed in standard units is the amount of gas at standard conditions that is required to effect the same mass flow. The reasoning behind this approach is to relate the volumetric flow to the mass flow at given operating conditions, because the mass flow at 100 psig (689.5 kPag) is quite different from the mass flow at 5,000 psig (3,447 kPag) due to density change.

Accuracy

Accuracy for a flow measuring device is typically specified either as "% of flow rate" or as "% of full scale." The user should be careful when defining accuracy since "% of flow rate" and "% of full scale" are not the same. In "% of flow rate," the accuracy is the same for low flows as it is for high flows. For example, a device with 0-100 L/m range and ±1% flow rate accuracy, will have, at 100 L/m, an error of ±1 L/m and at a flow of 20 L/m, the error will be ±0.2 L/m (i.e., 1% of the measurement in both cases).

On the other hand, a "% of full scale" device has different measuring accuracies at different flow rates. For example, a device with 0-100 L/m range and ±1% full scale accuracy will have, at 100 L/m, an error of ±1 L/m and at a flow of 20 L/m, the error will still be ±1 L/m (i.e., 5% of the measurement). This is a much larger error than the flow of 20 L/m under "% of flow rate."

General Application Notes

Depending on which type of flow measuring device is selected, many parameters need to be considered when applying flowmeters. Ignoring such parameters will result in a measurement with a high error or one with a short life span. In addition to the requirements common to most measurements—such as process conditions, measuring range, and accuracy—flow measurement also requires a closer look at the following:

- The type of fluid and whether it is dirty or clean
- The velocity profile
- The piping considerations
- The line size

Where required, flowmeter sizing calculations are performed by vendors and are available to the plant at the bidding stage and also when the flowmeters are delivered to the plant.

Type of Fluid

The type of fluid may limit the type of flowmeter device available for the application. For example:

- On magnetic meters, severe service for conductive fluids can be measured, where orifice plates or vortex shedders are not suitable.
- On most turbine meters, steam cannot be measured.
- On vortex meters and differential-pressure devices, liquid, gas, and steam can be measured.

The condition of the fluid (i.e., clean or dirty) also presents limitations. Some measuring devices may become plugged or eroded if dirty fluids are measured. For example, differential-pressure devices would normally not be applied where dirty or corrosive fluids are measured (though flow nozzles may handle such applications under certain conditions). On the other hand, magnetic meters are capable of accurately measuring dirty, viscous, corrosive, abrasive, and fibrous liquids as long as they are conductive.

CHAPTER 5

Level Measurement

Overview

Level measurement is defined as the measurement of the position of an interface between two media. These media are typically gas and liquid, but they also could be gas and solids or two liquids. The first method of level measurement, a few thousands of years ago, consisted of a graduated stick that was referenced to an arbitrary datum line. In more recent times, the glass gage was developed as an evolution of the U-tube principle (this is described further in Chapter 6 on pressure measurement). Eventually, level measurement was used on pressurized tanks by connecting the upper end of the tube to the vessel (see Figure 5-2 in the "Differential Pressure" section). With equal pressure in the tube and the vessel, the liquid level in the tube was at the same point as the level in the tank.

Level measurement is a key parameter that is used for reading process values, for accounting needs, and for control. Of the typical flow, level, temperature, and pressure measurements, flow tends to be the most difficult, but level follows closely behind. This chapter provides some of the basic knowledge plant personnel need to select the correct level-measuring device.

Over the years, level measurement technology has evolved, and highly accurate and reliable devices are now on the market. New principles of measurement are being introduced, and existing principles are continuously improved upon. Many parameters need to be considered when applying level-measuring devices, depending on the type of level measurement selected. These parameters include the process conditions (such as pressure, temperature, and the material's properties, such as density) as well as the existence of foam, vapor, and turbulence. Ignoring such parameters may result in a measurement with a high error or one with a short life span.

Like any item of instrumentation and control, level-measuring devices should be installed where they can be easily accessed for inspection and maintenance. Installation considerations include the need for isolation valves as well as bypass chambers and stilling wells (see Figure 5-1). Bypass chambers and stilling wells

- provide a calmer and cleaner surface,
- isolate the transmitter from disturbances, such as pipes, agitation, fluid, flow, foam, and the like, and
- allow sensor removal from a tank for servicing without affecting the process.

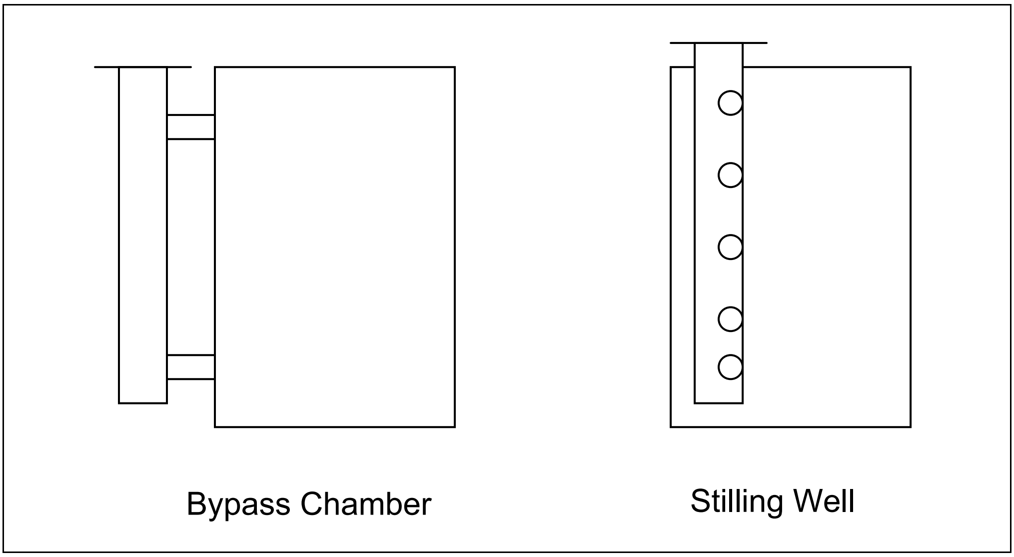

Figure 5-1. Bypass Chamber and Stilling Well

However, they increase the installation cost (material and labor) and should be used only with clean nonviscous fluids.

Classification

Level devices operate under different principles. They can be classified into three main categories that measure:

- The position (height) of the surface
- The pressure head
- The weight of the material through load cells

Level measuring devices can also be classified into different types, such as:

- Mechanical:
  - Float
  - Weight and cable
  - Tape (float and tape)
- Buoyancy:
  - Displacement
- Hydrostatic:
  - Gage
  - Diaphragm
  - Bubbler (dip tube)
  - Differential pressure (or pressure/static head)
- Electrical:
  - Capacitance
  - Conductivity
  - Resistance tape

CHAPTER 6

PRESSURE MEASUREMENT

Overview

Pressure is measured as a force per unit area. Pressure measurements are important not only for monitoring and controlling pressure itself, but also for measuring other parameters, such as level and flow (through differential pressure). Pressure measurement is one of the most common measurements made in process control. It is also one of the simplest in terms of which measuring device to select. One of the key items to consider is the primary element (strain gage, Bourdon tube, spiral, etc.—described later in this chapter). Primary-element materials should be selected to provide sufficient immunity from the process fluids and, at the same time, the required measured accuracy under the process conditions they will encounter.

Pressure-measuring instruments convert the pressure energy into a measurable mechanical or electrical energy. Pressure measurement is always made with respect to a reference point. There are basically three types of pressure-sensing configurations (see Figure 6-1)

1. Gage pressure, where the reference is atmospheric pressure
2. Absolute pressure, where the reference is complete vacuum (i.e., absolute vacuum)
3. Differential pressure, which represents the difference between two pressure levels (note that gage pressure is a differential pressure between a value and atmospheric pressure)

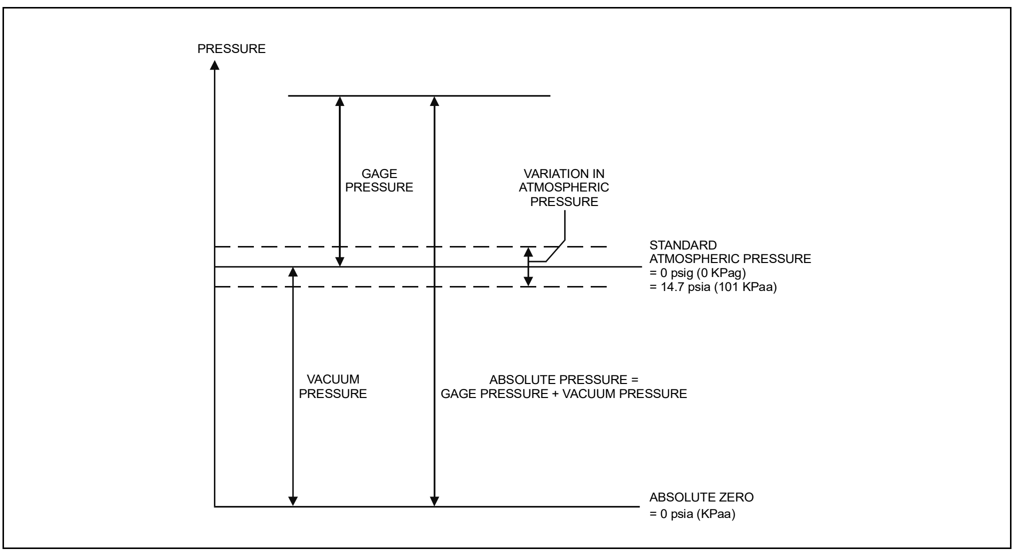

Figure 6-1. Absolute and Gage Pressure

In certain cases, pressure devices must conform to specific requirements. For example, on pressures greater than 15 psig (103 kPag) or in applications that contain lethal, toxic, or flammable substances, pressure devices may need to be registered, regardless of the design temperature.

Units of Measurement

Most industrial pressure measurements function within a range between the atmospheric pressure and the operating pressure. This pressure measurement is known as *gage pressure*, it is a measurement that plant personnel commonly use. Units such as *psig* or *kPag* are used in these cases. When referring to units of pressure, it is important to ensure that the measuring units are clearly stated (i.e., gage or absolute). In uses where the pressure is measured in absolute terms, as is the case in making engineering calculations (i.e., in reference to full vacuum), the units used are *psia* or *kPa* absolute (sometimes referred to as *kPaa*).

Differential pressure is the difference between two process pressures. The common units of measurements are psi and kPa, although some plants use the *psid* and *kPad* terminology to avoid misunderstandings. Standard atmospheric pressure is equal to 14.7 psia (101.3 kPa absolute).

Gages

Normally, pressure gages intended for field mounting are 4 1/2 in. (about 110 mm) in diameter and contain a blowout disk and a standard bottom connection of 1/2 in. (or 3/4 in.) male NPT (National Pipe Taper thread), unless different requirements are dictated by pipeline or vessel specifications. Instrument air applications typically use 1/4 in. connections. Generally, the maximum working pressure to which a gage is subjected should be around 75 to 80% of full-scale pressure range.

Transmitters

A typical pressure transmitter consists of two parts: the primary element and the secondary element. The primary element (which includes the pressure sensor or pressure element) converts the pressure into a mechanical or electrical value to be read by the secondary element. The primary element is the part that is most subject to failure because it faces the process conditions.

The secondary element is the transmitter's electronics: basically, a transducer to convert the output from the primary element into a readable signal—digital (e.g., fieldbus) or analog (e.g., 4–20 mA). Typically, electronic-based sensors, such as strain gages, have a better response and a higher accuracy than mechanical-based types, such as Bourdons, which are commonly used in pressure gages and switches.

Filled Systems and Diaphragm Seals

Filled systems consist of a flexible diaphragm seal that is attached to a transmitter (or other pressure-sensing device), through either a capillary tube (see

Figure 6-2A) or a direct-mount-style connection (see Figure 6-2B), and a fill fluid such as silicone oil. The thin, flexible seal diaphragm and fill fluid isolate the pressure-sensing elements from the process fluid. The diaphragm flexes due to changing process pressure and transfers the measured pressure through the fill fluid to the pressure-sensing element in the transmitter. Filled systems protect the primary sensing element from corrosive, toxic, or highly viscous process fluids. They are also used to prevent the effects of deposits or solidification in the impulse line or at the sensing element.

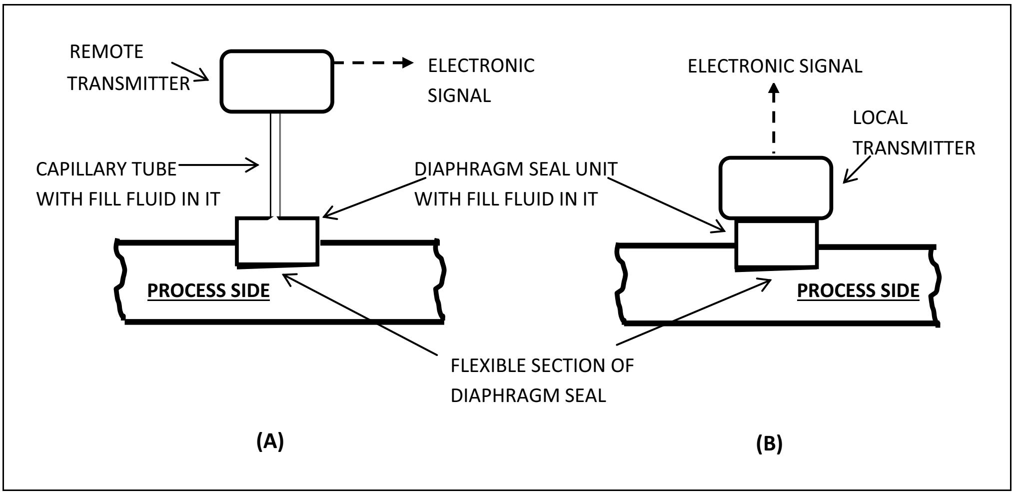

Figure 6-2. Diaphragm Seals

When diaphragm seals are implemented, users should consider the following:

1. There may be a potential need for a flushing connection because a diaphragm covered with deposits from the process will not perform as intended.
2. The diaphragm diameter is dependent on the measuring requirements and process conditions, and is typically calculated by the equipment vendor.
3. The rating and material of flanges must comply with the pipeline or vessel specifications.
4. The seal fill fluid must be compatible with the process fluid. This will prevent the introduction of unwanted seal fluid into the process due to a diaphragm leakage. This is critical in applications that involve pharmaceuticals, foodstuffs, and hazardous chemicals.

Installation

Where process conditions permit, the common practice is to isolate pressure instruments from the process with a valve (see the example in Figure 10-10). Such an isolating valve (and its associated piping/tubing) must comply with the piping requirements for the process fluid in question. This isolation permits maintenance and equipment testing activities to be performed without

CHAPTER 7

Temperature Measurement

Overview

Temperature is a widely used measurement. Galileo is credited with inventing the first thermometer in 1595. Over the years, thermometer technology has evolved, and measuring principles are continuously being improved upon. Today, highly accurate and reliable devices are available. This chapter provides some of the basic knowledge users need to select the proper temperature-measuring device. However, it is essential that the instrument selector take into consideration the users' experiences.

For process applications, a typical temperature measurement assembly consists of a thermowell, a temperature element, sometimes extension/connecting wires, and a temperature transmitter (local or remote). Temperature elements frequently include a spring-loaded mechanism to ensure that the element tip makes positive contact with the internal bottom of the well.

Temperature elements should be installed where good mixing is ensured, such as in pipe bends and in the liquid phase (if a vapor/liquid interface exists). The optimum immersion length for temperature elements varies with the application. If they are installed perpendicular to the line, then the tip of the element should be between one-half and one-third the pipe diameter. If they are installed in an elbow (the recommended option), with the tip pointing towards the flow, about one-quarter pipe diameter is sufficient because the flow is impinging on the tip of the temperature element. In all cases, the installation should follow the vendor's recommendations.

Units of Measurement

The most commonly used units of temperature measurement are the Fahrenheit scale and the Celsius scale. The Fahrenheit scale was invented by Daniel G. Fahrenheit and published in 1724. It is still extensively used in the United States, although some industries are gradually converting to Celsius. The Celsius scale was developed by Anders Celsius, a Swedish scientist, in 1742 and is the most commonly used temperature unit worldwide.

Degrees fahrenheit (°F), degrees Celsius (°C), and Kelvin (K, used mainly for scientific work) are recognized internationally as scales for measuring temperature. The Fahrenheit and Celsius scales have been developed from two fixed points: ice and steam, at atmospheric pressure.

Conversion from one scale into the other follows these equations.

Point	°F	°C	K
Steam point	212	100	373.15
Ice point	32	0	273.15
Absolute zero	-459.67	-273.15	0

$$°F = \left(°C \times \frac{9}{5}\right) + 32$$

$$°C = K - 273.15$$

Classification

Physical properties that change with temperature are used to measure temperature. For example, the property of material expansion when heated is used in liquid-in-glass, bimetallics, and filled-system measurement. The electromotive force (emf) principle is used in thermocouples, and electrical resistance changes are used in resistance temperature detectors (RTDs). Other means of temperature measurement include temperature-sensitive paint and crayons, and optical devices.

In the traditional medical thermometer, liquid-in-glass measurement takes the form of mercury enclosed in glass. Obviously, the delicate nature of the glass and the toxicity of mercury limit the usefulness of this type of thermometer in industrial applications. An improvement on the liquid-in-glass thermometer is the filled system.

Temperature-sensitive paint and crayons can be applied to a surface to determine its temperature. Some of them are reversible, such as desktop thermometers, while others are irreversible. They are available in a wide range of temperatures. Both crayons and paints have ranges up to 2,000°F (1,090°C).

Thermowells

Thermowells (T/Ws) are used to protect the element (which is typically fragile) and to make it easier to replace the element without interrupting the process (see Figure 7-1). If a plant does not need a well, for safety reasons, a label should be attached to the element to indicate that no well is present. The downside of T/Ws is that they create a time delay. If, for example, a temperature measurement without a well has a 1- to 10-second time delay, with a well the measurement may degrade to a 20- to 50-second delay.

Thermowells are used in most cases where temperature elements are installed, with some exceptions, such as:

- The internals of some equipment (e.g., compressors, turbines, etc.)
- Bearings where space is very limited

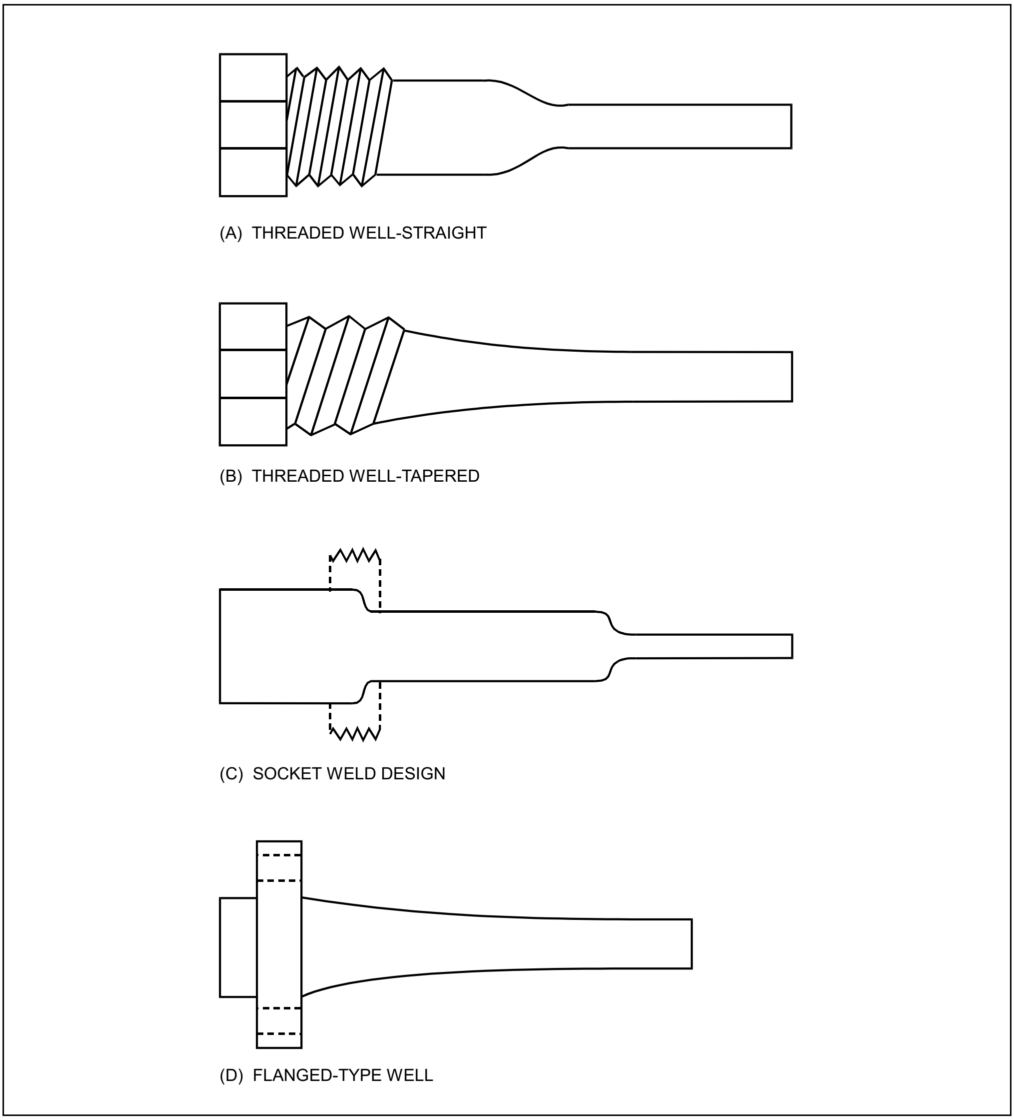

Figure 7-1. Thermowell Profiles

- In measuring surface temperature
- In fast-response applications (i.e., if thermowells create too much of a delay)
- In measuring air-space temperature

Thermowells must comply with the pipeline or vessel specifications. The thermowell's construction and material must be carefully matched with the process requirements (including abnormal and emergency conditions). Many plants have standardized the connection size and material of wells, for example:

- The well connection to the process may be standardized to 1 1/2 in. flanged or 1 in. NPT (National Pipe Taper) thread. This connection should always comply with the piping specification. Note that the

CHAPTER 8

CONTROL LOOPS

Overview

Historically, control functions were originally performed manually by operators (see Figure 8-1). The operator typically used the senses of sight, feel, smell, and sound to "measure the process." To maintain the process within set limits, the operator would adjust a device, such as a manual valve, or change a feed, such as adding a shovelful of coal. The quality of control was poor by today's standards and relied heavily on the capabilities, response, and experience of the human operator.

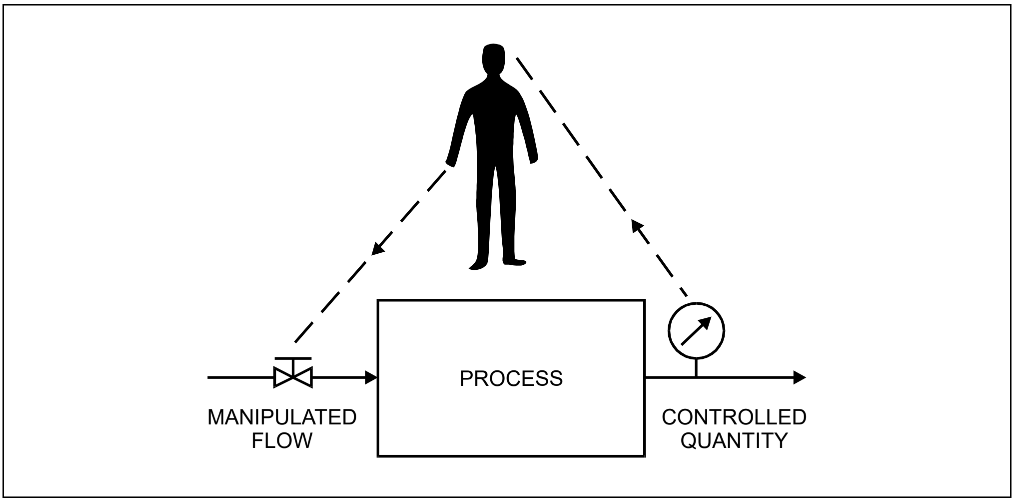

Figure 8-1. Typical Manual Control

In modern systems, by contrast, the operator's control function has been replaced by a control unit that continuously compares a measured variable (the feedback) with a set point and automatically produces an output to maintain the process within set limits (see Figure 8-2). This control unit is the *controller*. The operator acts as a supervisor to this controller by setting its set point, which the controller then works to maintain. Automatic controls provide consistent quality products, reduced pollution, labor savings, optimized inventory and production, increased safety, and control of processes that could not be operated manually with any efficiency. In addition, automatic controls release the operator from the need to perform tedious activities, making possible more intelligent and efficient use of labor.

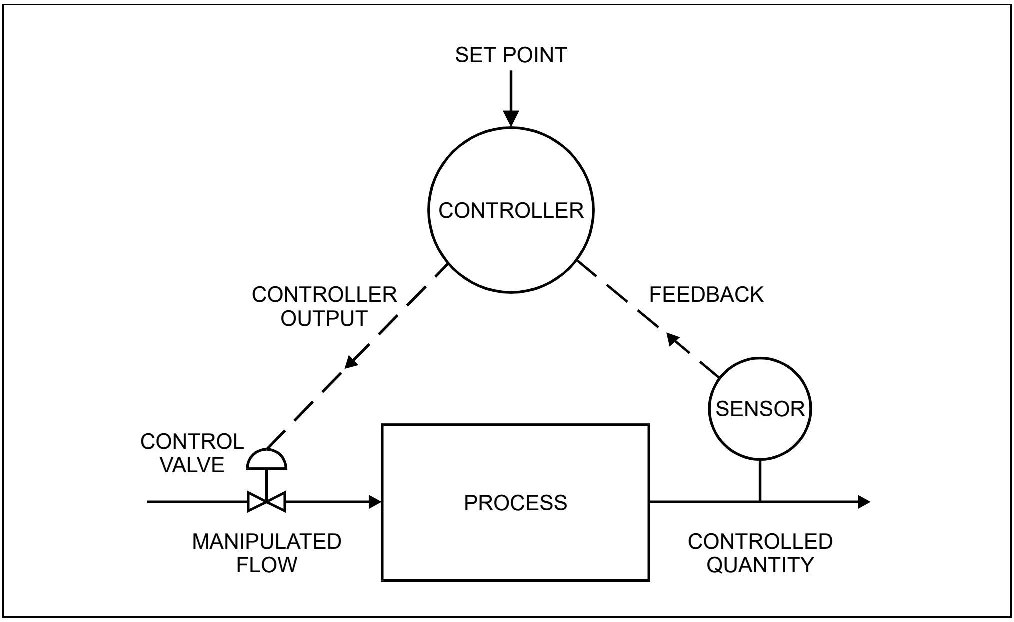

Figure 8-2. Typical Automatic Control

Controllers have evolved from simple three-mode pneumatic devices to sophisticated control functions that are part of a larger computer-based system such as a distributed control system (DCS) or a programmable logic controller (PLC). Such microprocessor-based units commonly provide self-tuning, logic control capabilities, digital communication, and so forth.

When selecting a controller for an application, users should keep in mind certain basic requirements to ensure correct operation. Controller basic requirements include range of input and output signals, accuracy, and speed of response. In addition, personnel selecting controllers should also consider:

- The ability of the control function to switch bumplessly from automatic to manual and manual to automatic
- The implementation of direct-reading scales in engineering units
- The inclusion of built-in external feedback connection (or anti-reset windup) to prevent the development of reset windup caused by the application (refer to the “Modulating control” section later in this chapter)
- The effect on the process if the controller fails and the potential need for manual takeover or automatic shutdown

Control Modes

The two basic modes of automatic control are *on-off* and *modulating*. In either case, the values that are the object of measurement are generally referred to as *measured variables* or *process variables* (PV). These variables include chemical composition, flow, level, pressure, and temperature. These measured variables represent the input into the control loop. Before loops can be controlled, the variables must be capable of being measured precisely. The more precisely the variable can be measured, the more precisely the controller controls.

On-Off Control

On-off control (see Figure 8-3) is also known as *discrete control* or *two-position control*. In it, the output of the control function changes from one fixed condition to another fixed condition. Control adjustments are made to the set point and to the differential gap, if that gap is adjustable. The differential gap basically creates two set points, that is, the On and Off settings.

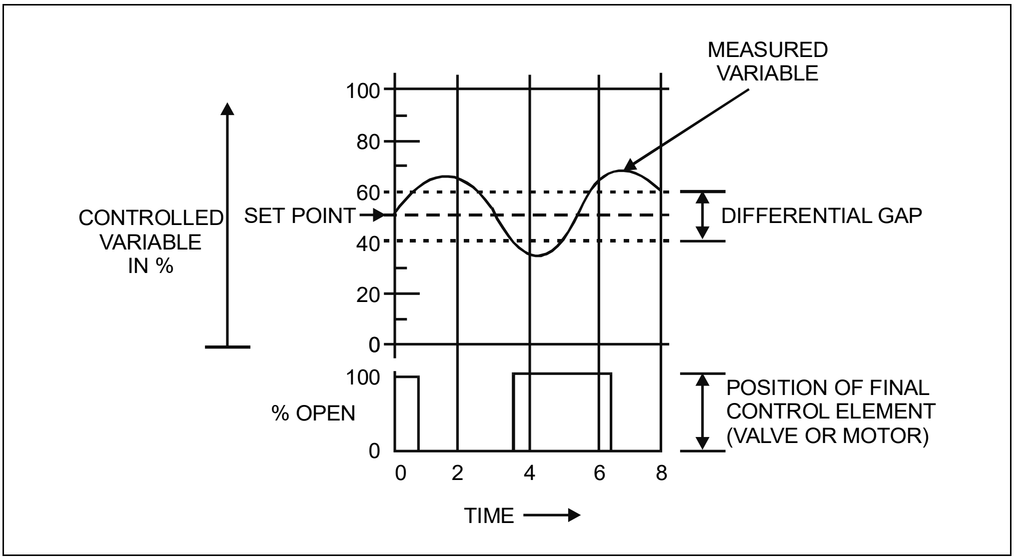

Figure 8-3. On-Off Control

On-off control is the simplest and least expensive form of automatic control. It provides some flexibility since the valve size is adjustable. However, it should only be used where cyclic control is permissible (e.g., in large-capacity systems). On-off control cannot provide steady measured values, but it is good enough for many applications (such as level control in large tanks).

Modulating Control

In modulating control, the feedback controller operates in two steps (see Figure 8-4). First, it computes the error between the measured variable (the process feedback) and the set point. Then it produces an output signal to the control valve to reduce the measured error to zero.

CHAPTER 9

PROGRAMMABLE ELECTRONIC SYSTEMS

Overview

The majority of modern control systems today are programmable electronic systems (PESs). They are typically supplied with display systems, printers, and communication links. PESs include the following systems:

- Direct digital control (DDC)
- Personal computers (PCs) with input/output modules
- Distributed control systems (DCSs)
- Programmable controllers (PLCs) and personal computers (PCs)
- Microprocessor-based standalone PID controllers

Before the introduction of PESs, standalone indicators, controllers, recorders, annunciators, and the like were used for monitoring and control. Such standalone devices are still used for small applications, but for large applications they would be expensive and relatively difficult to modify. In addition, these standalone devices have limited features that are not acceptable in today's control requirements, take up a large amount of space in the control room, and have limited capabilities for field-control room data exchange.

When implementing PESs, plant personnel should always keep these three key items in mind:

1. The simplest solution that meets the plant requirements is generally the best approach.
2. The operator, who is really the end user, should be involved from the time the equipment is selected through the design and implementation phases, including graphics design and color selection. In addition, the operator must be well trained in how to use the system.
3. A successful implementation depends crucially on the quality of engineering and equipment.

Components

A PES is made of hardware and software. The hardware (see Figure 9-1) consists of input modules (accepting analog, discrete, or digital signals), control modules (which perform the logic), output modules (which send out analog, discrete, or digital signals), communication components, and, typically, operator interfaces connected to the control modules.

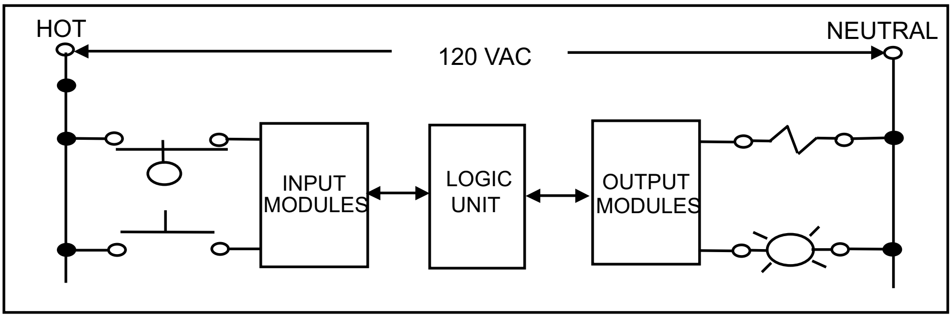

Figure 9-1. Simplified Diagram of a PLC

- Input modules sense the process conditions and feed their own outputs to the control modules (see Figure 9-2).

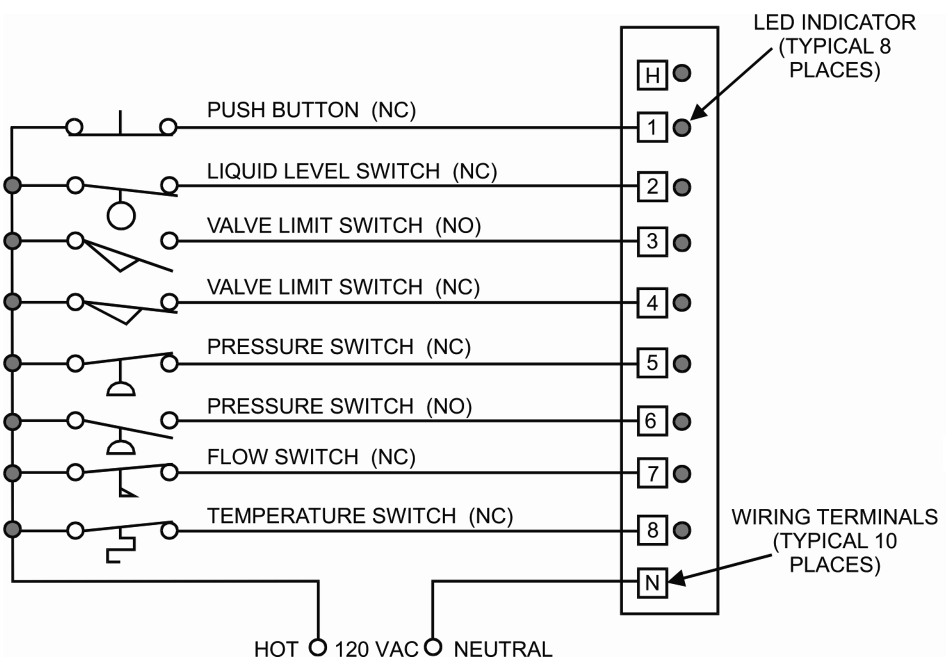

Figure 9-2. Typical Discrete Input Module

- Control modules form the computer portion of the PES and provide the data processing, logic, PID, and mathematical capabilities to meet the functional intent of the PES. The main components of the control modules are the processor and memory. The memory is classified as either volatile or non-volatile. Volatile memory will lose its content (the program) when power is lost unless it is supported by a battery backup.

CHAPTER 10

ALARM AND TRIP SYSTEMS

Overview

Plants that are implementing alarm and trip systems (ATSs) must follow the legislative and regulatory requirements in effect at the site, in particular the requirements covering the safety, health, and environmental legislation. For the process industries, such legislation provides detailed information on implementing critical/safety ATSs for process applications, in particular where programmable electronic systems (PESs) are used as the logic function. Information on such legislation is covered in government standards (such as OSHA in the United States) or in organization standards (such as the latest version of ISA-84 and ISA-91, as well as the IEC 61508 and IEC 61511).

The purpose of a plant alarm system is to bring a malfunction to the attention of the operator(s), whereas a trip system takes protective or corrective action when a fault condition occurs. A plant trip system could shut down the process in a controlled fashion, or it could switch over from some defective unit (such as a pump) to a standby unit. In most cases, a trip system remains dormant until there is a demand on the system (or if it is being tested). ATSs protect only when they are functional.

The reliability of ATSs is achieved through the following:

- Their design and the quality of equipment used
- The conditions under which they operate
- The capabilities of properly trained plant maintenance personnel
- The frequency at which they are tested

Processes are generally provided with two ATSs. The first are the trip systems for normal operation (commonly part of the basic control system), which are typically related to production, quality, and financial issues. The second are the safety instrumented systems (SISs) for handling critical ATSs. Critical ATSs protect the safety and health of people, and, in many cases, prevent environmental issues by taking the process to a safe state when predetermined hazardous conditions are about to be reached. Additional categories can be generated to account for plant/process-related requirements.

These two systems—the normal control system and the SIS—should be physically separate to maintain their independence. This will increase their reliability and minimize the possibility that they both fail as a result of a common cause. Separation, which includes power supply circuits, reduces the probability that both the basic control system and the SIS are unavailable at the same time or that changes to the basic control system affect the functionality and/or availability of the SIS. Where possible, different types of measurement should be used for each system of control. For example, if a capacitive probe is used for level control, then, if appropriate, a radar sensor may be used for the SIS. It is imperative to ensure, particularly for the SIS, that the components selected are approved for the application (see the following "Safety Integrity Level" section).

A SIS is composed of sensors, logic, and final elements that are required to take the process to a safe state. Since the failure of a SIS could harm the environment and, more importantly, lead to loss of life, it is incumbent on the plant to ensure that the SISs (including their power supply systems) function properly and reliably. Therefore, SISs must be regularly tested, and their design must allow for such testing. Bypassing, disabling, or forcing any function of the SIS can only be allowed by approved procedures and, where possible, should be annunciated to the operator.

Once a SIS places a process in a safe state by tripping it, it must maintain the process in that safe state until the hazard is removed and a reset has been initiated. This reset function is typically a manual action by an operator. In addition to automatic trips, the SIS implementation should consider, at the design stage, the need for manual means (i.e., independent of the logic) to be provided to actuate the SIS's final elements. Manual shutdown may be needed due to unforeseen events, thus requiring operator intervention.

Fail-Safe and Deenergize-to-Trip

Systems will fail sooner or later. A fail-safe system will go to a predetermined safe state in the event of a failure. In a deenergize-to-trip system, the outputs and devices are energized under normal operation; removing the power source (electricity, air) causes an alarm and/or trip action. Where possible, it is preferable to implement all plant ATSs as fail-safe and deenergize-to-trip. For SISs in particular, implementing them as fail-safe and deenergize-to-trip is strongly recommended. Fail-safe and deenergize-to-trip implementation may not be possible or suitable for an application because of the severe consequence of a nuisance trip. In these cases, additional safeguards are required to maintain the safety of the process when the SIS malfunctions.

Where possible, the design should ensure

- that sensor failure or loss of electrical power or instrument air will activate the alarm or trip and go to a safe condition,
- that the initiating contacts energize to close during normal operation and deenergize to open when the alarm or trip condition occurs,
- that if a high process value is the trip condition, the sensor is reverse acting (i.e., a high value generates a low signal) so the trip occurs on the loss of signal,
- that solenoid valves are energized under normal operating conditions but deenergize to trip, and

CHAPTER 11

CONTROL CENTERS

Overview

The design of control centers must meet the codes and regulations in effect at the site, as well as the requirements for the plant's operation. *Control centers*, also commonly referred to as *control rooms*, form the nerve center of a plant. They are generally air-conditioned, sometimes pressurized with clean air, and their temperature and humidity are controlled to preset conditions.

When designing a control center, the designer must develop a layout (see Figure 11-1) and ensure that the center's design and use conforms to good engineering practice and standards as well as to the needs of the operator(s). Some of the items that should be addressed when planning control centers are design, physical aspects, security, fire protection, air conditioning, electrical/ electronic, and communication. These are discussed in this chapter.

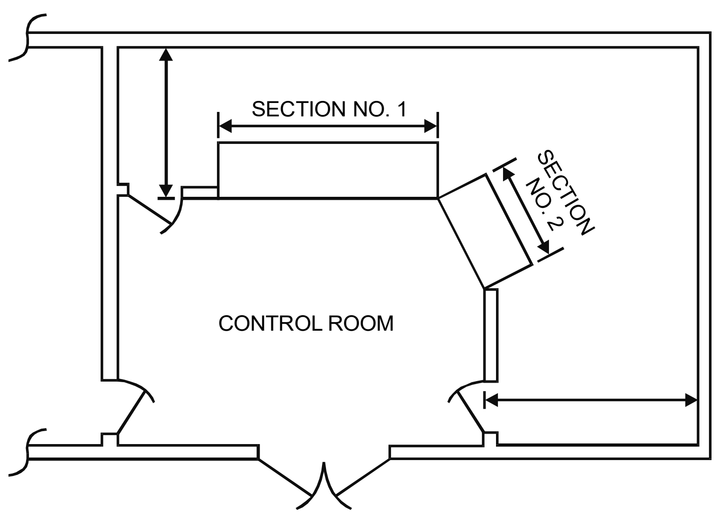

Figure 11-1. Example of a Simple Control Center Layout

Design

Many points should be considered when designing control centers. For example, the control room should be located, whenever possible, away from sources of vibration and completely protected from rain, external fire-fighting water, and the like. In some cases, the control room must be earthquake-proof. For safety purposes, no process lines should enter the control room except for instrument air. The electrical area classification should be taken into account when locating and designing the control room.

Where required (and where economically justifiable), the control room may need a false floor for the passage of cables and/or tubing. In this case, smoke detectors should be installed underneath the false floor, and the floor should be made of a flame-resistant and anti-static material. Where equipment has to be accessed, space should be allowed between that access area and the nearest obstruction (such as a wall), with a minimum of 3 ft (1 m) clearance. In most cases, control room doors are self-closing. Also, there should be a few power receptacles in the control room for portable power tools and other uses.

Easy and safe access must be available so the control room equipment can be brought into the room. As obvious as this may sound, many control rooms were completed before it was realized that the purchased equipment would not fit through the doors. Construction and warehousing personnel should coordinate to ensure that openings are left in walls so large equipment can be installed.

Information on the ergonomic design of control centers is available from the ISO 11064 standard and the latest ISA-60 standards.

Physical Aspects

When designing control centers, the physical characteristics of the operators should be considered and reflected in the design. Locating controls in hard-to-reach areas that require extreme physical movement will produce fatigue and should be avoided. The dimensions shown in Figures 11-2 and 11-3, as well as in Tables 11-1 and 11-2, reflect average static anthropometric data. It should be refined as needed to reflect the physical characteristics of a given plant's actual operators.

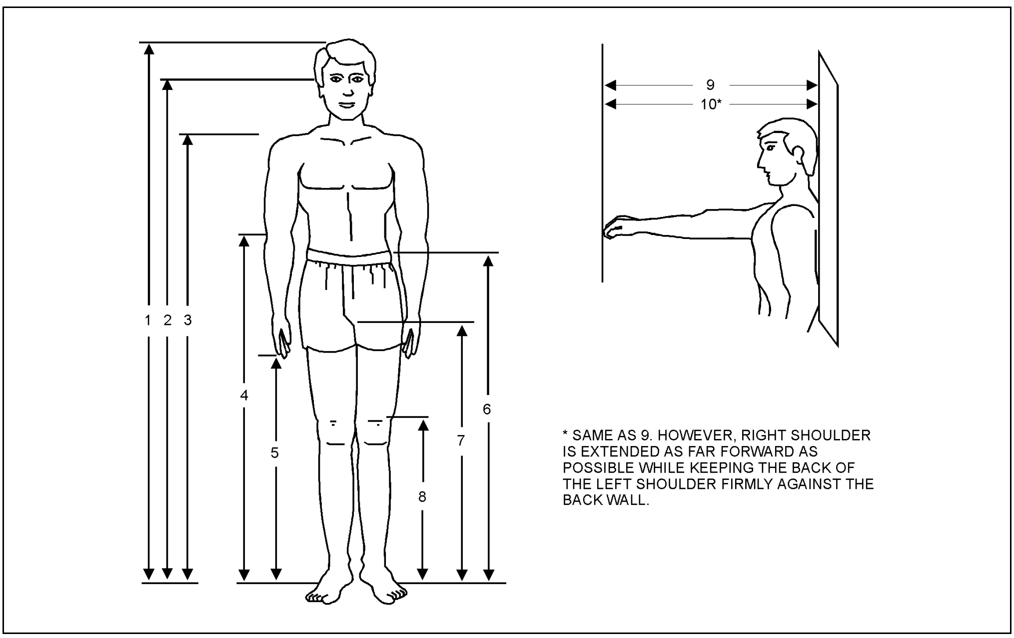

Figure 11-2. Standing Body Dimensions

ENCLOSURES

Overview

Enclosures, which include control panels and cabinets, house items of process control equipment as well as their peripherals such as wiring, terminal blocks, power supplies, and the like. Enclosures are typically assembled in an assembly shop by professionals who should know in detail what the plant's requirements are. It is therefore important that the plant prepare a specification that covers the design, construction, assembly, testing, and shipping of the enclosure (see Appendix J for an example of a panel specification).

A typical enclosure specification should address the following topics: general requirements, documentation, fabrication, protection and rating, nameplates, electrical considerations, pneumatics, temperature and humidity control, inspection and testing, certification, and shipping. This chapter will address these topics.

There are many types of control panels (see Figure 12-1).

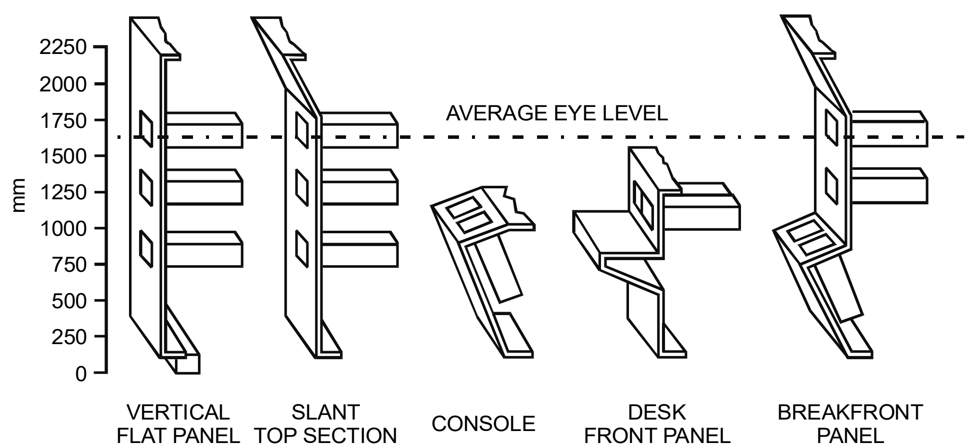

Figure 12-1. Panel Front Shapes

- Vertical panels are simple in design and cost less than the others; they could be wall or floor mounted.
- Annunciators or semi-graphic displays are typically mounted to the slanted section of slant-top panels.
- Consoles are used to facilitate operator access to push buttons and indicator lights.

- Desk front panels are commonly used to provide an operator with a "look-over" capability.
- Breakfront panels provide good access and improve aesthetics. They tend to be custom built and therefore cost more than regular panels.

General Requirements

One of the first rules in building enclosures is to ensure that all electrical components comply with the requirements of the current edition of the electrical code in effect at the site and that they are approved by and bear the approval label of the testing organization (UL, FM, CSA, etc.).

In most cases, the assembly shop furnishes the enclosure completely fabricated and finished, with all components mounted, piped, wired, and tested. This work should be done in accordance with the requirements the plant identified in the enclosure specification. These requirements will vary with project needs, but typically a specification states that:

- All equipment that is not specified to be supplied to the assembly shop by the plant, shall be supplied by the assembly shop. This ensures that no devices, however minor, are forgotten.
- The work of assembling the enclosure should be carried out by certified and trained tradesmen, who should have adequate supervision and the equipment necessary to complete the work. The assembly shop may also be required to produce evidence of tradesmen's certification and training to ensure that only qualified personnel assemble the enclosure.
- The assembly shop is responsible for correctly installing and assembling all equipment and for carefully reading and rigidly adhering to the manufacturer's instructions. Any damage caused by failure to observe the manufacturer's instructions must be the responsibility of the assembly shop.
- Uniformity of manufacture must be maintained for any particular item throughout the panel. This facilitates the inventorying of spare parts and reduces the need for training of on-site maintenance personnel.
- All equipment must be installed and connected so that it can be maintained and removed for servicing without having to break fittings, cut wires, or pull hot wires. This includes providing the necessary unions and tubing connections for all pneumatic equipment (to facilitate their removal for maintenance).
- For enclosures that are located outdoors, rain shields are commonly required even if the enclosures are of weatherproof construction. This is because rainwater could drip inside the panel while the doors are open during construction or maintenance, therefore damaging electronic equipment.

CHAPTER 13

CONTROL VALVES

Overview

A control valve is a continuously varying orifice in a fluid flow line that changes the value of a process variable by changing the rate of flow. The typical control valve consists of three main components: the body, the trim (the varying orifice), and the actuator.

In most applications, a control valve is the final element in a control loop. It provides the power needed to translate the controller's output to the process, either in a two-position (on-off) or proportional (throttling) control mode. Of the three basic components of a typical control loop (sensor, controller, and valve), the valve is subject to the harshest conditions and is typically the least understood. To complicate matters, the valve is also the most expensive element and the most likely to be selected incorrectly.

A successful control valve installation requires both knowledge and experience. Additional information on control valves is available from the latest version of ANSI/ISA-75 standards.

Selecting the right valves involves the following factors:

- Process requirements: The type of fluid passing through the valve, the inlet pressure and differential pressure (dp) across the valve, the maximum and minimum flows, the flowing temperature, and the required degree of valve shutoff.
- Correct sizing of the valve: The valve must be able to handle its maximum design flow (say, at 75% fully open). However, the designer must avoid oversizing or undersizing because they degrade the valve's operation. Typically, a properly sized valve should not operate below the 10% or above the 90% open valve position.
- Suitable flow characteristics: The valve's flow characteristics must match the process requirements (i.e., linear, equal percentage, or quick-opening), refer to the "Trim" section in this chapter.
- Fail-safe mode (on air and/or signal failure): An air-to-open valve is a fail-closed valve (FC); a spring closes the valve on air failure, and air must open it. An air-to-close valve is a fail-open valve (FO); a spring opens the valve on air failure, and air must close it (see Figure 13-1). Also, some valves are designed to fail in their last position (FL).
- Proper choice of valve body type (i.e., globe, ball, etc.) and accessories: For example, bellows seals may be required for applications that are toxic or environmentally hazardous.

- Correct installation: always refer to the vendor's recommendations.

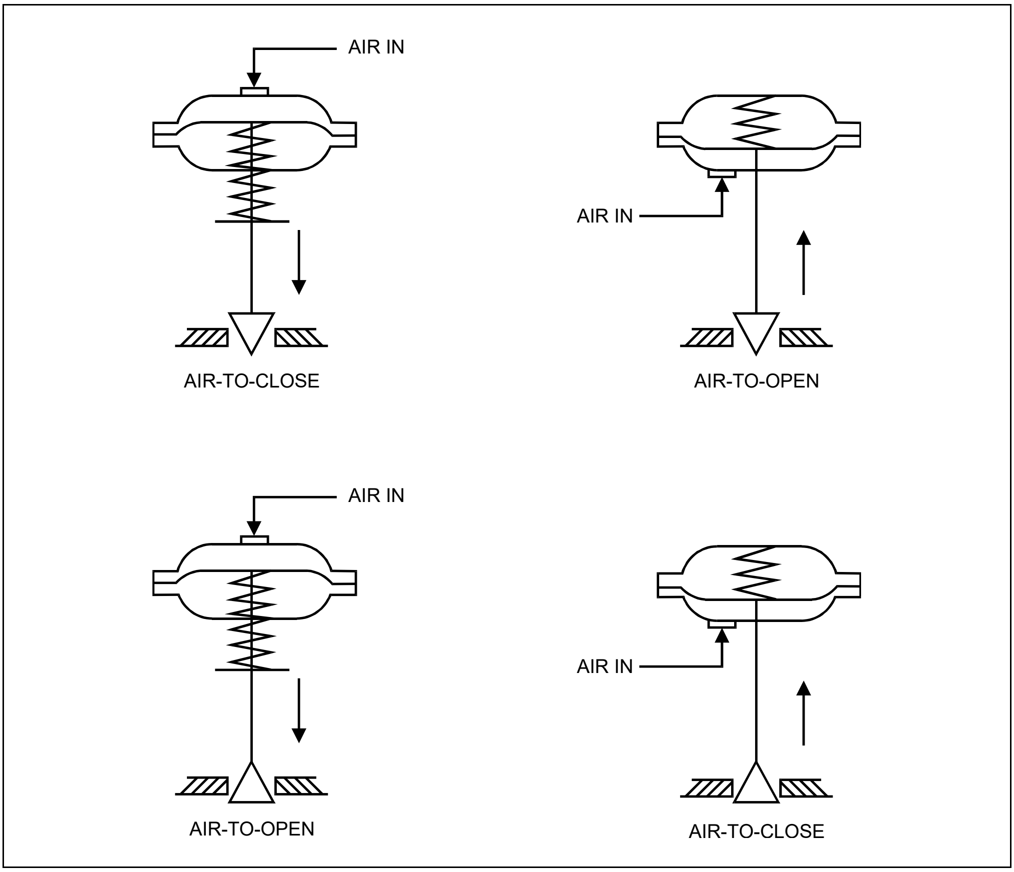

Figure 13-1. Valve Failure Mode with Different Valve/Actuator Setups

Shutoff

Control valves that are well designed provide valve tightness on closure. However, a slight leakage will normally occur through the valve trim, particularly on valves that have been in service for a while. The amount of allowable valve leakage can be defined at the design stage. In accordance with ANSI/FCI 70-2, valve leakage is classified according to six classes, which are summarized as follows:

Class I: No test required.

Class II: 0.5% of rated valve capacity, tested with clean air or water at either the maximum operating differential pressure or at 45 to 60 psi (300 to 400 kPa), whichever is lower.

Class III: 0.1% of rated valve capacity, tested with clean air or water at either the maximum operating differential pressure or at 45 to 60 psi (300 to 400 kPa), whichever is lower.

CHAPTER 14

ENGINEERING DESIGN AND DOCUMENTATION

Overview

Engineering design and documentation activities can be split broadly into two parts: front-end engineering and detailed engineering. Front-end engineering will vary according to the project size and conditions, but in the end, its content must define the project requirements, engineering standards, plant guidelines, and statutory requirements that are in effect at the site, setting the foundation for successful detailed engineering.

Detailed engineering encompasses the preparation of all the detailed documentation necessary to support bid requests, construction, commissioning, and maintenance of the plant. In the present business environment, the size of the corporate and plant engineering staff are generally at minimum levels, so the detailed engineering phase on large projects is frequently given to an engineering contractor or to an equipment supplier. In most cases, the control portion of a project is contracted out as part of a larger engineering package that includes other disciplines such as civil, electrical, mechanical, and the like.

Front-End Engineering

Front-end engineering is the first step in engineering design. It defines the process control requirements and covers the preparation of the engineering data that is needed to start the detail design. This phase, from a process control point of view, typically parallels the preparation of preliminary process and instrumentation diagrams (P&IDs)—sometimes known as *engineering flow diagrams*—and the completion of hazard analysis for the process under control.

The hazard analysis is an essential part of the design activities. However, since it is not normally an activity led by control engineering, it will not be discussed in this handbook.

In general, three documents should be prepared during the front-end engineering phase and completed before the start of detailed design. They are: the P&IDs, the control system definition (which may include a preliminary control equipment index also known as instrument index), and the logic diagrams. On large projects, two additional documents may be required: a scope-of-work definition for the engineering contractor that will do the detailed engineering (see Appendix C), and a scope-of-work definition for the supplier of packaged equipment that includes process control equipment, such as water treatment facilities, boilers, compressors, and so on (see Appendix D).

Front-end engineering documents must be updated as changes are made during the project, and changes do occur. Once these documents are approved and agreed on, no changes should be implemented without prior approval from the project manager and the assigned control engineer (or control supervisor, depending on company policy). The reason for this approach is to maintain control of changes; since these documents are the guidelines for the detailed engineering that affects contractors and vendors, and therefore they impact the schedule and budget.

Detailed Engineering

Detailed engineering must be based on the statutory requirements in effect at the site and on the front-end engineering. The documentation produced under detailed engineering will vary with the process complexity, the project's requirements, and the plant's philosophy and culture. The following is considered to be the minimum technical information for the field of process control; engineering management must decide whether any additional documents are required:

- Instrument index
- Process data sheets
- Instrument specification sheets, including calculations (for control valves, orifice plates, vortex flowmeters, etc.)
- Loop diagrams
- Interlock diagrams
- Control panel specifications (including an overall layout; see Chapter 12 on enclosures)
- Control room requirements (see Chapter 11 on control centers)
- Manuals for programmable electronic systems (DCS, PLC, PC, etc.)
- Alarm and trip-system documentation and testing procedures (see Chapter 10 on alarm and trip systems)
- Installation specifications (see Chapter 15 for further details on installing I&C equipment)

In addition to these documents, location drawings are prepared showing the location of all control devices (for further information, see Figure 15-1 in Chapter 15). Also, three additional documents that are generally not prepared by the process control discipline but are of prime importance to the process control detailed design phase are:

- Piping drawings; these drawings show the locations on process equipment that instruments will connect to. They are typically prepared by the mechanical/piping discipline.
- Location and conduit layout drawings; these drawings show the routing of all process control wiring. They are typically prepared by the electrical discipline.

CHAPTER 15
INSTALLATION

Overview

The installation of instruments, control systems, and their accessories follows the final stage of the engineering design. The installation is then followed by check-out, commissioning, and plant start-up (see Chapter 16). It is important to prepare an installation specification that defines the plant's requirements—this prevents misunderstandings, extra costs, and construction delays. The content of such a specification typically covers the following topics: code compliance, scope of work, installation details, equipment identification, equipment storage, work specifically excluded, approved products, pre-installation equipment check, onsite calibration of field control equipment, execution, wiring, and tubing. All of these topics are discussed in this chapter. It should be noted that the following guidelines apply to the majority of installations. Certain harsh or special environments may need additional requirements.

Code Compliance

It should be the responsibility of the installing contractor to ensure that all installation work is in compliance with the code in effect at the plant even though the plant produced the engineering documentation and may be reviewing and approving the installation. There will be cases where the drawings or specifications call for material, workmanship, arrangement, or construction of quality that is superior to that required by any applicable codes. In such cases, the drawings and specifications should prevail. Otherwise, and without exception, the applicable codes and standards must always prevail.

To comply with local codes and especially with insurance requirements, all electrically operated instruments or the electrical components incorporated in a control device should be approved and bear the approval label (UL, FM, CSA, etc.). Modifications to an approved piece of equipment may void the approval and therefore should not be allowed.

Scope of Work

An installation contractor's scope of work typically includes all items of instrumentation and control systems shown in the documentation supplied with the installation specification. Depending on the size and complexity of the project, this set of documents typically includes, but is not limited to, the following: P&IDs, the instrument index, instrument specification sheets, loop drawings, interlock diagrams, installation details, vendors' data, location drawings, related piping drawings, and location and conduit layout drawings. This documentation is used by the installing contractor to bid on the job to do the installation work. In addition, and to avoid future unwanted surprises, it is strongly recommended that the contractor visit the site before tendering a bid to understand the conditions that must be met in carrying out the work. This includes reviewing and accepting the safety requirements in effect at the plant. The contractor is responsible for reviewing all documentation and equipment received before commencing the installation work. Should there be inconsistencies (and there normally are), the contractor should immediately notify the plant to decide on a solution.

The contractor is typically required to submit a detailed completion of activities of all the work to be done. This can take the form of a table with the completed activity for each piece of equipment. An example of such a table is shown in Table 15-1. The table should be modified to meet the plant's culture, the agreements with the contractor, and the project needs. The contractor is expected to submit the updated table on a set frequency (weekly?) as the work progresses. The onsite plant representative is expected to check the completed activities on a random basis as he or she is touring the construction site to ensure that the table submitted reflects the actual construction completion.

Table 15-1. Installation Completion Status

Note 1: Refer to Chapter 16 for activities checked by the contractor prior to the final check-out done jointly by plant personnel and the contractor.

Tag number	Received and checked with specification	Out of storage for installation	Field mounted	Connected to process	Wired	Air supply connected (for control valves)	Activities checked by contractor (note 1)	Notes
FIT-123								
FV-123								
etc....								
....								

All instrumentation devices listed in the instrument index should be mounted and connected by the contractor to form a complete operating system. A manufacturer, such as a panel assembly shop, may ship pieces of control equipment separately, however these pieces should be installed and connected by the installing contractor.

It is expected that the installation work will be carried out by certified and trained personnel with adequate supervision and equipment necessary to complete the work. The plant may require the contractor to produce evidence of the personnel's certification and training and to ensure that the construction crew (and in particular their supervisor) will remain on the job until completion.

In situations where an electrical certificate of final inspection must be furnished to the plant, the contractor should apply for it and pay all fees required for the certificate.

CHAPTER 16

CHECK-OUT, COMMISSIONING, AND START-UP

Overview

There are three key activities that follow the installation of control equipment. Each of these three activities is dependent on the successful completion of the previous one. These activities confirm the correct operation of the control system before the start of full plant production. They are:

1. Checking the integrity of each loop (check-out). This is done to ensure that all loops, following installation, are properly installed, connected, and ready for commissioning.

2. Commissioning the plant with its control equipment and getting it ready for plant start-up.

3. Starting up the plant and putting it into operation with its control equipment.

Before even starting with these three activities, some preparation work and activities need to first be considered. They are:

- Team organization
- Safety equipment
- Required documents
- Troubleshooting
- Lockout and tagout procedures

Team Organization

Team organization should be established before the installation of all equipment reaches completion. The project manager must determine the number of participants needed to implement the upcoming activities and the responsibility of each participant. The decision is dependent on the size of the project and the time allocated to complete these three activities.

Teams from different disciplines, and often from different companies, are assembled and organized to work together during check-out, commissioning and start-up. It is important that all operate together as a team to achieve success. The project manager's role is critical in maintaining a good working relationship among all team members, thereby helping to ensure successful implementation as planned.

A kick-off meeting is the first step in which the team members are assembled. The meeting is chaired by the project manager, who assigns responsibilities to all team members and describes all the upcoming steps required to reach completion within a set time frame (the schedule). In real life, check-out, commissioning, and start-up are done with limited available personnel, meaning long working hours for all the team members.

The project manager may ask for additional manpower from the discipline managers (including the manager of control systems), who have to balance the needs of check-out, commissioning, and start-up against the needs of other ongoing projects. However, personnel should remain flexible as last minute emergency needs will arise, often requiring personnel to re-allocate priorities. The better the engineering and installation, the fewer emergencies will surface.

Experts of specialized equipment or services (mainly vendor personnel), may be involved in the activities with plant personnel, working with them for support and learning.

Most projects are behind schedule by the time check-out, commissioning, and start-up are due to occur. This puts a lot of pressure on the project manager to implement a 24-hour/7-day work schedule. And even if key personnel are off-site, they must still be available on-call. On demand, they must return to the site to resolve issues that cannot wait until the following day.

Safety Equipment

The use of personal protective equipment (PPE) is a requirement in most industrial facilities. This usually includes hard hats, safety glasses, and safety shoes or boots. Where breathing protection is required, equipment such as masks or respirators is mandatory. In addition, some may require fire retardant clothing or coveralls. It all depends on the type of industry and on the products at the plant. Nuclear facilities have additional requirements.

Safety training requirements may be as simple as watching a video that indicates the type of safety equipment to use, what to do in case of emergency, and how to recognize the different alarms announcing emergencies in a plant. It could also be as intense as attending a series of classroom courses followed by exams and certification. It all depends on the industry or plant in question.

Safety requirements must be followed by all site personnel, regardless of whether they are on site for many months, for a whole day, or for just for a few minutes. These safety rules must be strictly enforced by the project manager and plant management.

CHAPTER 17

MAINTENANCE

Overview

Following plant start-up and with the control systems operating correctly, the responsibility reverts to maintenance for keeping the systems in good working condition and for ensuring that the operation of these systems meets the design intent. In addition, not only is the maintenance to be done correctly but any alterations or improvements done by maintenance must comply with all established codes, such as the electrical code in effect at the site.

It is imperative to underline that the content of this chapter is only a memory jogger and should not be taken "as is" because statutory, technical, and corporate needs vary from one site to the other. Post-installation and maintenance requirements vary with plant needs and specifics.

The two main activities of the maintenance team are

1. plant improvements and modifications (generally a pre-planned activity) and
2. plant maintenance (corrective and preventive types).

Maintenance activities in general, and in particular for control systems, consist of a large portion of human interrelations and teamwork. Maintenance is typically done by plant personnel; however, the help of outside contractors is sometimes needed. In such cases, contract maintenance programs with outside contractors are generally implemented.

Maintenance must at all times be kept in the designer's mind when control systems are being implemented at the design stage. Items that are inaccessible, badly designed, or difficult to calibrate will be poorly maintained, eventually deteriorating, adversely affecting process performance and ending up in the garbage—a waste of time and money due to a poor design effort.

Management has a few basic responsibilities to maintenance personnel and to the public at large. They include ensuring and maintaining a safe work environment, as well as providing maintenance personnel with the proper training, tools, and procedures to work safely and efficiently.

Because no product is absolutely perfect, everything eventually fails. The function of maintenance is to ensure the continued, reliable operation of the equipment on demand. It should be mentioned at this point that ISO 9000 states: "Sufficient control should be maintained over all measurement systems used in the development, manufacture, installation, and servicing of a product to provide confidence in decisions or actions based on measurement data." The above definition of measurement systems includes related computer software.

A maintenance shop should be clean and have sufficient tools in good condition to perform the required work. Generally, maintenance personnel will assess their needs based on the scope of their work and responsibilities. Maintenance personnel should always remember that modifications to approved equipment may void the approval of such equipment.

Maintenance activities can be broken down into steps. This breakdown may be required for estimates, scope of work, and job descriptions. The breakdown shown in Figure 17-1 is an example that should be adjusted to fit particular applications.

1. **Receive a request for maintenance from the operator.**
2. **Select the required procedures, tools, and manpower to do the job.**
3. **Get a work permit from the operator.**
4. **Isolate the process.**
5. **Remove the instrument from the process.**
6. **Decontaminate the instrument.**
7. **Perform the maintenance activity, part of which is the diagnosis of the problem.**
8. **Recalibrate the instrument, which includes**
    - **collecting the required technical information,**
    - **ensuring it is the correct information for the instrument in question,**
    - **selecting the calibration equipment,**
    - **connecting the instrument to be calibrated,**
    - **calibrating, and**
    - **disconnecting the calibrated instrument.**
9. **Prepare for instrument reinstallation.**
10. **Reinstall the instrument.**
11. **Check its correct operation.**
12. **Advise the operator.**
13. **Complete the required paperwork.**

Figure 17-1. Example of a Typical Maintenance Activity

CHAPTER 18

CALIBRATION

Overview

A control system is made of one or more devices (the control equipment). When connected to each other they should all be operating within their expected accuracy—and therefore the need for calibration. Calibration of process control equipment is a key maintenance activity. It is needed to ensure that the accuracy designed into the control system is maintained.

This activity can be performed online with the process in operation, at a vendor's facility, or in the plant's calibration shop, where most of the calibrating equipment is located. The quality of the calibration shop, the quality and accuracy of the instruments used for calibration, and the calibration records kept for all control equipment are important facets of calibration activities.

Calibration is performed in accordance with written procedures typically available from the vendors' maintenance procedures. It compares a measurement made by a device being tested to that of a more accurate instrument to detect errors in the device (control equipment) being tested. Errors are acceptable if they are within a permissible limit.

Calibration should be done for all control equipment prior to first use to confirm all settings. This can be done either by the equipment vendor (who will issue a calibration certificate with the device) or by the calibration shop at the plant on receipt of that device. Vendors generally charge a fee for this activity.

Most analog control equipment has adjustable zeros and spans. In most cases, calibration consists of correcting the zero and span errors to an acceptable tolerance (see Figures 18-1 and 18-2).

Typically, a device is checked at several points through its calibration range (i.e., from the lower end of its range—the zero point—to the upper end of its range). The zero point is a value assigned to a point within the measured range and does not need to be an actual zero. The difference between the lower end and upper end is known as the *span*. The calibrated span of a device is, in most cases, less than its available range (i.e., the device's capability). In other words, a device is calibrated to function within its workable range.

The calibration of control equipment in a loop should be performed one device at a time. This approach ensures that any device with an error (i.e., that is out-of-tolerance) will be corrected.

When several devices are in a loop, the combined accuracy of these devices is equal to the square root of the sum of the square. That is,

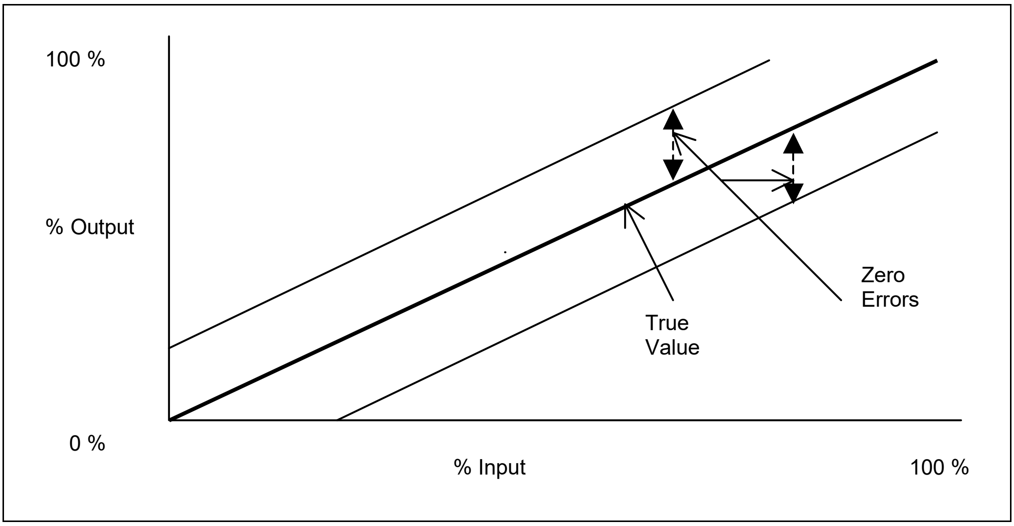

Figure 18-1. Zero Errors

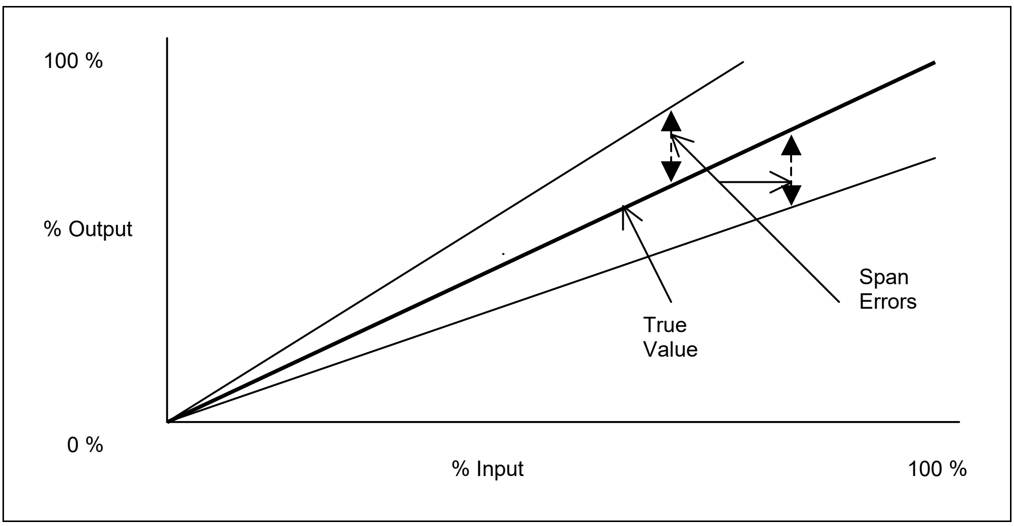

Figure 18-2. Span Errors

$$\textit{Loop total error} = \sqrt{(\textit{Sensor Error})^2 + (\textit{Transducer Error})^2 + (\textit{Indicator Error})^2 + \textit{etc.}}$$

A calibration management system is generally required to provide calibration data and procedures to plant personnel, to record and store calibration data, and to ensure that the calibration conforms to the specifications. In addition, a calibration management system should define what will be calibrated, by whom, when, and where the calibration will be done. Technicians need to be trained and available, and records should be kept for further reference.

CHAPTER 19

Project Implementation and Management

Overview

If a comparison is made between the human body and a typical plant, the following functional similarities are found. The bones are similar to a plant's structure. The muscles are the equivalent of electrical motors (taking their command for action from the brain and the nervous system). The veins correspond to the electrical wires (carrying the energy). The organs are similar to process equipment, such as reactors. The senses are the equivalent of industrial sensors (measuring the process conditions). The brain and the body's nervous system correspond to the plant's control system (a blend of human operators and control equipment). In other words, control system personnel implement and maintain the senses, nervous system, and brain of an industrial plant.

Modern control systems have been accused of eliminating jobs and creating unemployment. The reply is yes and no. Fewer people are needed to do tedious repetitive operations, but these control systems actually secure jobs by preventing plant closures through the maintenance of plant efficiency and competitiveness. In the end, and in most cases, modern control systems increase the number of jobs because of the increased market, both national and international.

This chapter covers project implementation and management for process control systems. It should not be taken "as is" because statutory, technical, and corporate needs vary from one project to another and from one site to another. Also, this chapter cannot cover all possibilities because every project is different—however, it will attempt to take a start-to-finish approach applicable to most industrial projects.

All projects require careful planning, particularly when control systems are complex and implemented with tight budgets and short schedules. For all projects, documents are vital. The quality of the documentation produced by engineering is essential to the successful construction and maintenance of a facility. It allows others to pick up the project where designers left off, keeping in mind that hundreds or even thousands of different components form the ingredients of a control system. Unfortunately, it is quite common that project descriptions are not sufficiently detailed, and therefore, many reviews, evaluations, and revisions typically occur.

Project personnel typically consist of four main participants: a client (i.e., an industrial plant), engineering personnel, equipment suppliers, and contractors. The client's needs should be clearly defined through documents (e.g., specifications and drawings). The project manager must coordinate the activities of the client, engineering personnel, suppliers, and contractors. Engineering personnel, suppliers, and contractors should conform to the client's requirements (as identified in all the documents produced) and be in compliance with the applicable codes and standards.

Generally, a project starts because of

- potential market opportunities, or
- disposal (or conversion) of a process by-product, or
- compliance with regulatory requirements (e.g., reduced emissions), or
- replacement of obsolete equipment, or
- new plant or client needs, or
- a need to maintain market competitiveness.

The life cycle of a project goes through many stages. The importance of each stage and its duration will vary with the project. In most cases, a project's life-cycle consists of the following processes:

- Define the scope and activities
- Define the sequence of activities and their duration, and then develop a schedule
- Allocate human resources, assign roles and responsibilities, and develop an organizational chart
- Estimate the project cost and obtain budgets
- Plan a purchasing schedule to coincide with budget availability
- Develop team and supply training where required
- Start the project and ensure proper coordination (this may involve compromises, tradeoffs, and alternatives)
- Complete the project
- Close the project (resolve open items, project evaluation, and identify lessons learned for future projects)

Quite often, once process engineering and/or researchers develop the required process, it is tested in a lab and then implemented—first in a small-scale pilot plant and then in a full-scale plant. When it is fully defined and the main problems are resolved, the feasibility of the project is assessed, and if it is successful, budgets are allocated before the work in the full-scale plant starts. Once the budgets are approved, a multi-disciplinary team is assembled to design the plant.

Projects are managed by project managers who generally use proven project management methods. Some of these methods are published, and some are just common sense, based on experience. A successful project manager will customize his or her project management method to the task at hand.

A project manager assigns roles to the team members, allocating responsibilities and authorities and identifying the reporting relationships in a project. He or she should ensure that the group works as a team and that interaction

CHAPTER 20

Decision-Making Tools

Overview

Managers and users of process control systems are quite often faced with a situation where a decision is required on matters involving large sums of money. In today's economy, the game is survival of the fittest, and the game has a set of rules that is played on the global scene (some say there are no rules). If you lose, you are out. Markets that were guaranteed a few decades ago are now threatened by international competition.

Product life cycles are much shorter, and technology is changing at an unwavering rate. In addition, production needs to be faster, less expensive on a per unit basis, and of high quality. The olden days, when products had a long lifecycle, the domestic market was secure, and the economical conditions could be predicted, are all gone. We are in a new world, a world of international competition, where survival is a daily issue and vital decisions are frequently required.

A mismatch of process, production capabilities, and customer requirements generally results in poor quality, high cost, and low morale. On the other hand, success not only means survival but also increased markets and increased profits. From a process control point of view, one of the main tools in achieving success is the proper implementation of modern process control systems (see Chapter 9 for further details). These systems are, when well applied, an aid to cost-effective, reliable, high-quality, pollution-reducing, and flexible production (i.e., an aid to survival).

In existing plants, the implementation of modern control systems consists of replacing existing obsolete controls. The replacement must be done with the minimum of interruption to plant production and with the knowledge that the investment is worth taking.

When decisions are made, they must be the correct ones. The techniques learned in this chapter should help the decision-making process by assessing and/or justifying certain major modifications. Four basic tools commonly used in the decision-making process are

1. auditing,
2. evaluation of plant needs,
3. justification, and
4. system evaluation.

These basic tools are presented later in this chapter.

In many plants, the auditing of industrial control systems is becoming a requirement to ensure proper operation and the maintenance of corporate assets. In today's economy, control systems are becoming more and more vital to plant operation, and therefore, their functionality must be ensured. The failure of control systems could be a sizeable financial loss, and, even worse, it could be hazardous to life and to the environment. On the other hand, their efficient functionality will provide safety and quality products and will handle fast, complex, and hazardous processes. Auditing may be defined as a form of quality assurance for the control system to evaluate its intended functionality.

The evaluation of plant needs is an activity that identifies the needs of a plant. These needs, once identified, typically become the basis of a control system specification. This is a process in which decisions regarding the plant needs must be made. These decisions must consider the available choices and should be based on facts, not on the opinion of the person (or persons) with the loudest voice or the highest authority. Evaluation of plant needs is generally done following an audit or sometimes instead of an audit.

Justification assesses the need to invest, helps establish the objectives, and identifies the profitability of the investment. Without justification, the investment could be unprofitable, that is, a waste of funds. In many cases, the funds required for large investments in process control systems need to be borrowed, while at the same time, management has many other needs for funds in the plant. The decision on where to invest funds and which improvement project or expansion is to be chosen depends on the return on that investment and the amount of risk involved. In general, this is a difficult decision that must be substantiated, thus the need for justification.

System evaluation is a tool commonly used to evaluate bids following the submittals from different vendors, and a decision must be made concerning which one most closely meets the plant needs. This is done through a quantified system evaluation.

These four decision tools are actually interrelated and are often used together (see Figure 20-1).

1. **Auditing**
   (to verify the status of the existing control system and decide what to do next)
2. **Evaluation of Plant Needs**
   (to identify the needs of a plant and decide what is required to be done)
3. **Justification**
   (to ensure that the money to be spent is worth the investment and that it will resolve the issues raised by the audit and/or the evaluation of plant needs)
4. **System Evaluation**
   (to decide which of the systems submitted by vendors is the best for the application; this decision is based on a quantified approach)

Figure 20-1. Relationship Between Different Decision Tools

CHAPTER 21

ROAD TO CONSULTING

Overview

What Is Consulting?

Consultancy, by definition, is the work of a person (or a company) that provides advice. In the world of engineering, and more specifically in process control, consultants not only provide engineering services but also may provide other technical services, such as auditing, justification, system evaluation, participation in installation, commissioning, and start-up activities.

A consultant has sound knowledge and extensive experience. The consultant has skills and talent to provide a certain expertise to people and organizations lacking this expertise and in need of it. A professional consultant makes that expertise available to clients for a fee. A consultant's scope of work is typically shaped by the client's needs.

Is There a Need for Consultants?

The need for a consultant generally occurs when an organization's internal staff lacks the special skills or expertise to resolve an issue or problem. The organization is then typically faced with three options; training its staff for the task, hiring full-time employees with the expertise for the task, or retaining a consultant.

The advantages of an outside consultant are:

- the objective can be reached in a short period of time,
- the client obtains highly skilled and experienced personnel relatively cheaply to use for a specific project/application,
- the consultant is available on demand and gone when the job is done,
- the consultant provides an impartial opinion because he or she is independent of the organization's political system and brings a new and different perspective, and
- the consultant often can also design, develop, and conduct various training programs.

Hiring a consultant is generally beneficial to both the consultant and the client.

The need for skilled and experienced temporary assistance (i.e., good quality consultancy) is on the increase. This is due to the need created by the absence of trained and skilled professional in the field of process control (following personnel layoffs due to budget cuts or the retirement of experienced employees). The need is also due to the continuous demand for process automation to maintain a competitive edge (i.e., survival). In addition, the speed of technological change may be a handicap to small organizations whose staff does not have the time to stay abreast of the complexity of modern automation, its ever changing and growing technology, and increasing regulations.

The demand for consultancy also exists, and is at present growing very rapidly, in third-world nations. Their economic growth is often at a much higher rate than their ability to produce skilled personnel—and therefore they need outside sources to supplement and train their own skilled task force.

Where Do Consultants Come From?

Consultants are found from different sources. The most common are referrals. The client typically would first consider consultants with whom they worked successfully in the past. If this is not possible, the client may contact acquaintances and ask for referrals.

Other sources include consultants' directories; placing an ad in the local paper; looking for a consultant's ad; looking for leading authorities, such as book or article authors; contacting trade and professional associations or local universities; or searching on the Internet with a few key words.

One word of advice here: the client should always first define its needs and objectives, determine what it wants from the consultant, and then start the search for the appropriate consultant. Not having a clear understanding of the consultant's scope before the search starts inevitably leads to mismatching, misunderstandings, delaying projects, and increasing costs.

What Are the Qualities of a Consultant?

The life of a consultant is not as rosy as it looks from the other side of the fence. To become a consultant certain qualities are required.

- The consultant should first of all have the necessary knowledge, expertise, skills, and talent to provide the required services to the clients.
- The consultant must be self-reliant, resourceful, and have a good personality.
- The successful consultant is typically a self-starter with excellent self-discipline.
- A consultant is not a typical employee. No guidance is provided by a manager and therefore decisions are generally not reviewed.

A successful consultant must carefully listen to the client needs and often read between the lines. The consultant must be tactful, yet strong enough to maintain control of discussions with the client to be able to understand their needs and desires and respond to those needs. The consultant is expected to provide an effective solution to a client's issue in a timely manner and within budget. This leads to a successful consultation and a satisfied client.

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