CHAPTER 1

INTRODUCTION

P R E V I E W

The objective of this introductory chapter is to present the role of the instrumentation and sensors in industrial environments. In the first section , we review the purpose and functions of instrumentation and measurement systems. In Section 1.2, we learn how to express the details of a process in terms of block diagrams. Block diagrams help to view the subfunctions of each part of a process and determine its input and its output, and how they are linked with each other. In Section 1.3 we learn how to read and construct Process and Instrumentation diagrams. P&I Diagrams consist of graphical symbols and lines which illustrate the process and its flow, and identify the location and functions of its instruments, e.g. sensors, valves, recorders, indicators, and instrument interconnections. Section 1.4 describes the main components of a measurement system. Finally, Section 1.5 gives a historical background on the evolution of the process instrumentation from world war II until now, and the market growth at the turn of the century.

I N S T R U C T I O N A L O B J E C T I V E S

After reading this chapter, you should be able to

- Draw a block diagram of a process control, illustrating the subfunctions of each of its parts with an abbreviated description of each element.
- Read simple P&I diagrams including valves, transmitters, indicators, controllers, and recorders.
- Understand the role of the basic parts of an instrumentation system, namely; sensors, signal conditioning, signal processing, and indicators.

1.1 Instrumentation in the Process Industry

Human progress from a primitive state to our present complex, technological world is marked by learning new and improved methods to monitor and/or control the environment. The purpose of environmental monitoring is to improve our ability to adapt, predict, reduce risks, or to eliminate its adverse effects on life and property. On the other hand, the term *control* means methods to force parameters in the environment to have specific values. The functions or the objectives of the Instrumentation and Measurement systems can be classified into the following categories:

1- **Value or quality assessment**. This is probably the oldest purpose of measurement in the history of civilization. A good example of value assessment instrument is the commercial balance. The balance helps us by means of comparison with standard weights to estimate the values of the goods. Utility metering systems (for water and electricity) are other examples. In industrial environment many measurements serve the purpose of quality assurance, i.e., the product meets specified requirements.

2- **Safety and protection**. The objective here is to monitor the environment for detection of certain hazardous situation in order to take adaptive, protective, or preventive actions. For example, the purpose of monitoring the weather condition is usually to take adaptive actions, or protective actions. In some cases the measurement system is made to trigger audio/visual *Alarms* (e.g. fire alarms), or take other actions such as opening a pressure relief valve to prevent excessive pressure from causing possible explosion.

3- **Automatic Control**. As stated earlier, the term *control* means methods to force parameters in the environment to have specific values. This can be as simple as making the temperature in a room stay at 21°C or as complex as manufacturing an integrated circuit or guiding a spacecraft to Jupiter. In general, all the elements necessary to accomplish the control objectives, including the instrumentation systems, are usually described by the term *control system.*

4- **Data collection**. The purpose of Hubble space probe can not be classified according to any of the above three objectives. The real reason is the unlimited eagerness of man for knowledge and for understanding the universe in which he lives. This apparently unexplainable unjustifiable objective is very essential for the evolution of knowledge. In many situations data is collected and archived for no immediate clear reason. Hopefully, at one stage or another the man would develop techniques to extract useful information and develop a better model for the process under observation. Even in the industrial environment, where every piece of instrument must be economically justified, we see in almost all the recent installations, the process is provided with abundant data acquisition systems in anticipation for the future needs by the new analysis and knowledge based systems for better control of the industrial processes.

The technology of artificial control was first developed using a human as an integral part of the control action. When we learned how to use machines, electronics, and computers to replace the human function, the term *automatic control* came into use.
In process control, the basic objective is to regulate the value of some quantity. To regulate means to maintain that quantity at some desired value regardless of external influences. The desired value is called the *reference value or setpoint.*

The following paragraphs use the development of a control system for a specific process-control example to introduce some of the terms and expressions in the field. Figure 1.1 shows the process to be used for this discussion. Liquid is flowing into a tank at some rate q_{in} , and out of the tank at some rate q_{out} . The liquid in the tank has some height or level ***h***. Now, we want to maintain the level at some particular value H, regardless of the input flow rate.

Manual Control. To regulate the level, the tank is provided with a glass "sight tube", S, as shown in Figure 1.1. The actual liquid level or height, h, is called the *controlled variable.* In addition, a valve has been added so the output flow rate can be changed by the operator. The output flow rate is called the *manipulated variable or controlling variable.*

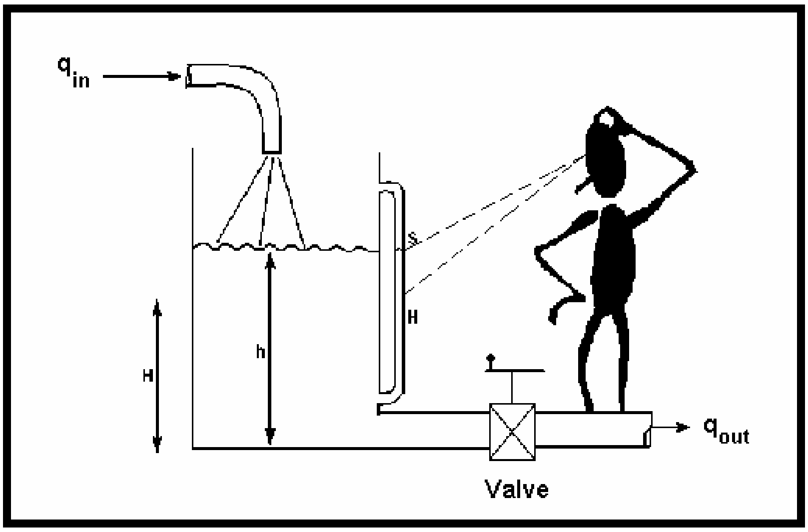

FIGURE 1.1
Manual Level Control.

By manipulating the valve position, the operator controls the liquid level of the tank as close as possible to the desired level **H**.

Here, the human operator uses his eyes as the level sensing element. In general, in manual operation, the human senses; vision, touch, smell, taste, and hearing constitute the measurement system. In many cases the human operator may be assisted by other sensors, e.g., level indicator, temperature indicator, or a pressure indicator.

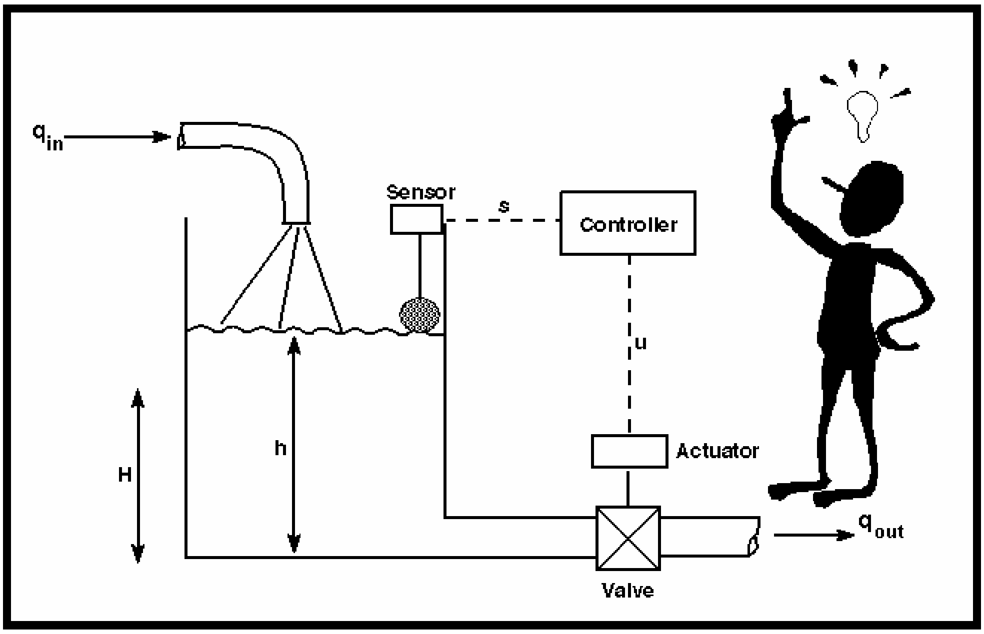

FIGURE 1.2
Automatic level control of liquid in tank.

Automatic Control. To provide automatic control, the system is modified as shown in Figure 1.2 so machines, electronics, or computers replace the operations of the human. An instrument called a *sensor* is added that is able to measure the value of the level and convert it into a proportional signal s. This signal is provided as input to a machine, electronic circuit, or computer, called the *controller. This* performs the function of the human in evaluating the measurement and providing an output signal u to change the valve setting via an *actuator (motor or a pneumatic system)* connected to the valve by a mechanical linkage. This is a typical example of *automatic process control.*

A possible instrumentation for the proposed automatic control system of Figure 1.2 is shown in Figure 1.3. The level sensor sends its measurement as an electrical signal to an electronic controller. The controller is programmed to compare the received signal with the stored value of H The controller then calculates a value for a signal to be sent to the control valve/actuator unit to change the flow. The controller can also be connected to a computer or a recorder. In a more realistic situation we may need to generate Alarms to alert the remote operator if the level in the tank runs too high or too low that could result from failure of the valve/actuator or broken pipe or crack in the tank, etc.. We may also want to monitor the outlet flow rate or the total volume flow for some accounting purpose by adding additional instruments at the tank outlet. These measurements would normally be sent to the computer, which is in turn connected to the company computer network, for processing by other departments. For maintenance purpose, many of the field instruments are also provided with local *Indicators*, i.e., the measured value is displayed locally in the field, and sent as well to the *control center.*

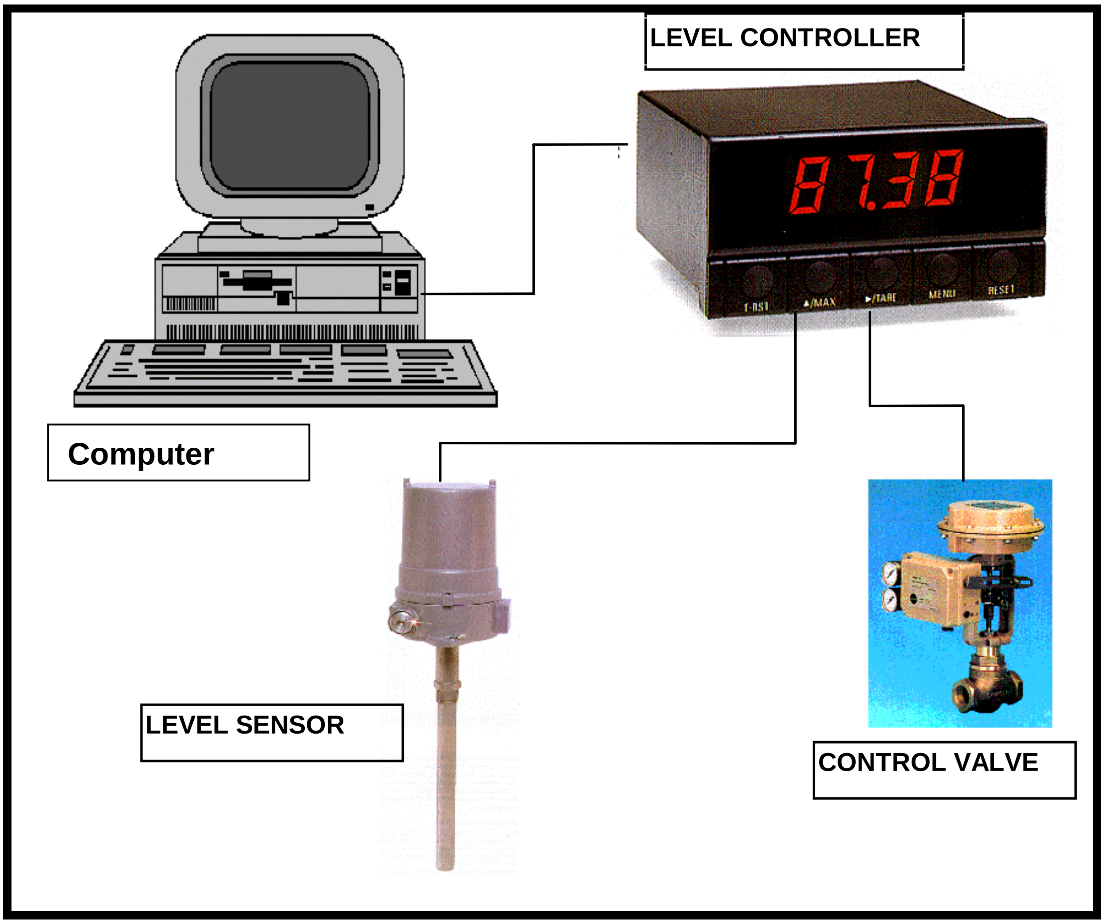

FIGURE 1.3
Instrumentation of the automatic level control.

1.2 Process Control Block Diagram

The purpose of a block diagram approach is to allow a process to be analyzed as the interaction of smaller and simpler subsystems. If the characteristics of each element of the system can be determined, then the characteristics of the assembled system can be established by the interconnection of these subsystems. A model may be constructed using blocks to represent each distinctive element. The characteristics of a process operation may then be developed from a consideration of the properties and interfacing of these elements.

Elements of Process control loop
The elements of a process-control system are defined in terms of separate functional parts of the system. The following paragraphs define the basic elements of a process control system and relate them to the example presented earlier. Figure 1.4 shows a block diagram constructed from the elements defined previously. The controlled variable in the

process is denoted by y in this diagram, and the measured representation of the controlled variable is labeled y_m. The controlled variable setpoint is labeled y_{sp}, for reference.

The error detector is a *subtracting-summing point* that produces an *error signal* $E = y_{sp} - y_m$ to the controller for comparison and action.

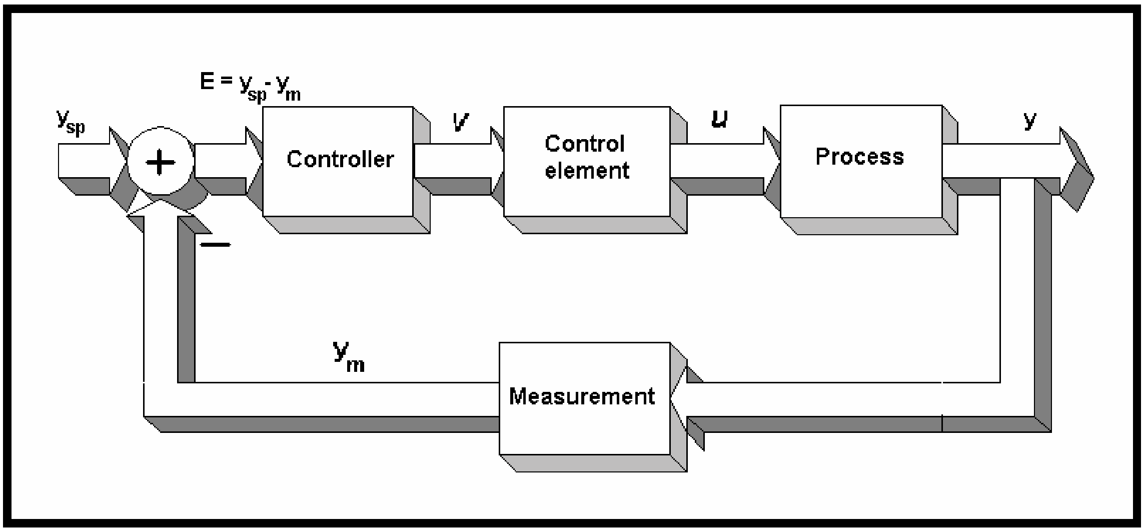

FIGURE 1.4
Block diagram of a process-control loop.

The specification of a process-control system to regulate a variable y within specified limits and with specified time responses, determines the characteristics the measurement system must possess. The choice of a specific technology for the instrumentation in the loop is dependent on the overall requirements and specifications of the underlying control system.

The main terms used for describing the elements in a control loop are defined next**.**

Process : In the previous example the flow of liquid in and out of the tank, the tank itself, and the liquid all constitute a process to be placed under control with respect to the fluid level. In general, a process can consist of a complex assembly of phenomena that relates to some manufacturing sequence. Many variables may be involved in such a process, and it may be desirable to control all these variables at the same time. There are ***single-variable*** processes, in which only one variable is to be controlled, as well as ***multivariable*** processes, in which many variables, perhaps interrelated, may require regulation.

Measurement : Clearly, to effect control of a variable in a process, we must have information on the variable itself. Such information is found by measuring the variable. In general, a *measurement* refers to the conversion of the variable into some corresponding ***analog signal*** of the variable, such as a pneumatic pressure, an electrical voltage, or current. A **sensor** is a device that performs the initial measurement and energy conversion of a variable into analogous electrical or pneumatic information. Further transformation or ***signal conditioning*** may be required to complete the measurement function. The result of the measurement is a transformation of the variable into some proportional information in a useful form required by the other elements in the process-control operation.

Transducer: The sensor used for measurement may also be called a ***transducer***. The word *sensor* is preferred for the initial measurement device, however, because "***transducer***" represents a device that converts any signal from one form to another. Thus, for example, a device that converts a voltage into a proportional current would be a transducer. In other words, all sensors are transducers, but not all transducers are sensors.

Error Detector: In Figure 1.2, the operator observes the difference between the actual level h and the ***setpoint*** level H and calculates the **error**. This error has both a magnitude and polarity. For the automatic control system of Figure 1.3, this same kind of error determination must be made before any control action can be taken by the controller. Although the error detector is often a part of the controller device, it is important to keep a clear distinction between the two.

Controller : The next step in the process-control sequence is to examine the error and determine what action, if any, should be taken. The evaluation may be performed by an operator (as in the previous example), by electronic signal ***processing***, by pneumatic signal processing, or by a computer. Computer use is growing rapidly in the field of process control because computers are easily adapted to the decision-making operations and because of their inherent capacity to handle control of multivariable systems. The controller requires an input of both a ***measured indication*** of the controlled variable and a representation of the ***reference value*** *of* the variable, expressed in the same terms as the measured value. The reference value of the variable, you will recall, is referred to as the ***setpoint.*** Evaluation consists of determining action required to bring the controlled variable to the setpoint value.

Control Element : The final element in the process-control operation is the device that exerts a direct influence on the process; that is, it provides those required changes in the controlled variable to bring it to the setpoint. This element accepts an input from the controller, which is then transformed into some proportional operation performed on the process. In our previous example, the control element is the valve that adjusts the outflow of fluid from the tank. This element is also referred to as the ***final control element***.

The Loop : Notice in Figure 1.3 that the signal flow forms a complete circuit from process through measurement, error detector, controller, and final control element. This is called a ***loop***, and in general we speak of a process-control loop. In most cases this is called a ***feedback loop***, because we determine an error and feed back a correction to the process.

1.3 Process & Instrumentation Diagram

An important means for engineering communication in the process industry is the so called Process & Instrumentation (P&I) diagram. Figure 1.5 shows the P&I diagram of a typical industrial heat exchanger. Heat exchanger is a process unit in which steam is used to heat up a liquid material. The material (called feedstock) is pumped at a specific flow rate into the pipes passing through the heat exchanger chamber where heat is transferred from steam to the material in the pipe. It is usually desired to regulate the temperature of the outlet flow irrespective of the change in the demand (flow rate) of the feedstock or change in the inlet temperature of the feedstock. The regulation of the outlet temperature is achieved by automatic control of the steam flow rate to the heat exchanger. The P&I diagram utilizes certain standard symbols to represent the process units, the instrumentation, and the process flow.

A Process & Instrumentation diagram consists of:

1- A pictorial representation of the major pieces of equipment required with major lines of flow to and from each piece.

2- All other equipment items with design temperatures, pressures, flow, etc..

3- All interconnecting piping with size, material and fabrication specifications indicated.

4. All major instrument devices.

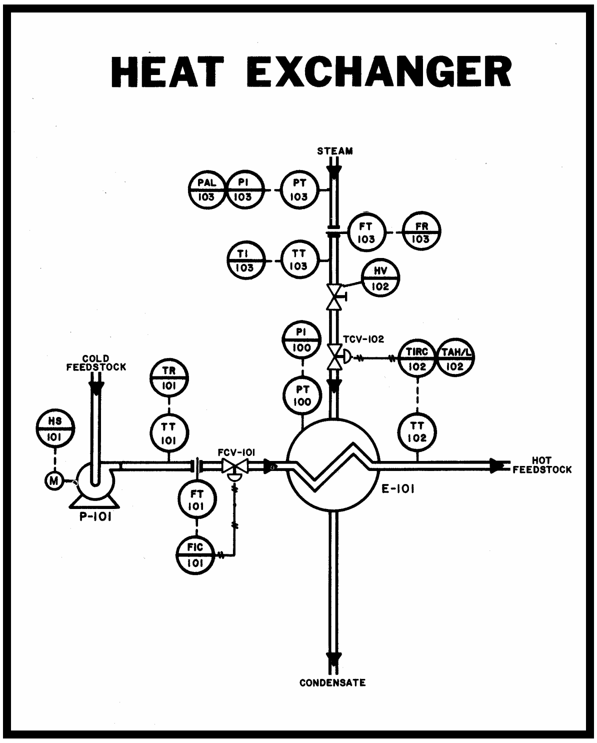

FIGURE 1.5
P&I Diagram of a Heat Exchanger

A partial list of the symbols and abbreviations are given in the tables in Appendix 1.A at the end of this chapter. A comprehensive coverage may be found in the ISA standard in reference [1]. Instruments are shown on the P&I diagram by circles, usually called “balloons”. The balloons contain alphanumeric which reflect the function of the instrument and its tag number. For example, TT102 means Temperature Transmitter number 2 in the process unit (or area) number 1. The number 102 is called tag number. Each Temperature Transmitter (TT) must have a unique tag number in the plant. Tag numbering may be different from one user to the other. P&I diagrams provide a valuable reference for proper project installation. The instrument engineer uses it as a source for many documents which must be prepared.

Another type of diagrams is known as ***Process flow Sheet.*** Process flow sheets consist also of a pictorial representation of the major pieces of equipment required with major lines of flow to and from each piece. However, additional information often given includes operating conditions at various stages of the process (flows, pressures, temperatures, viscosity, etc.), material balance, equipment size and configuration and, in some cases, utility requirements. On the other hand, instrumentation on process flow sheets may or may not be essentially complete.

A third type of diagrams is called ***Loop Wiring Diagrams.*** Electrical loop wiring diagrams are electrical schematic drawings which are prepared for individual (or typical) electrical loops. The simplest loop is one that contains only a transmitter and a receiver.

Other loops may contain many items such as; transmitters. recorders. controllers, alarm units, control valves, transducers, integrators, and perhaps other items. Loop wiring Diagrams are intended to show the location of the instruments, their identification numbers and termination of interconnecting wiring. Cable routing, wire size intermediate terminal points and other pertinent information are necessarily shown in other drawings.

However, knowledge of these diagrams is not required to understand the material of this book. Understanding the basic P& I examples shown in this book can easily be achieved following the heat exchanger example. The reader should consult Appendix 1.A to verify and understand the following instruments list of the heat exchanger P&I diagram.

Instrument	Description
FIC-101	Flow Indicator and Controller.0 to 50 m3/Hr, (normal reading 30 T/Hr). This instrument controls the flow of cold feedstock entering the tube side of the heat exchanger by positioning a valve on the cold feedstock flow path.
FR-103	Flow Recorder, 0 to 10 Ton/Hr, (2.14 T/Hr). This instrument records the steam flow rate.
HS-101	Hand Switch, ON/OFF (ON). This switch turns on/off cold feedstock pump P-101. When the switch is in the ON condition, the pump is running. When the switch is in the OFF condition, the pump is not running.
HV-102	Hand Valve, OPEN/CLOSED, (OPEN). This switch opens/closes the steam block valve through which steam is routed from the header to the shell side of the heat exchanger. When the switch is in the OPEN condition the block valve is open. When the switch is in the CLOSED condition, the block valve is closed.
PAL-103	Pressure Alarm Low, (Normal). This alarm fires should the steam header pressure be less than 6 kg/cm.sqr.
PI-100	Pressure Indicator, 0 to 15 kg/cm.sqr , (3.18 Kg/cm2). This instrument displays the steam pressure at the shell side of the heat exchanger.
PI-103	Pressure Indicator, 0 to 15 kg/cm.sqr, (10.55 Kg/cm2). This instrument displays the steam header pressure.
TAH/L-102	Temperature Alarm High/Low, (Normal). This alarm fires should the temperature of the feedstock at the exchanger outlet exceed 85 °C or be less than 71°C.
TI-103	Temperature Indicator, 0 to 200°C, (186 °C). This instrument displays the temperature of the steam entering the shell side of the heat exchanger.
TIRC-102	Temperature Indicator, Recorder, and Controller, 0 to 200°C, (80 °C). This instrument controls the temperature of the feedstock at the exchanger outlet by positioning the valve that regulates the steam flow to the exchanger.

TR-101 Temperature Recorder, 0 to 200°C, (38 °C).
This instrument displays the temperature of the feedstock entering the exchanger.

1.4 Components of Measurement Systems

The purpose of a measurement system is to present an observer with a numerical value corresponding to the variable being measured. In general this numerical value or measured value does not equal the true value of the variable. Thus the measured value of the flow rate in a pipe as presented on an indicator may be 7.0 m^3/Hr, whereas the true flow may be 7.4 m^3/Hr ; the measured speed of an engine as indicated on a digital display may be 3000 r.p.m. whereas the true speed may be 2950 r.p.m. The problems involved in trying to establish the true value of a variable will be discussed in the next sections. For the present, it is sufficient to realise that the input to the measurement system is the true value of the variable and the output is the measured value (see Fig. 1.6).

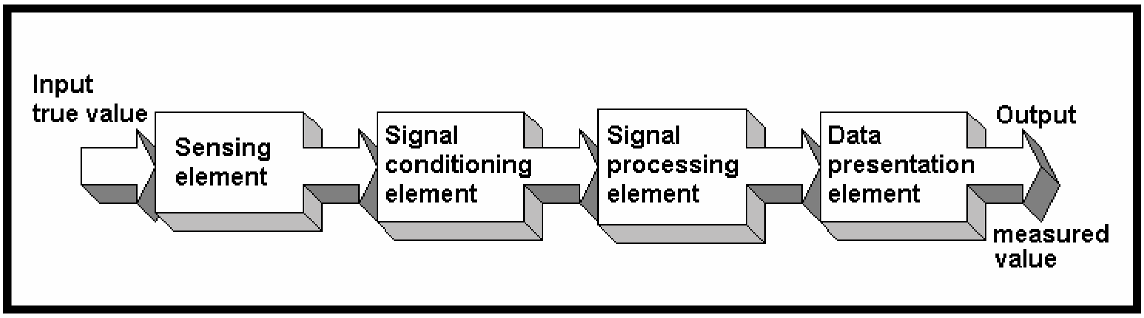

FIGURE 1.6
Block diagram of a measurement system.

The measurement system consists of several elements or blocks. It is possible to identify four types of elements, although in a given system one type of element may be missing or may occur more than once. The four types are shown in Figure 1.6 and can be defined as follows.

Sensing element

This is in contact with the process and gives an output which depends in some way on the variable to be measured. If there is more than one sensing element in cascade, the element in contact with the process is termed the ***primary sensing element***, the others are called ***secondary sensing elements***. The output from a sensor could be a change in resistance, a change in voltage, a change in current, a frequency, etc..

Signal conditioning element

This takes the output of the sensing element and converts it into a form more suitable for further processing, usually a d.c. voltage, d.c. current or frequency signal. Examples are: deflection bridge which converts an impedance change into a voltage change; amplifier which amplifies milli-volts to volts; oscillator which converts an impedance change into a variable frequency voltage. In the majority of cases the output of the signal conditioning element takes standard signal levels; e.g. 0 -10 Volts or 0-5 Volts. If the signal is to be transmitted over wires to a control room, the output from the signal conditioning element is 4-20 mA. In this case the combination of the sensor and the signal conditioning element is called ***Transmitter***. For a temperature transmitter which measures temperature, say, between 0-120 °C, an output of 4mA corresponds to 0 °C. and an output of 20 mA corresponds to 120 °C.

Signal processing element
This takes the output of the conditioning element and converts it into a form more suitable for presentation. Examples are: analogue-to-digital converter which converts a voltage into a digital form for input to a computer; a microcomputer which calculates the measured value of the variable from the incoming digital data, Typical calculations are:
the computation of total mass flow from the volume flow rate and density data; analysis of the harmonic components of a vibration measurement, and correction for sensing element non-linearity.

Data presentation element
The data presentation element presents the measured value in a form which can be easily recognized by the observer. Examples of such elements are :indicators, a simple pointer-scale indicators; chart recorders; alphanumeric displays; and computer monitors.

Example 1.1 ***NEED A FIGURE HERE***
Figure 1.7 shows a weighing balance with a digital readout. The balance consists of a spring S, a potentiometer P, an amplifier A, an Analog to Digital converter A/D, and a digital readout R. The spring S, the primary sensor, produces a linear displacement of 0-4 cm for weights between 0-9.999 kg. The displacement it is then measured by the potentiometer P. The potentiometer, which acts as a secondary sensor, produces an output voltage V_1 between 0-2.5 volts when it varies between 0-4.0 cm. The amplifier has again of 4.0, i.e., its output V_2 varies between 0-9.999 volts. The A/D converter produces a digital number, which can then be displayed by the digital readout circuit.
Identify the elements of this measurement system.

Answer
The spring S is the primary sensing element.
The potentiometer is a secondary sensing element (or a transducer).
The amplifier and the A/D converter are signal conditioning elements.
The digital readout is the indicator element.

1.5 Evolution of Instrumentation

In the late 1940's and early 1950's, analog instrumentation hardware was generally based on pneumatic (air pressure), large-case (approximately 18x 18 in.) concepts. Each instrument was directly connected to a process sensing point and usually located near that point. As a result, process measurement and control were largely decentralized and the operator could only view one section of one unit operation. With the development of pneumatic transmission techniques, centralized control became possible, gradually permitting more control hardware to be placed in one section of a control panel. However, the receiving instrumentation was still fairly large and cumbersome and was usually dedicated to the display and/or control of one process variable.

A new revolution in instrumentation came as a result of the invention of transistor in 1947. In the late 1950's, the miniaturization trend of the receiver instrumentation continued at high pace and its case size had decreased to 6x6 in. and eventually to 3x6 in. and 2 x 6 in. standards. About this time, electronic instrumentation hardware was inaugurated, based on transistor technology. This allowed for electronic transmission development and a consequent further centralization of instrumentation on one control panel. This led to the birth of centralized control rooms.

During the early 1960's, the digital computer was introduced to process control, adding peripheral hardware to the control room. New interface hardware, such as printers, typewriters, CRT screens and keyboards, were now introduced to the operator, making the control room scene more complex, as all of the new hardware was still backed by the conventional analog instrument panel. Thus, the operator had to learn new techniques while recalling old ones in an emergency. This was the current state-of-the-art of control panel design until very recently.

During late seventies and early eighties, a revolution in man-machine interface design philosophy began, with the introduction of a distributed architecture based on microprocessor hardware. This new hardware digitized the usual analog hardware and made applicable new control modes. It also introduced the communications network into the conventional analog loop and enabled the return of some decentralization of control to the field, while at the same time centralizing more information at the main control console(s). Extensive studies were made on evaluation of the human engineering aspects of information gathering, e.g., the ISA recommendation (ISA-RP60.3-1977) entitled "Human Engineering for Control Centers". These studies lead to a new revolution in human interfacing of computer based measurement systems during the 80s.

The distributed systems then made it possible to place all relevant process information on these control consoles within easy reach of a seated operator. That, essentially, is the revolution. Figure 1.8 illustrates the evolution in control panel design from the 1950's to the current centralized overview CRT consoles of the 1970's and 1980's.

These distributed systems were introduced by most of the major instrument manufacturers, namely, Honeywell, Inc., Foxboro Corporation, Taylor Instrument Company, the Bristol Company, Fisher Controls Corporation, EMC Corporation and some others. Honeywell, Inc.'s "TDC2000" was one of the first introduced ("TDC" stands for Totally Distributed Control). The system is based on microprocessor hardware configured into a "data highway" network. A typical modern control center is shown in Figure 1.9.

Finally during 90's the display station utilizes high technology to enhance human interface and enable the operator to supervise larger amount of information. The display is based on the "Windows" technology, animation, 3D display, Icons, mouses, touch screens, videos, and virtual instruments. The future development will be in the operator support software, where intelligent software will be used to consolidate and analyze large amount of data and provide the operator with intelligent summary, analysis, and expert advises.

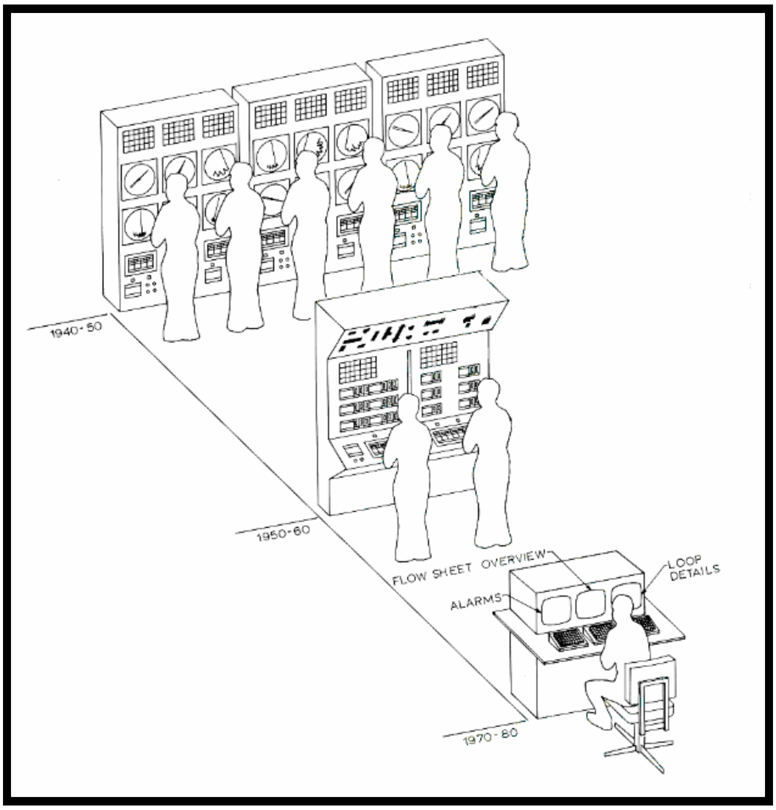

FIGURE 1.8
Evolution of Control Panel and Instruments.

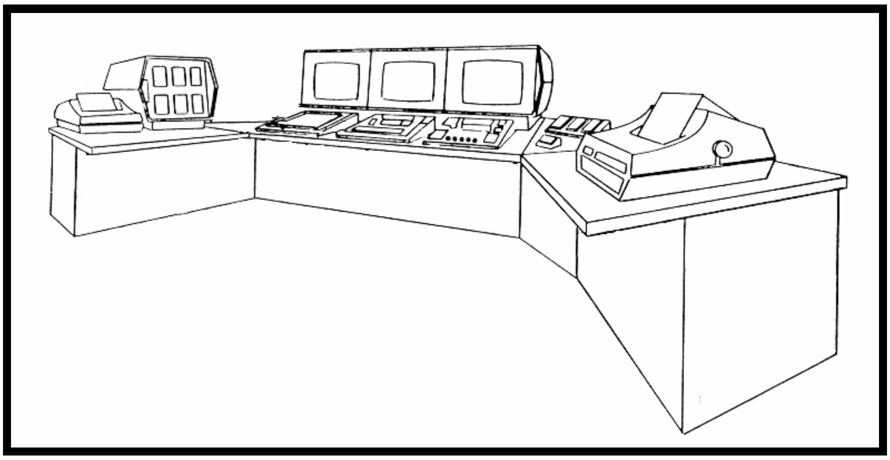

FIGURE 1.9
Typical Control Center.

The signal transmission during 50s and 60s was based on pneumatic techniques. In this system the analog signal is transmitted through pipes as variable air pressure between 3 and 15 psi. During the 70, 80 and 90s the electric wire standard 4-20 mA became the most popular method for signal transmission in the instrumentation field. During 90s the advance in digital communications, microelectronics, and networking, there were many attempts to introduce digital transmission techniques. The sensors become more sophisticated and a new generation of smart transmitters took a considerable market share. The fieldbus technology was eventually standardized in 1997. The field bus enables a single wire cable to be connected to many sensors in the field. The digital transmission enables faster responses and increases the amount of information that can be transmitted over the field bus. Digital transmission is expected to revolutionize the process instrumentation with a much bigger scale than the revolution that was triggered by the electrical transmission during 70's and 80's as illustrated in Figure 1.10. The intelligence is also becoming distributed and embedded in the smart transmitters. The Instrumentation environment will be revolutionized by networking, fiber optics, solid-state sensors, and Artificial Intelligence technologies. A summary of selected milestones in the development of Process Instrumentation is given in Table 1.1.

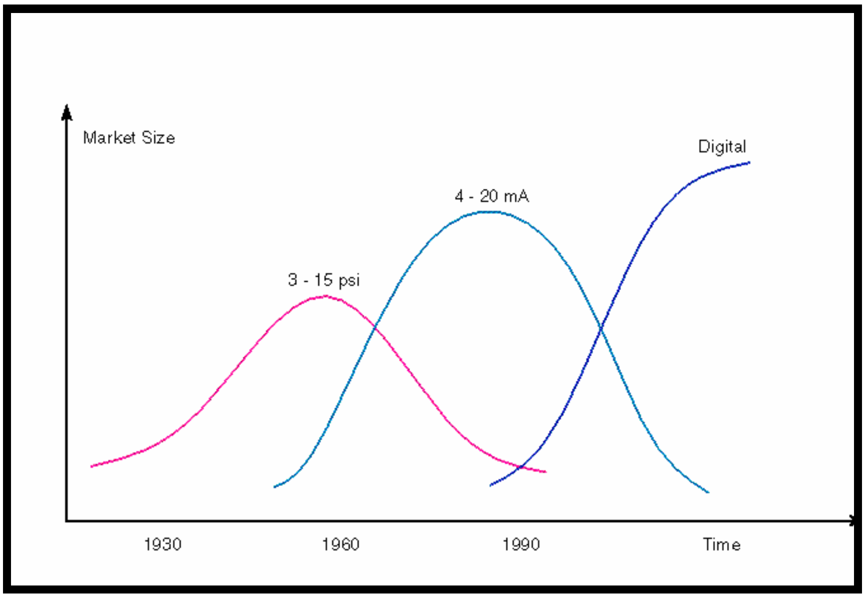

FIGURE 1.10
Evolution of the field communication technology.

Market Forecast

According to [14], 1996 global sales of process-control equipment were valued at about $29.4 billion. The studies on *The World Market for Process Controls* predict that total process control equipment sales growth will rise to 13.5% per year by 2000, when worldwide sales will reach $49 billion.

Computerized hardware and software will continue to enjoy the most rapid increases, reflecting the growing importance of software and advances in computer technology, network communications, and user interfaces. The research firm also sees advanced process control becoming more practical, and emergence of the PC and Windows 95 or NT, especially NT, as the preferred platform for new control systems.

The world process-control market is dominated by chemical and petrochemical end-use industries, which accounted for 31.5% of sales or $8.2 billion in 1995. Chemicals are predicted to narrowly outpace the overall market, growing 14.2% a year versus 13.5% for petrochemicals, through 2000. Water and wastewater will emerge as the next largest segment, with 18.5% compound annual growth rate (CAGR) from 1995 to 2000. Oil and gas applications will rise from 1995's $3.4 billion, but at a somewhat lower rate, slipping to the number three end-use rank, the report contends.

Geographically, the 1996 process-control equipment market was divided as North America (36.70/o), western Europe (33.5%), Japan (15.3%), and rest of world (14.5%). Experts see improved growth in all markets from 1995 to 2000, but forecast that developing markets (India, China, etc.) will continue to gain global share, growing 18.7% per year, rising to $8.3 billion. Global demand will rise at an average rate of 13.5%.

TABLE 1.1 Evolution events in modern instrumentation technology

Year	Event
1900 - 1908	Manual control with gauges and valves
1910 - 1920	Large case instruments in the field
1920-1940	Pneumatic signal & instruments
1945	ISA (Instrument Society of America) was founded
1947	Invention of Transistor at AT&T Bell lab
1948	First Pneumatic differential pressure Transmitter (Foxboro).
1948	National Bureau of Standards(NBS) developed a differential manometer to compare pressure of gases, organic vapors, and non-corrosive liquids.
1950’s	Development of central control rooms.
1951	UNIVAC, the first automatic control computer
1952	A.T.James and A.J.P. Martin developed the process of gas Chromatography.
1954	Electromagnetic flowmeters (Foxboro).
1954	DIGITAC process control computer (Hughes Aircrafts).
1955	Ultrasonic flowmeters.
1956	First commercial gas chromatograph (Beckman Instruments).
1957	Ultrasonic level sensors.
1959	4 to 20 mA analog transmission (Honeywell).
1959	All Solid-state controller (Baily meters Co.).
1959	Discovery of superconductivity (Westinghouse).
1960’s	DDC Direct digital Control. Introduction of Programmable Logic Controllers PLCs (General Motor)..
1964	IBM mainframe system/360
1965	PDP-8 minicomputer (Digital Equipment Corporation).
1970’s	minicomputers, PLCs, and Networking.
1974	Remote sensing satellite.
1974	MOS technology (RCA)
1975	Fiber optics.
1976	Interactive digital display
1977	First redundant computer configuration.
1977	DCS Distributed Control systems.
1981	Interactive color graphics work station (US-DATA)

1980’s	Expert systems, Neural Networks, and Artificial Intelligence.
1981	IBM Personal Computer
1986	MAP Network Manufacture Automation Protocol. CIM Computer Integrated Manufacturing.
1987	First AI controller (Foxboro), HART protocol..
1990’s	Smart transmitters, Fieldbus, digital transmission, networking, 3D Windows user interface. Autotuning, Fuzzy controllers
1990’s	InTouch interactive human interface (Wonderware). Open Architecture. MES (Manufacture Execution Systems). Powerful microprocessors, RISC Chips, Pentium, Alpha, and PowerPC.
1995	SP88 Batch control standard, Windows NT, OLE, OPC (Object oriented Process Control)
1997	Field Bus Standard, Internet instrumentation.
2000+	Open System Architecture, Wireless LANs, Internet instrumentation. Reliable PC architectures and RT Windows OS, Multiprocessors.

SUMMARY

1. The main functions of an instrumentation system are : value and quality assessment, safety and protection, control, and data collection.
2. Block diagrams help to view the subfunctions of each part of a process and determine its input and its output, and how it is linked with the other parts of the process.
3. The main parts of a control loop are the process, the measurement, error detector, controller, and control element.
4. P&I diagrams consist of graphical symbols and lines which illustrate the flow of a process and identify the location and functions of its instruments, e.g. sensors, valves, recorders, indicators, and instrument interconnections
5. An instrumentation system consists of four basic function parts ; sensors, signal conditioning, signal processing, and indicators.

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APPENDIX 1.A

Process & Instrumentation Diagram

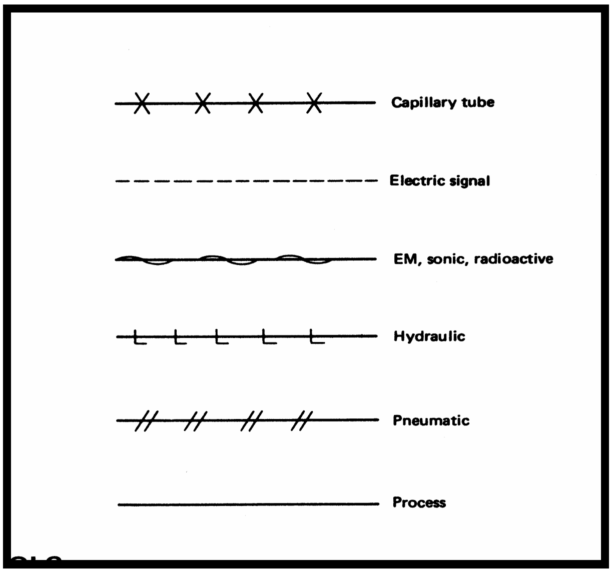


FIGURE 1.A-1
Line Symbols of the P&I Diagrams.

Table 1.A-1. Meanings of Identification Letters

First Letter	Succeeding letters	
A	Analysis	Alarm
B	Burner flame	
C	Conductivity	Control
D	Density or specific gravity	
E	Voltage	Primary element
F	Flow rate	
H	Hand (manually initiated)	High
	Current	Indicate
	Power	
K	Time or time schedule	Control station
L	Level	Light or low
M	Moisture or humidity	Middle or intermediate
O		Orifice
P	Pressure or vacuum	Point
Q	Quantity or event	
R	Radioactivity or ratio	Record or print
S	Speed or frequency	Switch
T	Temperature	Transmit
V	Viscosity	Valve, damper, or louver
W	Weight or force	Well
Y		Relay or compute
Z	Position	Drive

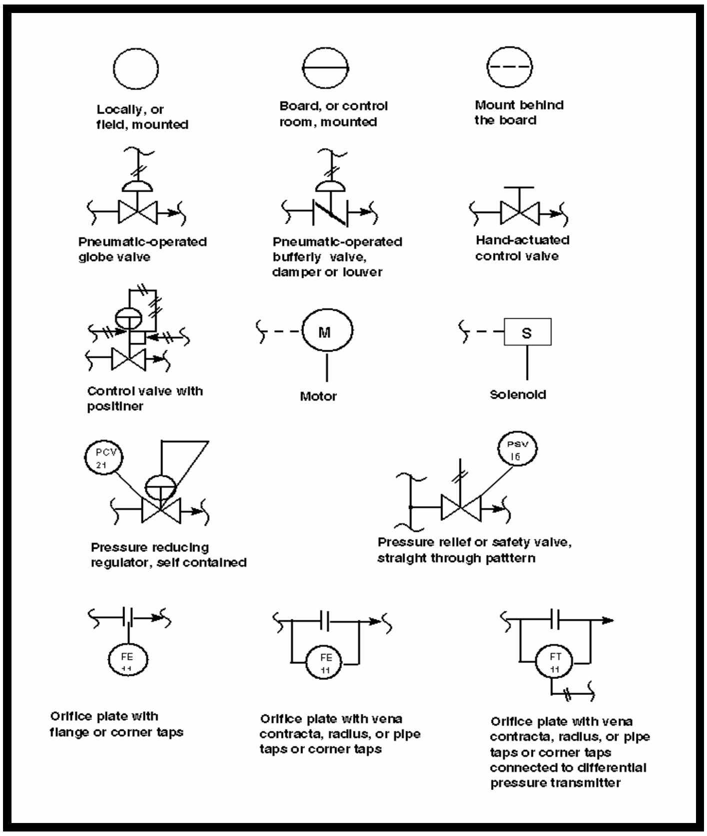


FIGURE 1.A-2
Summary of common symbols used in P&I diagrams.

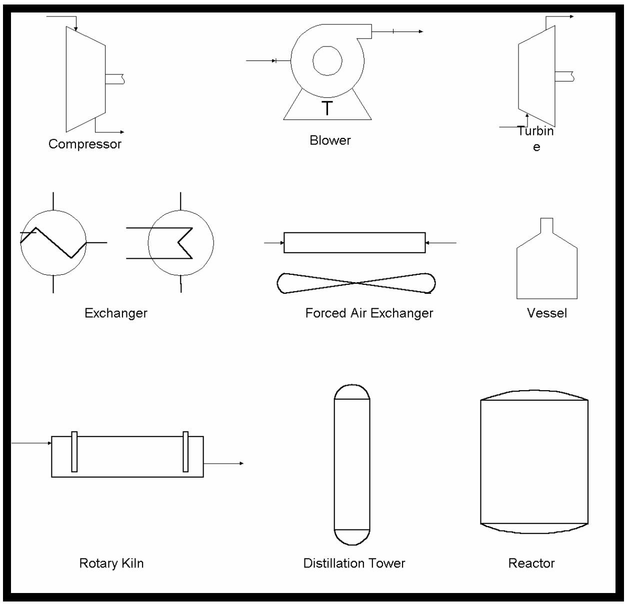


FIGURE 1.A-3 Common symbols of process units.

EXERCISES

(Straight forward applications of the concepts of the chapter)

E1.1) Explain using block diagram the function of your home heating system.

E1.2) A chef places a pie in an oven with glass window. Explain in terms of a block diagram the man-process interaction. Suggest techniques to automate this backing process.

E1.3) One way for automating the garden irrigation system is to utilize a timer which switches on and off the water at specific intervals. However this system suffers from several drawbacks. The system will operate irrespective of whether the soil is still wet or not from rain. On the other hand-in hot weather, the soil could run over dried before the timer reaches its on period. Suggest a suitable measurement system and propose an automatic irrigation system. Explain your idea using a block diagram.

E1.4) Home laundry dryers usually operate on fixed timed cycles. However that scheme may not be economical because if the material dries quickly, the machine continues to operate unnecessarily to complete its cycles. On the other hand for heavy cotton material it may require attention and inspection several times to finish its job. Suggest a suitable measurement system and propose an automatic system for the home laundry dryer. Explain your idea using a block diagram.

E1.5) Shower water temperature control. One common bathroom problem is to get the temperature of shower according to your desire. We usually try to achieve that by adjusting the hot water and the cold water taps, however, in many cases after wasting a lot of hot water or with unnecessarily high flow rate. It would be economical and convenient if you can design such automatic control system. For efficient operation it needs to measure the temperatures of the inlet cold water, the temperature of the inlet hot water, and the output temperature. Explain with the help of a block diagram the operation of such system, indicating clearly the various elements of the feedback control.

E1.6) Search the library on market study forecast of the smart transmitters.

PROBLEMS

(Problems require extending the concepts of this chapter to new situations)

P1.1) Fig P1.1 shows the P&I Diagram of a vessel pressure control system. Complete the missing instruments.

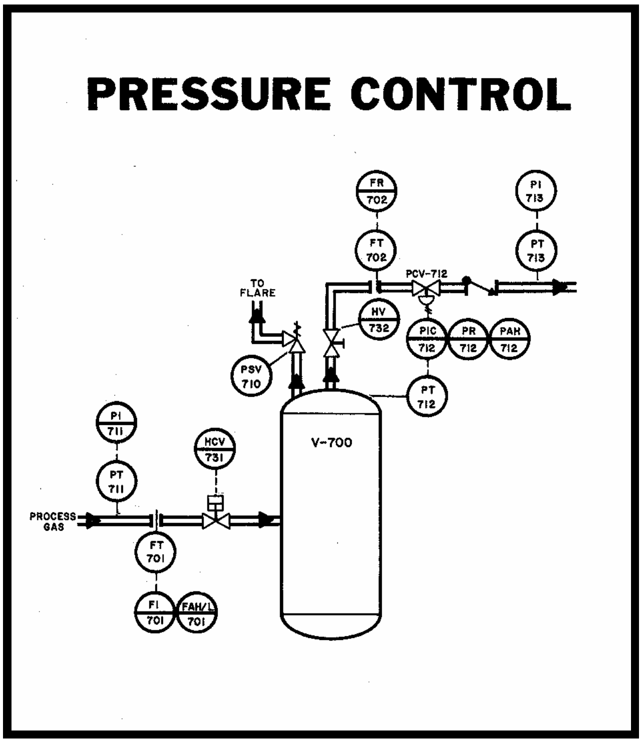


FIGURE P1.1

P1.2)For the level control system shown in the P&I diagram of Fig. P1.2 write down the labels of the missing instrumentation systems.

P1.3)Draw the P&I Diagram of the example in Figure 1.2.

P1.4) Draw a P&I Diagram of a gas vessel showing the following instruments

a) Inlet flow hand value.
b) Inlet flow transmitter, flow indicator and flow recorder.
c) Outlet pressure transmitter, outlet control value and a pressure controller.
d) Outlet pressure alarm high.

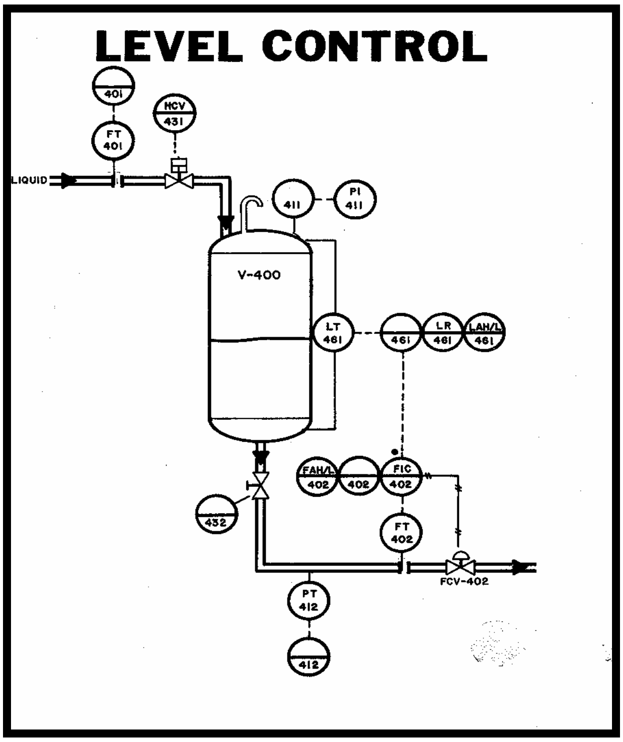


FIGURE P1.2

P1.5) A temperature measurement system, measurement temperature 0-199.99 ^{o}C consists of temperature sensor, an amplifier, and a digital voltmeter. The temperature sensor has a sensitivity of 40 V ^{o}C and indicator has a scale from 0-199.99 mV.

a) Draw a black diagram of this instrumentation system and label the function of each element.
b) What should be the gain of the amplifier so that the digital voltmeter scale indicates directly the measured temperature?
c) If the amplifier gain can be adjusted to within ±0.5% of the desired value; plot the relation between the actual temperature and the indicated temperature showing the region of the minimum and maximum indicated values.

P1.6) In a pressure measurement systems, the pressure acts on a piston as shown in Fig. P1.6.

Fig. P1.6

The movement of the piston is opposed by a spring. The displacement of the spring is proportional to the applied pressure.

$F = PA = Kx,$ where A is the area of the Piston

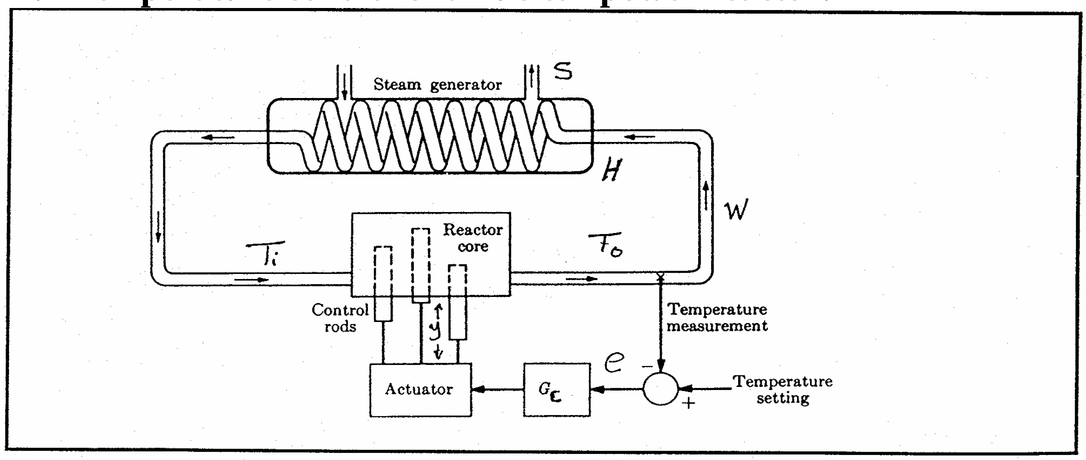
The displacement is measured by a variable resistance. The change in resistance is measured by an electric circuit and amplifier (not shown) which produces a voltage between 0-10 volts. This resulting voltage is then converted to a digital number by an analog to digital converter and read by a computer. Finally the computer converts the digital reading to appropriate pressure units and display its value on the screen.

Draw a detailed black diagram of the measurement system and label the primary sensor, the secondary sensor (s), the signal conditioning elements, signal processing elements and the data presentation elements.

DESIGN PROBLEMS

(Design Problems emphasize the design task.)

D1.1 Temperature control of a nuclear power reactor:



Automatic control of a nuclear reactor.

In nuclear power plants, the rate of reaction is controlled by graphite or lead rods. when the rods are inserted in the reactor, neutrons are absorbed by the rods, and less neutrons will be available to cause fission of the uranium in the reactor. The resulting nuclear power energy is used to heat a pressurized fluid W. This hot fluid is used in turn to generate steam **S** in a heat exchanger **H.** The resulting steam is used to run steam turbines and electrical generators.

When the demand for electricity increases, more heat energy will be taken from the steam. This will cause the temperature **Ti** of the circulating fluid **W** to drop. If the rods position is fixed the outlet temperature **To** will drop. Similarly, if the demand for electricity decreases, reactor temperature will increase, causing **To** increase. The objective of the shown control system is to maintain the temperature **To** at certain desired value inspite of the fluctuation of the demand for electricity (Load). In the shown closed loop control the temperature **To** is measured by a proper sensor and compared with a desired temperature set point (reference value). The error **e** is then processed by a controller **Gc** which generates control signal to activate actuators. The actuators move the rods until the outlet temperature **To** is equal to the desired value; i.e. to make the error equal zero.

A) Draw a block diagram of the control system.
B) Draw a P&I diagram for the system, indicate the location of the instrumentation necessary for the control loop.
C) Suggest additional instrumentation for safe operation of the nuclear reactor.

TERMS AND CONCEPTS

✔ **Automation**
The control of a process by automatic means.

✔ **Closed-loop feedback control system**
A system that uses a measurement of the output and compares it with the desired Output.

✔ **Control system**
An interconnection of components forming a system configuration that will provide a desired response.

✔ **Design**
The process of conceiving or inventing the forms, parts, and details of' a system to achieve a specified purpose.

✔ **Multivariable control system**
A system with more than one input variable or more than one output variable. **Negative feedback** The output signal is fed back so that it subtracts from the input signal.

✔ **Open-loop control system** A system that utilizes a device to control the process without using feedback. Thus the output has no effect upon the signal to the process.

✔ **Positive feedback** The output signal is fed back so that it adds to the input signal.

✔ **Process** The device, plant, or system under control.

✔ **Productivity** The ratio of physical output to physical input of an industrial process.

✔ **Robot** Programmable computers integrated with a manipulator. A reprogrammable, multifunctional manipulator used for a variety of tasks.

✔ **Specifications** Statements that explicitly state what the device or product is to be and to do. A set of prescribed performance criteria.

✔ **System** An interconnection of elements and devices for a desired purpose.