INSTRUMENTATION PROCESS CONTROL
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PART A: NOTES

CHAPTER 1
INTRODUCTION TO PROCESS INSTRUMENTATION

Process Instrumentation is the study of designing of the instruments for the correct measurement of various process parameters like Temperature, Pressure, pH, Flow rate, etc.

1.1 INTRODUCTION TO TRANSDUCERS

In a measurement system all the quantities being measured, could not be displayed as such. In such situation, the accurate measurement of a quantity is usually done by converting the related information or signal to another form which is more conveniently or accurately displayed. This is achieved with the help of a device which is known as transducer.

A sensor senses the condition, state and value of the process variable which reflects the output of the instrument. The transducer is a device which provides a usable output in response of corresponding input, which may be physical or mechanical quantity, property or condition. More precisely, a transducer is a device, which transforms energy from one form to another. The transducer may be mechanical, electrical, magnetic, optical, chemical, thermal nuclear, acoustic, or a combination of among of two or more.

All forms of transducers have some merits and demerits but most of the shortcomings have been overcome with the introduction of electrical transducers. The most instrumentation systems having Non-Electrical input quantity and this non-electrical quantity is generally converted into an electrical form by a transducer.

1.1.1 Basic Requirements of Transducer

The following are the basic requirements of a good quality transducer:

a) Ruggedness
b) Linearity
c) No hysteresis
d) Repeatability
e) High output signal quality
f) High reliability and stability
g) Good dynamic response
h) No deformation on removal of input signal

1.1.2 Classification of Transducers

The transducers could be classified in several ways. This classification could be on the basis of their application, method of energy conversion, the nature of signal output and according to whether they are self generating or the externally powered units. The transducers can be broadly classified as:

1) Primary transducers and Secondary transducers.
2) Analog transducers and Digital transducers.
3) Active transducers and Passive transducers.
4) Transducers and Inverse transducers

Primary transducers and secondary transducers

The transducer that directly senses the input signal and converts the physical property into the electrical signal is called primary transducer or a sensor. Thermistor is an example of primary transducer. It senses the temperature directly and causes the changes in its resistance with respect to temperature.

On the other hand, if the input signal is sensed first by some detector or sensor and its output, which may be of some other form than the input signal, is given as input to another transducer for conversion into electrical form, then such a transducer is called as secondary transducer.

Analog transducers and digital transducers

The output from the transducer may be a continuous function of time or it may be in discrete function of time. On this basis the transducers may be classified into two categories.

A transducer, which converts input signal into output signal in a continuous function of time is known as Analog transducer. Linear variable differential transformer (LVDT), thermo-couple are the examples of Analog Transducer.

On the other hand, a transducer, which converts input signal into output signal in the form of pulses i.e., it gives discrete output is called a digital transducer. The digital transducers are becoming very popular and useful because the digital signals can be transmitted over a long distance, with minimum distortion due to amplitude variation and phase shift.

Fig. 14.1 (b) Digital voltmeter

Fig. 14.1 (a) Analog voltmeter

Active and passive transducers

On the basis of methods of energy conversion used the transducers are classified in to following two categories:

A transducer, which develops its output in the form of electrical current or voltage without any auxiliary source, is called active transducer or the self generating transducers. The energy required for this is absorbed from the physical phenomenon which is being measured. This type of transducer draws energy from the system under measurement. Examples are thermocouples, piezo-electric transducers, photovoltaic cell etc. Such transducers normally give very small output and so amplification of the signal becomes essential.

Externally powered transducers are those which derive the power required for energy conversion from an external power source. An electrical transducer, in which electrical parameter like resistance, inductance or capacitance changes with change in the input signal, is called as a passive transducer. They may also absorb a little power from the process variable being measured. Resistive, inductive and capacitive transducers viz., potentiometric devices, differential transformer etc. are known as passive transducers.

Inverse transducers

A transducer is generally defined as a device which converts a non electrical quantity into an electrical quantity. An inverse transducer is a device which converts an electrical quantity into a non-electrical quantity.

A current carrying coil moving in a magnetic field is an inverse transducer, because current by it is converted into a force, which causes translational or rotational displacement. A most useful application of inverse transducers is in feedback measuring systems.

An actuator is an inverse transducer as it is having an electrical input and a low-power non-electrical output. A piezo-electric crystal also acts as an inverse transducer because when a voltage is applied across its surfaces, it changes its dimensions causing a mechanical displacement.

1.1.3 Characteristics of Transducers

Performance criteria of the transducers are based upon certain set of characteristics that gives a meaningful description of quality of measurement. Normally these characteristics of a measurement system are those that must be considered when the system or instrument is used. All these characteristics have to be taken into account, when choosing a transducer for any application.

The characteristics of transducers are described as:

A) Input characteristics
B) Transfer characteristics
C) Output characteristics

Input characteristics

i). **Type and Operating Range of Input Quantity:** The first consideration for the selection of a transducer is the input quantity which is to be measured and its range of operation. The type of input quantities is generally known in advance. The useful operating range of transducer is an important factor in the choice of a transducer for a particular application. The maximum value or the maximum limit is decided by the transducer capabilities, whereas, the minimum value of range or the lowest limit is normally determined by the unavoidable noise which may originate in the transducer during measurement.

A good resolution is required throughout its operating range of a transducer.

ii). **Loading Effects:** In an ideal transducer, there is no loading effect on the input quantity being measured by the transducer. However, practically it may not be possible. The magnitude of the loading effects is expressed in terms of force, power or energy obtained from the input quantity. Hence the transducer which is selected for a particular application should ideally extract no force, power from the input quantity.

Transfer characteristics

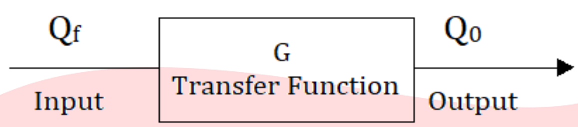
The transfer characteristics involve three separate elements:

i). Transfer function

ii). Sensitivity

iii). Error.

i) Transfer Function: It is defined as relationship between the input quantity and output and describes the input and output behaviour of the system.



$Q_0 = GO_i$

Where, Q_0 and Q_i are respectively output and output of the transducer.

ii) Sensitivity: The sensitivity of a transducer is the ratio of change in output for a given change in input

$$S = \frac{dQ_0}{dQ_i}$$

In general, the sensitivity of transducers is not constant and is dependent upon the input quantity (Q_i). In some cases the relation between output and input becomes linear.

If the sensitivity is constant over the entire range of the transducer it shall be defined as:

$$S = \frac{dQ_0}{dQ_i} = \frac{Q_0}{Q_i}$$

The inverse of sensitivity is called scaled factor.

$$Scale\ factor = \frac{1}{S} = \frac{dQ_i}{dQ_o}$$

iii) Error: Many a times the input-output relationship given by $Q_0 = GQ_i$ is not followed by transducer. In such cases, error is obtained in transducers.

Let at a particular input Q_i, ideally the output will be Q_0 but practically an output Q_0' is obtained, then the error of the instrument is:

$$e = Q_0' - Q_o$$

The error could be due to any of the followings:

a) Scale error.
b) Dynamic error.
c) Error on account of noise and drift.

a) Scale Error: There are four different types of scale errors:

i) Zero Error: In such type of error, the output deviates from the original value by a constant factor over the entire range of the transducer.

ii) Sensitivity Error: This type of error occurs where the observed output deviates from the correct value by a constant value.

iii) Hysteresis: The effect of hysteresis is obtained in all transducers. The output of a transducer not only depends upon the input but also upon input quantities previously applied to it. So, different output is obtained when the same value of input quantity is applied, depending upon whether it is increasing or decreasing.

iv) Non-Conformity: When experimentally obtained transfer function deviates from the theoretical transfer function for almost every input

b) Dynamic Error: This type of error occurs when the input quantity is varying with time. This type of error occurs where system contains energy storage element and due to this the output cannot follow input exactly. The dynamic error can be made small by having a small time constant.

c) Noise and Drift Error: Noise and drift signals originating from the transducers very with time and are superimposed on the output signal.

d) Error due to Change of Frequency: A sine wave input in a linear transducer, a sine wave output obtained, as the frequency of the sine wave input is increased, the transducer is required to respond more and more quickly. In this process beyond the range of a particular frequency the transducers can no larger respond with respect to its sinusoidal input is changing. Therefore the output of the transducer becomes smaller as well as the phase shift between the input and output increases. Hence the frequency increases the output of the transducer decreases.

Output characteristics

The output characteristics of a transducer are considered as given below :

i) Type of electrical output.

ii) Output impedance.

iii) Useful output range.

i) Type of Electrical Output: The output of transducer may be a voltage, current impedance or a time function of these amplitudes. The above quantities may or may not be acceptable to the latter stages of the instrumentation system. There is possibility to change their magnitudes or change in their format by signal conditioning equipment for making them drive the different stages of instrumentation system.

ii) Output Impedance: In ideal transducer the value of the output impedance should be zero, but practically it is not possible and, therefore, its value should be kept as low as possible to minimize the loading effects. The output impedance gives the information of amount of power than can be transferred to the further stages of the instrumentation system for a given output signal level. The value of output impedance is low compared to the forward impedance of the system, the transducer behaves as a constant voltage source (provided a voltage is the output of transducer), when the forward impedance is high as compared to the output impedance of transducer, it behaves as constant current source.

iii) Useful Output Range: The output range of a transducer is limited by noise signal at the lower end which may shroud the required input signal. The output range can be increased by adding of amplifier in the transducer in some cases. The addition of amplifier also increases the noise level and therefore in such situation the amplifier should be avoided.

Factors Affecting the Choice of Transducers

The following is the summary of the factors influencing the choice of a transducer for measurement of a physical quantity:

1. **Operating Principle:** The transducers are so many times selected on the basis of operating principle used by them. The operating principles used in transducer may be resistive, inductive, capacitive, opto-electronic, piezoelectric and so on.

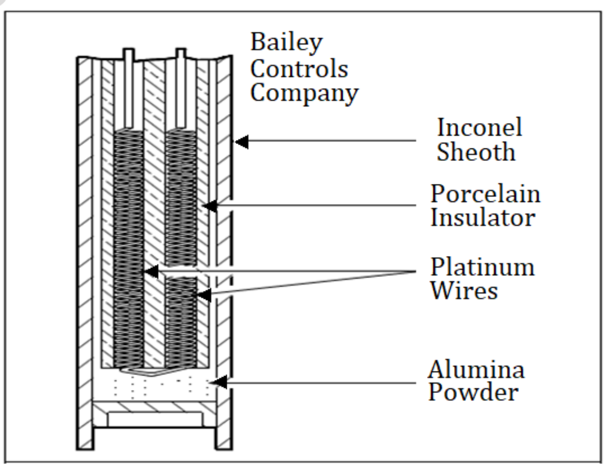
2. **Sensitivity:** The transducer should give a sufficient output signal per unit of measured input in order to yield meaningful data.
3. **Operating Range:** The transducer should maintain the range requirements and have a better resolution over its entire range.
4. **Accuracy:** High degree of accuracy is necessary for measurement.
5. **Error:** The errors inherent in the operation of the transducer itself, but it should maintain the expected input-output relationship as described with its transfer function so as to avoid errors.
6. **Transient and Frequency Response:** The transducer should meet the desired time domain specifications as well as it should ideally have a flat frequency response curve.
7. **Loading Effects:** To avoid loading effect, it is necessary that a transducer has high input impedance and a low output impedance.
8. **Physical Environment:** The transducer selected should be able to work under specified environmental conditions and maintain its output-input relationship

1.2 SENSORS

A device that gives an output by detecting the changes in quantities or events can be defined as a sensor. In general, sensors are termed as the devices that generate an electrical signal or optical output signal corresponding to the variations in the level of inputs. There are different types of sensors, for example, consider a thermocouple which can be considered as a temperature sensor that produces an output voltage based on the input temperature changes.

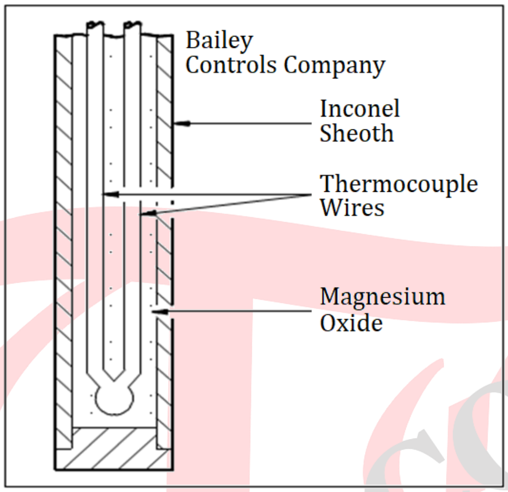
1.2.1 RTDs (Resistance Temperature Detectors)

This particular design has a platinum element that is surrounded by a porcelain insulator. The insulator prevents a short circuit between the wire and the metal sheath.



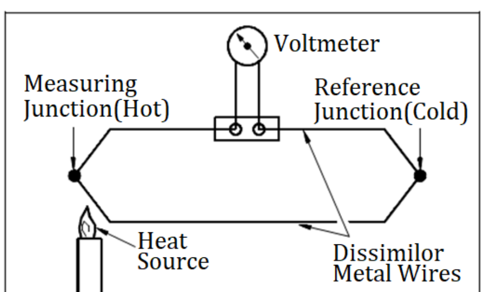
1.2.2 THERMOCOUPLE

A thermocouple is constructed of two dissimilar metal wires joined at one end. When one end of each wire is connected to a measuring instrument, the thermocouple becomes a sensitive and highly accurate measuring device. Thermocouples may be constructed of several different combinations of materials.



The performance of a thermocouple material is generally determined by using that material with platinum. The most important factor to be considered when selecting a pair of materials is the "thermoelectric difference" between the two materials.

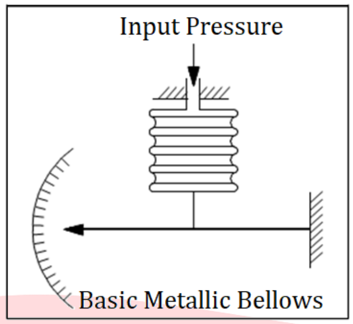
Other materials may be used in addition. For example: Chromel-Constantan is excellent for temperatures up to 2000°F; Nickel/Nickel-Molybdenum sometimes replaces Chromel - Alumel; and Tungsten-Rhenium is used for temperatures up to 5000°F. Some combinations used for specialized applications are Chromel-White Gold, Molybdenum-Tungsten, Tungsten-Iridium, and Iridium/Iridium-Rhodium.



Simple Thermocouple Circuit

Heating the measuring junction of the thermocouple produces a voltage which is greater than the voltage across the reference junction. The difference between the two voltages is proportional to the difference in temperature and can be measured on the voltmeter (in mV).

1.3 PRESSURE

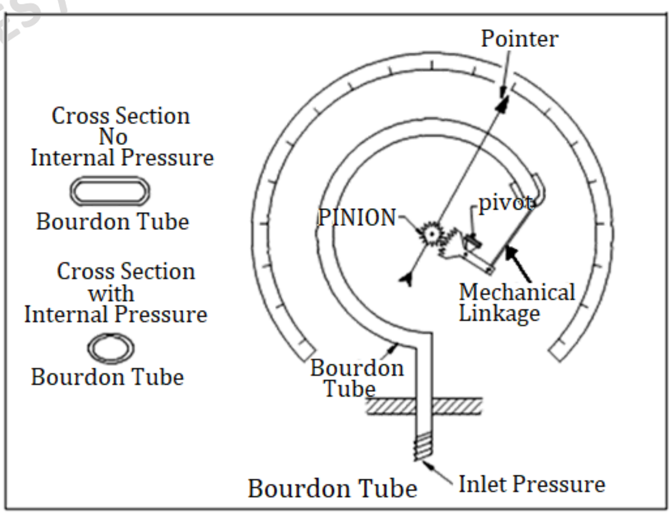


Many processes are controlled by measuring pressure. There are many of the detectors associated with measuring pressure. Some of them are as follows:

1.3.1 BELLOW TYPE DETECTORS

The need for a pressure sensing element that was extremely sensitive to low pressures and provided power for activating recording and indicating mechanisms resulted in the development of the metallic bellows pressure sensing element. The metallic bellows is most accurate when measuring pressures from 0.5 to 75 psig. However, when used in conjunction with a heavy range spring, some bellows can be used to measure pressures of over 1000 psig.

The bellows is a one-piece, collapsible, seamless metallic unit that has deep folds formed from very thin-walled tubing. The diameter of the bellows ranges from 0.5 to 12 in. and may have as many as 24 folds.



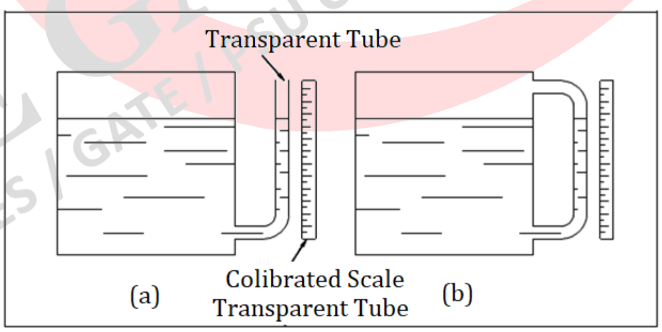
1.3.2 BOURDON TUBE TYPE DETECTORS

The bourdon tube pressure instrument is one of the oldest pressure sensing instruments in use today. The bourdon tube consists of a thin-walled tube that is flattened diametrically on opposite sides to produce a cross-sectional area elliptical in shape, having two long flat sides and two short round sides. The tube is bent lengthwise into an arc of a circle of 270 to 300 degrees. Pressure applied to the inside of the tube causes distention of the flat sections and tends to restore its original round cross-section.

This change in cross-section causes the tube to straighten slightly. Since the tube is permanently fastened at one end, the tip of the tube traces a curve that is the result of the change in angular position with respect to the center. Within limits, the movement of the tip of the tube can then be used to position a pointer or to develop an equivalent electrical signal (which is discussed later in the text) to indicate the value of the applied internal pressure.

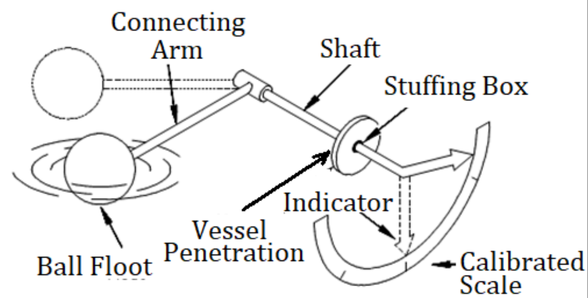
1.4 LEVEL

Liquid level measuring devices are classified into two groups: (a) direct method, and (b) inferred method. An example of the direct method is the dipstick in your car which measures the height of the oil in the oil pan. An example of the inferred method is a pressure gauge at the bottom of a tank which measures the hydrostatic head pressure from the height of the liquid.



1.4.1 GAUGE GLASS

A very simple means by which liquid level is measured in a vessel is by the gauge glass method. In the gauge glass method, a transparent tube is attached to the bottom and top (top connection not needed in a tank open to atmosphere) of the tank that is monitored. The height of the liquid in the tube will be equal to the height of water in the tank.



Ball Float Level Mechanism

Figure (a) shows a gauge glass which is used for vessels where the liquid is at ambient temperature and pressure conditions. Figure (b) shows a gauge glass which is used for vessels where the liquid is at an elevated pressure or a partial vacuum. Notice that the gauge glasses in Figure 1 effectively form a "U" tube manometer where the liquid seeks its own level due to the pressure of the liquid in the vessel.

1.4.2 BALL FLOAT

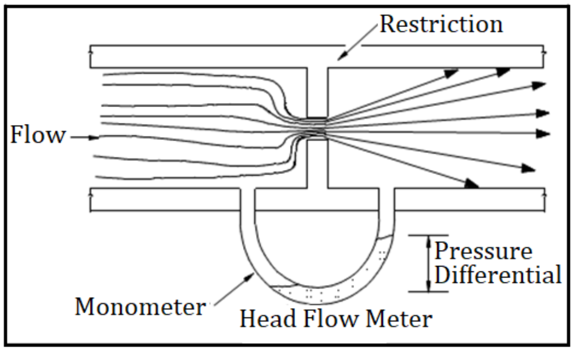
The ball float method is a direct reading liquid level mechanism. The most practical design for the float is a hollow metal ball or sphere. The design consists of a ball float attached to a rod, which in turn is connected to a rotating shaft which indicates level on a calibrated scale. The operation of the ball float is simple. The ball floats on top of the liquid in the tank. If the liquid level changes, the float will follow and change the position of the pointer attached to the rotating shaft.

1.5 FLOW

Flow measurement is an important process measurement to be considered in operating a facility's fluid systems. For efficient and economic operation of these fluid systems, flow measurement is necessary.

1.5.1 HEAD FLOW METER

Head flow meters operate on the principle of placing a restriction in the line to cause a differential pressure head. The differential pressure, which is caused by the head, is measured and converted to a flow measurement. Industrial applications of head flow meters incorporate a pneumatic or electrical transmitting system for remote readout of flow rate. Generally, the indicating instrument extracts the square root of the differential pressure and displays the flow rate on a linear indicator.



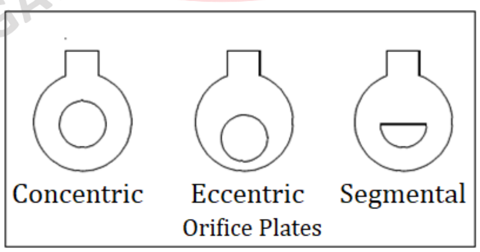
There are two elements in figure, Head Flow Meter a head flow meter; the primary element is the restriction in the line, and the secondary element is the differential pressure measuring device.

The flow path restriction, such as an orifice, causes a differential pressure across the orifice. This pressure differential is measured by a mercury manometer or a differential pressure detector. From this measurement, flow rate is determined from known physical laws. The head flow meter actually measures volume flow rate rather than mass flow rate.

1.5.1.1 ORIFICE PLATE

The orifice plate is the simplest of the flow path restrictions used in flow detection, as well as the most economical. Orifice plates are flat plates 1/16 to 1/4 inch thick. They are normally mounted between a pair of flanges and are installed in a straight run of smooth pipe to avoid disturbance of flow patterns from fittings and valves.

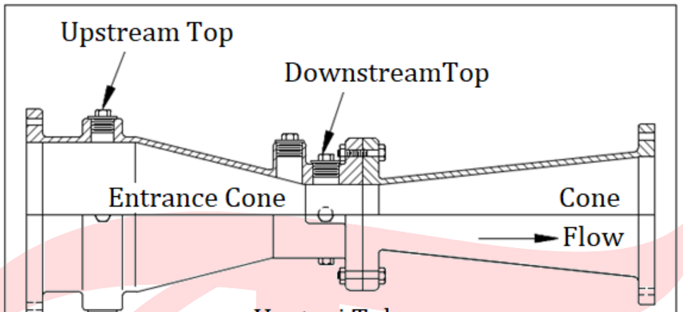
Three kinds of orifice plates are used: concentric, eccentric, and segmental (as shown in figure).



The concentric orifice plate is the most common of the three types. As shown, the orifice is equidistant (concentric) to the inside diameter of the pipe. Flow through a sharp-edged orifice plate is characterized by a change in velocity. As the fluid passes through the orifice, the fluid converges, and the velocity of the fluid increases to a maximum value. At this point, the pressure is at a minimum value. As the fluid diverges to fill the entire pipe area, the velocity decreases back to the original value.

1.5.1.2 VENTURI TUBE

The venturi tube, illustrated in figure, is the most accurate flow-sensing element when properly calibrated. The venturi tube has a converging conical inlet, a cylindrical throat, and a diverging recovery cone. It has no projections into the fluid, no sharp corners, and no sudden changes in contour.

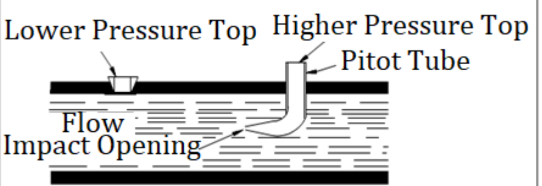


Venturi Tube

The inlet section decreases the area of the fluid stream, causing the velocity to increase and the pressure to decrease. The low pressure is measured in the center of the cylindrical throat since the pressure will be at its lowest value, and neither the pressure nor the velocity is changing. The recovery cone allows for the recovery of pressure such that total pressure loss is only 10% to 25%. The high pressure is measured upstream of the entrance cone. The major disadvantages of this type of flow detection are the high initial costs for installation and difficulty in installation and inspection.

1.5.1.3 PITOT TUBE

The Pitot tube, illustrated in figure, is another primary flow element used to produce a differential pressure for flow detection. In its simplest form, it consists of a tube with an opening at the end. The small hole in the end is positioned such that it faces the flowing fluid. The velocity of the fluid at the opening of the tube decreases to zero. This provides for the high pressure input to a differential pressure detector. A pressure tap provides the low pressure input.



Pitot tube

The Pitot tube actually measures fluid velocity instead of fluid flow rate. However, volumetric flow rate can be obtained using the equation given by

$$Q = KAV$$

Where Q= volumetric flow rate (ft^3 / sec.)
A = area of flow cross-section (ft^2)
V = velocity of flowing fluid (ft / sec.)
K = flow coefficient (normally about 0.8)

Pitot tubes must be calibrated for each specific application, as there is no standardization. This type of instrument can be used even when the fluid is not enclosed in a pipe or duct.

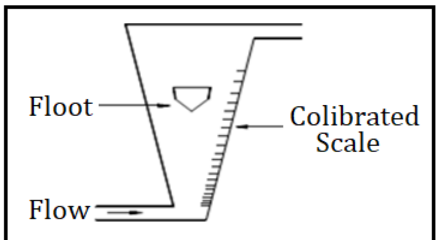
1.5.2 AREA FLOW METER

The head causing the flow through an area meter is relatively constant such that the rate of flow is directly proportional to the metering area. The variation in area is produced by the rise and fall of a floating element. This type of flow meter must be mounted so that the floating element moves vertically and friction is minimal.

1.5.2.1 ROTA METER

The rotameter, illustrated in figure, is an area flow meter so named because a rotating float is the indicating element.

The rotameter consists of a metal float and a conical glass tube, constructed such that the diameter increases with height. When there is no fluid passing through the rotameter, the float rests at the bottom of the tube. As fluid enters the tube, the higher density of the float will cause the float to remain on the bottom. The space between the float and the tube allows for flow past the float. As flow increases in the tube, the pressure drop increases. When the pressure drop is sufficient, the float will rise to indicate the amount of flow. The higher the flow rate the greater the pressure drop. The higher the pressure drop the farther up the tube the float raises.



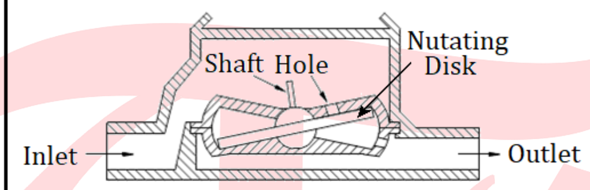
Rotameter

1.5.3 DISPLACEMENT METER

In a displacement flow meter, all of the fluid passes through the meter in almost completely isolated quantities. The number of these quantities is counted and indicated in terms of volume or weight units by a register.

1.5.3.1 NUTATING DISC

The most common type of displacement flow meter is the nutating disk, or wobble plate meter. A typical nutating disk is shown in figure.



Nutating Disk

This type of flow meter is normally used for water service, such as raw water supply and evaporator feed. The movable element is a circular disk which is attached to a central ball. A shaft is fastened to the ball and held in an inclined position by a cam or roller. The disk is mounted in a chamber which has spherical side walls and conical top and bottom surfaces. The fluid enters an opening in the spherical wall on one side of the partition and leaves through the other side. As the fluid flows through the chamber, the disk wobbles, or executes a nutating motion. Since the volume of fluid required to make the disc complete one revolution is known, the total flow through a nutating disc can be calculated by multiplying the number of disc rotations by the known volume of fluid.

1.6 Piping and Instrumentation Diagram (P&ID)

The P&ID refers to the detailed drawing of plant layout that includes pictorial representation of entire piping and instrumentation blocks used in a plant. It has been standardized by American National Standards Institute (ANSI) and Instrument Society of America (ISA). Equivalent Indian Standard is also available, e.g. " IEC/PAS 62424 Ed. 1.0 en - Representation of process control engineering requests in P&I diagrams and data exchange between P&ID tools and PCE-CAE tools ". It describes and specifies how process control engineering requests are represented in a P&I diagram. It also defines the exchange of process control engineering request relevant data between a process control engineering tool and a P&I tool by means of a data transfer language (called CAEX). These provisions apply to the export/import applications of such tools. Following are the components of P&ID:

- Plant equipment and vessels showing location, capacity, pressure, liquid level operating range, usage and so on
- All interconnection lines distinguishing between the types of interconnection, *i.e.* gas or electrical and operating range of line
- All motors giving voltage and power and other relevant information
- Instrumentation showing location of instrument, its major function, process control loop number, and range
- Control valves giving type of control, type of valve, type of valve action, fail save features, and flow plus pressure information
- The ranges for all safety valves, pressure regulators, temperatures, and operating ranges
- All sensing devices, recorders, and transmitters with control loop numbers

P&ID can run into multiple sheets as it is not always possible to code them all in a single sheet. Each drawing should have a part list and that should be properly numbered. It should also have an area for revisions, notes and approval signature. More importantly they should always be up-to-date.

Instrumentation symbols

The symbols of transmission lines have already been discussed in the lecture 3 of Module 4 (Introduction to Feedback Controller). Symbols of standardized instruments are given in the following figure.

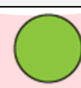
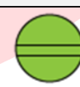
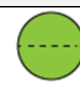
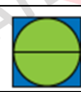
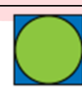
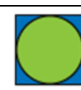
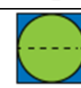
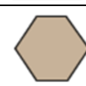
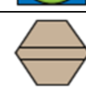
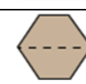
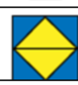
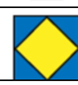
	Accessible to operator Primary	**Field location**	**Accessible to operator Secondary**	**Inaccessible to operator**
Discrete Instruments				
Shared display or control				
Computer Function				
PLC				

Fig. VII.1: Standardized Instruments Symbols

Each instrument is identified with a letter of English alphabet. Table. VII.1 refers to the identification letters

Table VII.1: Instruments Identification Letters

	Initiating or measured variable	Modifier	Readout or passive function	Output function	Modifier
A	Analysis		Alarm		
B	Burner, combustion		User's choice	User's choice	User's choice
C	User's choice			Control	
D	User's choice	Differential			
E	Voltage		Sensor		
F	Flow rate	Ratio			
G	User's choice		Glass, viewing device		
H	Hand				High
I	Current		Indicate		
J	Power	Scan			
K	Time	Time rate of change		Control station	
L	Level		Light		Low
M	User's choice	Momentary			Middle
N	User's choice		User's choice	User's choice	User's choice
O	User's choice		Orifice		
P	Pressure		Test point		
Q	Quantity	Integrate, totalize			
R	Radiation		Record		
S	Speed, frequency	Safety		Switch	
T	Temperature			Transmit	
U	Multivariable		Multifunction	Multifunction	Multifunction
V	Vibration, mechanical analysis			Valve, damper, louver	
W	Weight, force		Well		
X	Unclassified	x-axis	Unclassified	Unclassified	Unclassified
Y	Event, state, or presence	y-axis		Ready, compute, convert	
Z	Position, dimension	z-axis		Driver, actuator	

Fig VII.2 represents a few examples of the letters and numbering code that can be used to refer the instruments. Consider the example *TY178* which has two letters T & Y. Table VII.1 refers to the first letter *T* as temperature and second letter *Y* as converter. Hence it is a temperature transducer which converts a 4-20 mA current signal into a 3-15 psi pressure signal. The number 178 refers to the location of the transducer such as "zone 1, equipment number. 7, transducer number. 8". From Fig VII.1, we can further infer that transducer is a discrete instrument located in the field itself.

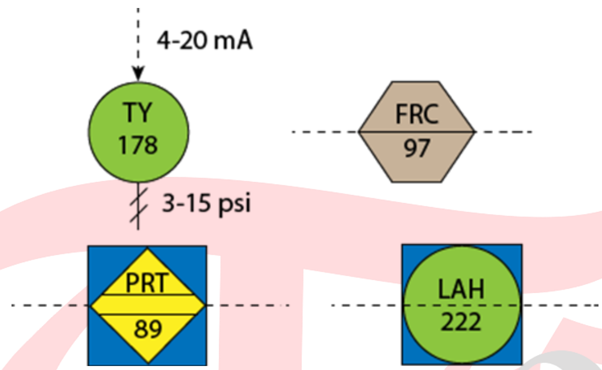
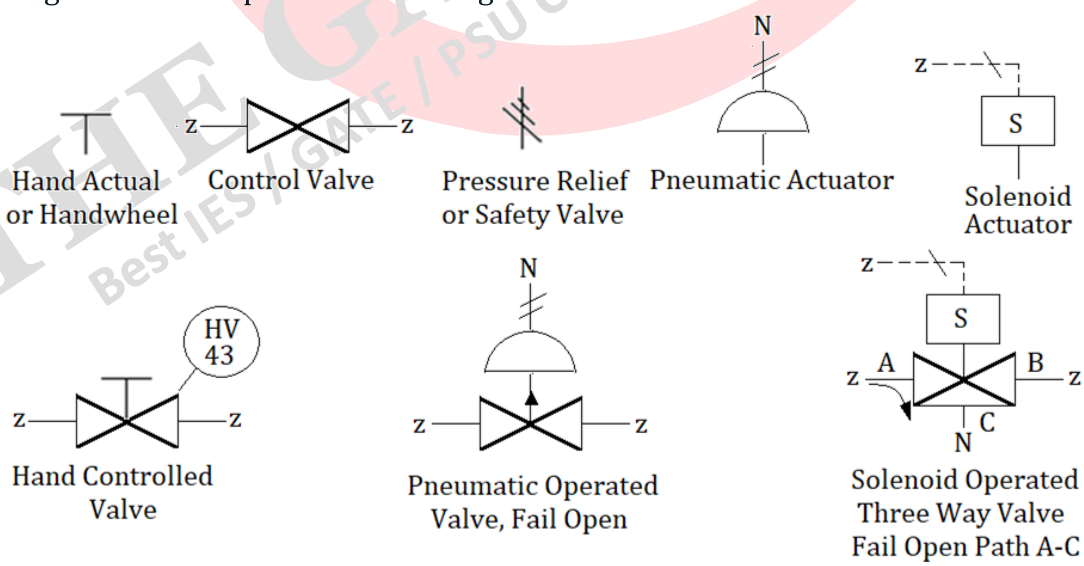


Fig. VII.2: Examples of the letters and numbering code

Symbols can be broadly classified into four types depending on their functions:

- Actuator
- Primary elements
- Regulators and safety valves
- Math function

Following are the examples of those categories:



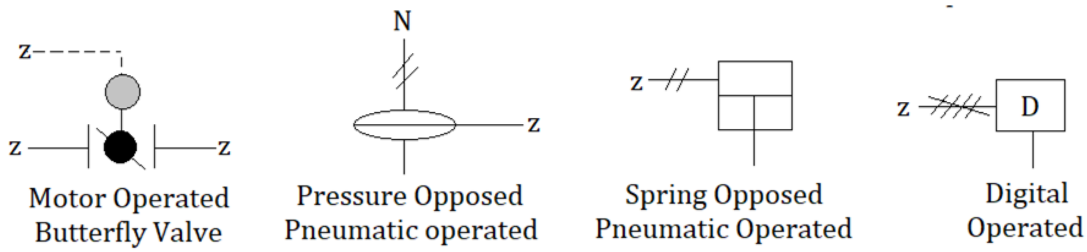


Fig. VII.3: Actuators

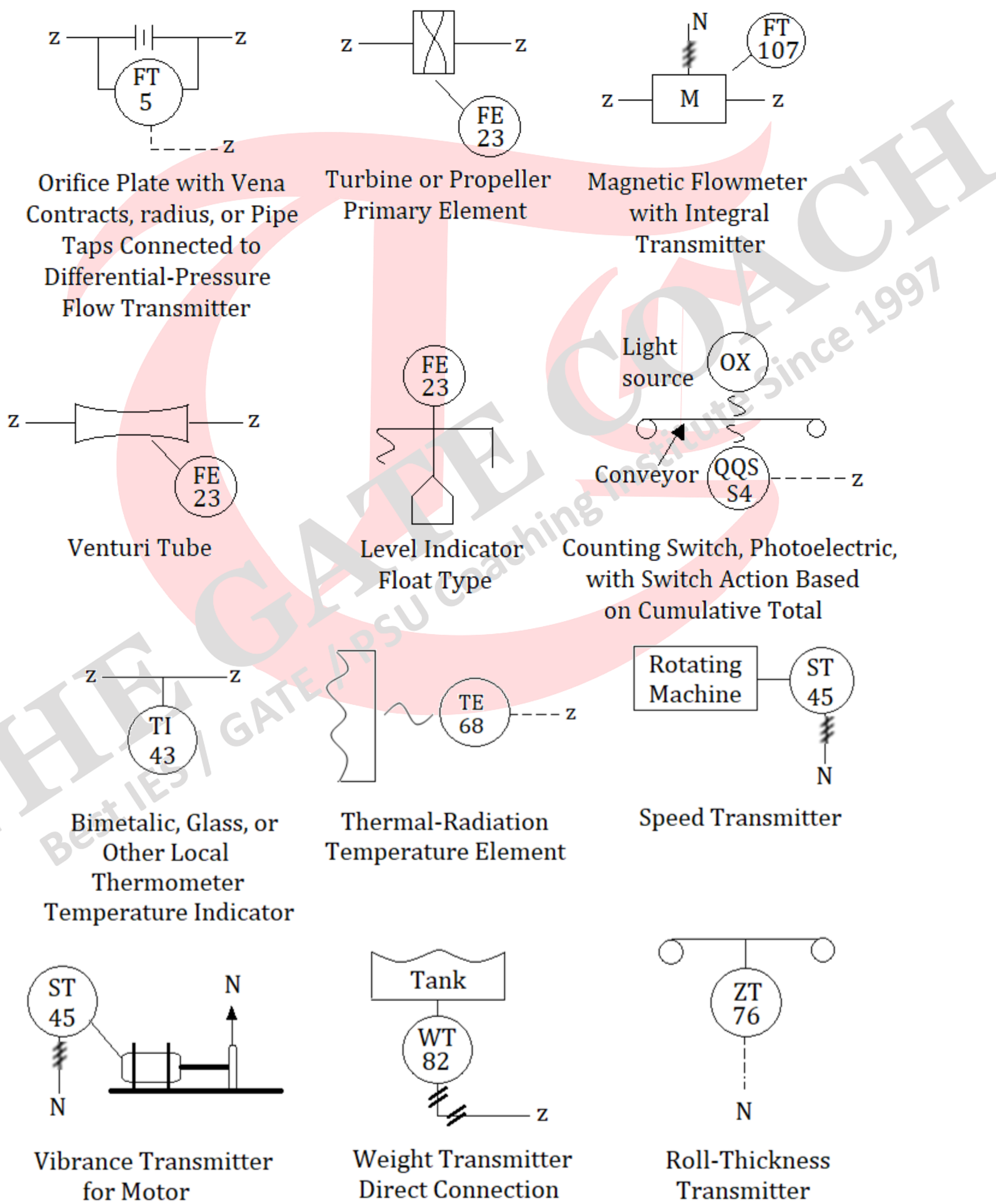


Fig. VII.4: Primary elements

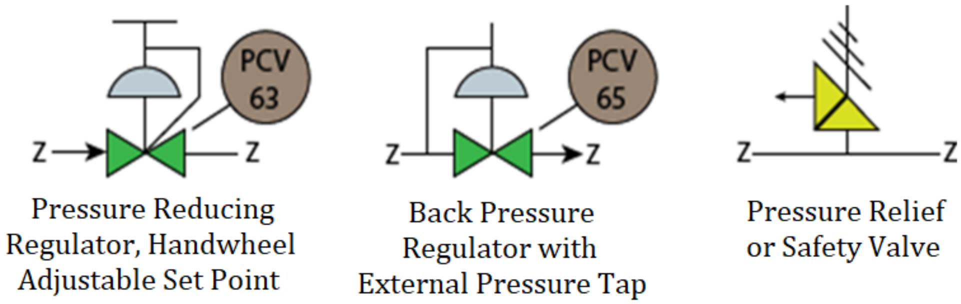


Fig. VII.5: Regulators and safety valves

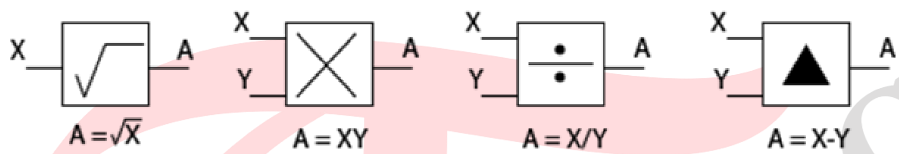


Fig. VII.6: Math function

VII.2.2 An example of P&ID of a small process plant

Following is an example of P&ID of a mixing station:

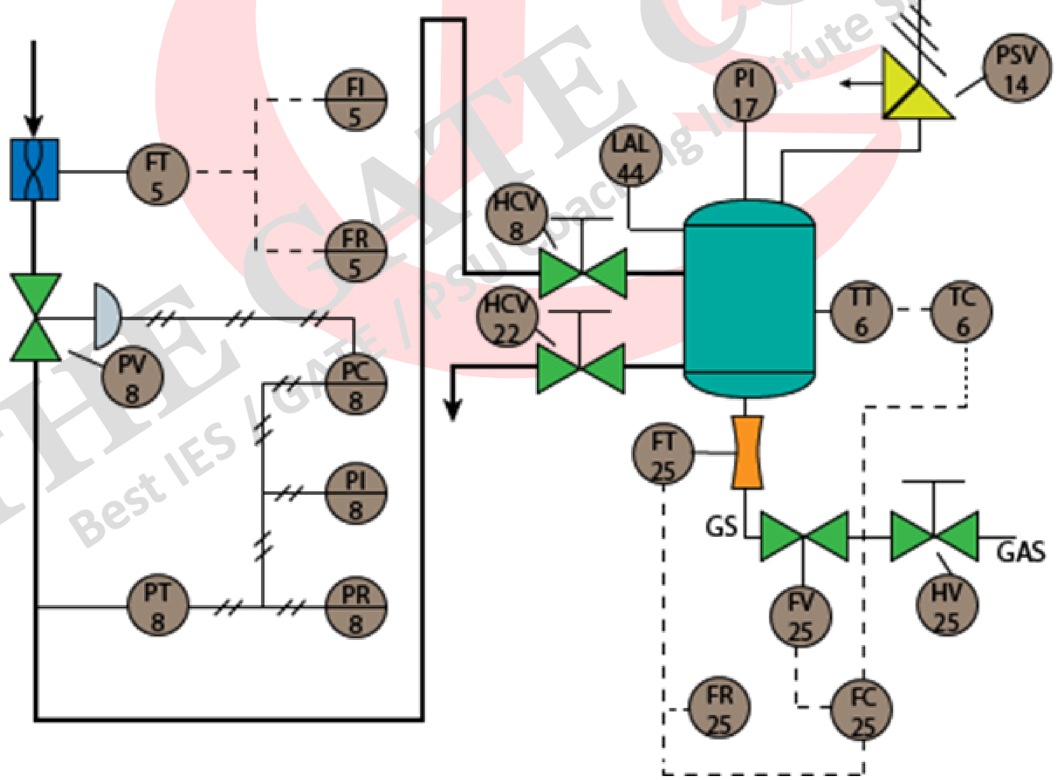


Fig. VII.7: P&ID of a mixing station

A P&ID should not include the following:

- Instrument root valves
- Control relays

- Manual switches
- Equipment rating or capacity
- Primary instrument tubing and valves
- Pressure temperature and flow data
- Elbow, tees and similar standard fittings
- Extensive explanatory notes

Transmission Lines

Measurement and/or control signals are carried through various transmission lines. Various process piping, connection and transmission lines, as per the standard set by International Society of Automation (ISA), are listed in the following figure.

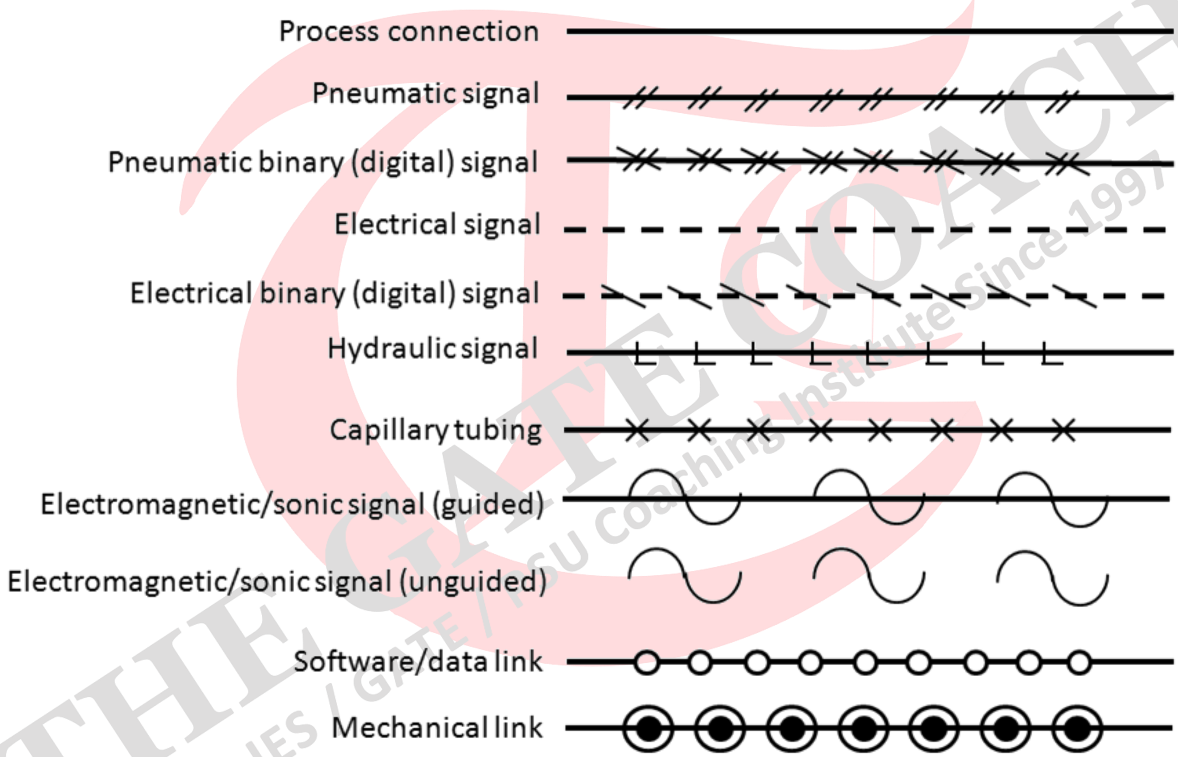


Fig. IV.4: Representation of process piping, connection and transmission lines

A heavy solid line represents piping,a thin solid line represents process connections to instruments, a dashed line represents electrical signals (e.g., 4–20 mA connections), a slashed line represents pneumatic signal tubes, a line with circles on it represents data links. Other connection symbols include capillary tubing for filled systems, (e.g., remote diaphragm seals), hydraulic signal lines, and guided/unguided electromagnetic or sonic signals. Electric/electromagnetic signals are instantaneous. Unless the process changes very fast and/or the transmission lines are too long, the dynamic behaviors of electric/electromagnetic transmissions are also usually ignored.

1.7 Standard P&ID Symbols Legend | Industry Standardized P&ID Symbols

Piping and Instrument Diagram Standard Symbols Detailed Documentation provides a standard set of shapes & symbols for documenting P&ID and PFD, including standard shapes of instrument, valves, pump, heating exchanges, mixers, crushers, vessels, compressors, filters, motors and connecting shapes.

Instrument

Indicator	Computer Indicator	LC 65 Level Controller	M Magnetic	Or Gate
Behind Control	Programmable Indicator	PT 55 Pressure Transmitter	Pitot Tube Type Flow	Not Gate
On Central Control	Displayed Programmable Device	PR 55 Pressure Recorder	Pitot Tube	Correcting Element
On Local Control Pane	Computer	PC 55 Pressure Controller	Wedge Meter	Diamond
Behind a Local Control	Unit Control Panel	PIC 105 Pressure Indicating	Target Meter	P Pressure Gauges
Indicator 2	TI Temp Indicator	PRC 40 Pressure Recording	Weir Meter	T Thermometers
T Indicator 3	TT Temp Transmitter	LA 25 Level Alarm	Ultrasonic Meter	Averaging Pitot Tube

T Indicator 4	TR Temp Recorder	FE Flow Element	V-cone Meter	Level Meter
Indicator 5	TC Temp Controller	TE Temperature Element	Venturi Meter	Coriolis Flow Sensor
50 Odometer	FI Flow Indicator	LG Level Gauge	Quick Change	Flow Nozzle Meter
Pressure Gauge	FT Flow Transmitter	AT Analyzer Transmitter	Turbine Meter	Flume Meter
Flow meter	FR Flow Recorder	1 P Transducer	Rotometer	Manhole
Thermometer	FC Flow Controller	S P X X Specially item	Double	Socket Connection
Shared Indicator	LI Level Indicator	S Sampler	Steam Traced	Support Bracket
Displayed Configurable	PI Pressure Indicator	Straightening Vanes	Venturi	Support Leg
Shared Indicator	LT 65 Level Transmitter	D Diaphragm Meter	Flowmeter	Support Ring
	LR 65	R Rotary Meter	Vortex Sensor	Support Skirt

	Level Recorder			
			And Gate	

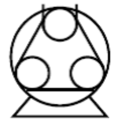
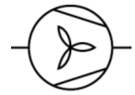
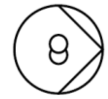
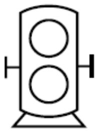
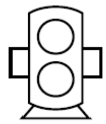
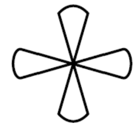
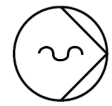
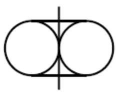
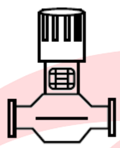
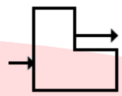
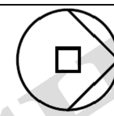
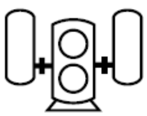
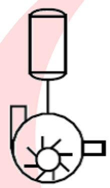
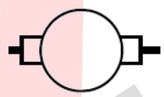
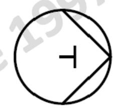
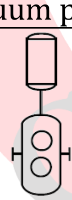
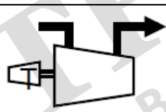
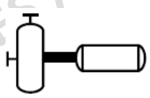
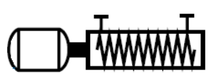
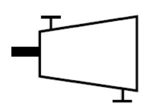
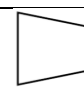
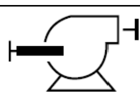
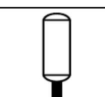
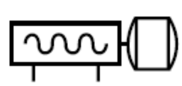
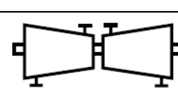
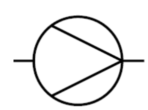
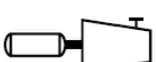
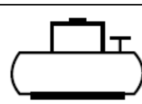
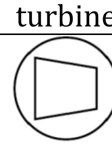
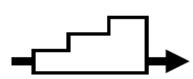
Valves

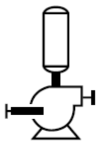
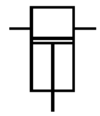
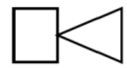
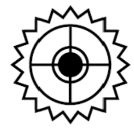
Hand-Operated Gate Valve	Butterfly Valve	Solenoid Valve	4-way Plug Valve	Pinch Valve
Gate Valve	Flanged Valve	Hydraulic Vale	4-Way Valve	Minimum Flow Valve
Closed Gate Valve	Flanged Valve	Motor-Operated Valve	Electro-Hydraulic Valve	Auto Recirculation
Hand-Operated Globe Valve	Flanged Valve 2	Pilot Gate Valve	Balanced Diaphragm Gate Valve	Gauge
Globe Valve	Angle Valve Hand-Operated	Weight Gate Valve	Spring Gate Valve	Bleeder Valve
Rotary Valve	Angle Globe Valve	Powered Valve	Ram Valve	Maual Integrated Valve
Needel Valve	Relief Valve	Float-Operated Valve	Slide Valve	Orifice
Control Valve	Angle Valve	Needled Valve	Metering Coke	Rotameter

Piston-Operated Valve	Angle Blowdown Valve	3-Way Valve	Knife Valve	Quarter Turn Valve Double Acting
Back Pressure Regulator	Ball	3-Way Valve 2	Excess Flow Valve	Quarter Turn Valve Spring Acting
Plug or Cock Valve	Normally Closed Ball	3-Way Plug Valve	Post Indicator	Water Flow Meter
Check Vale	Diaghragm		Self Draining Valve	Self-Operating Release Valve
	Plug Valve		Diaphragm Valve	

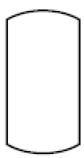
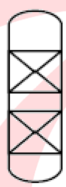
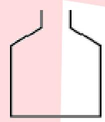
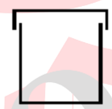
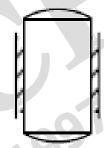
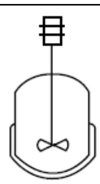
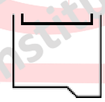
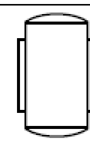
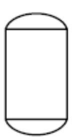
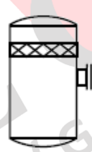
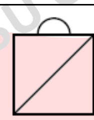
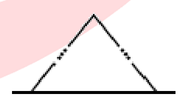
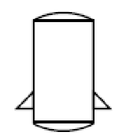
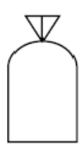
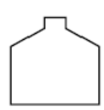
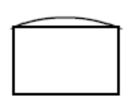
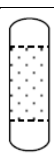
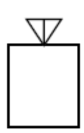
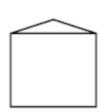
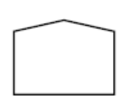
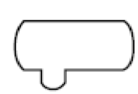
Pumps

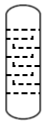
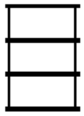
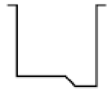
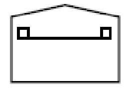
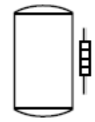
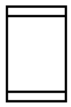
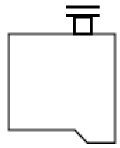
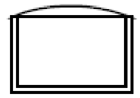
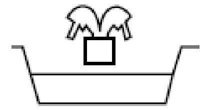
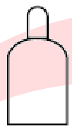
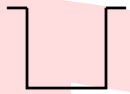
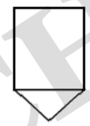
Compressor	Axial Compressor	Sump pump	Reciprocating pump	Diesel motor
Reciprocating Compressor	Centrifugal pump	Positive displacement pump 2	Turbine pump	ISO Liquid pump
Reciprocating Compressor 2	Centrifugal pump 2	Rotary pump	Pump 2	ISO centrifugal pump
Compressor silencers	Centrifugal pump 3	Rotary gear pump	Fan	ISO diaphragm Pump

 Centrifugal	 Centrifugal pump 4	 Peristaltic pump	 Selectable fan	 ISO gear pump
 Rotary Compressor	 Gas blower	 Gear pump	 Fan blade	 ISO Progressive Pump
 Rotary Compressor 2	 Vertical pump	 Proportioning pump	 Fan blades 2	 ISO positive displacement pump
 Rotary Compressor and silencers	 Liquid ring vacuum pump	 Vacuum pump	 Triple fan blades	 ISO reciprocating piston pump
 Liquid ring Compressor	 Positive displacement pump	 Screw pum	 Axial flow fan	 ISO screw pump
 Centrifugal Compressor	 Horizontal pump	 Screw pump 2	 Turbine driver	 Selectable Compressor Axial
 Centrifugal Compressor 2	 Vertical pump	 Cavity pump	 Doubleflow turbine	 Pump
 Centrifugal Compressor 3		 Submersible pump	 Motor driven turbine	 Positive displacement

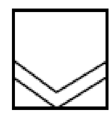
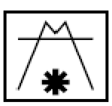
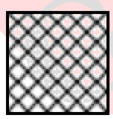
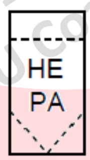
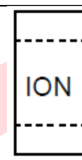
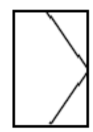
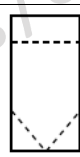
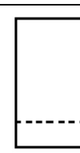
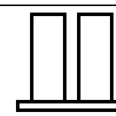
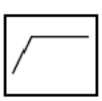
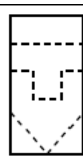
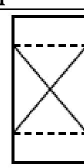
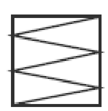
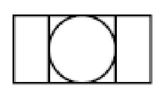
				Pump
 Centrifugal blower		 Reciprocating pump	 Ejector	 Motor
			 Spray	

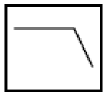
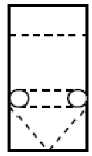
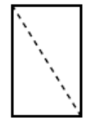
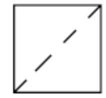
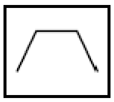
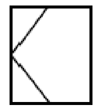
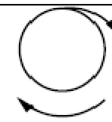
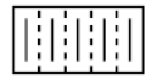
Vessels

 Vertical Vessel	 Packing column	 Boiler	 Covered Tank	 Thermal Insulation Vessel
 Mixing Vessel	 Drum	 Dome Boiler	 Floating Roof Tank	 Heating-cooling Jacket Vessel
 Column	 Knock-out drum	 Hot Liquid Boiler	 Open Bulk Storage	 Brackets Vessel
 Tray Column	 Bag	 Tank	 Dome Roof Tank	 Dished Ends Vessel
 Fluidized Bed Column	 Bag (ISO)	 Tank 2	 Cone Roof Tank	 Pit Vessel

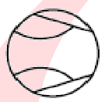
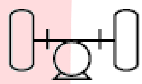
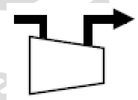
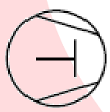
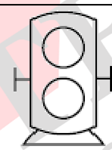
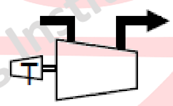
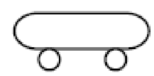
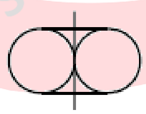
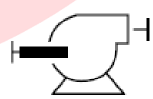
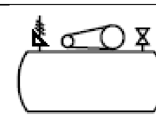
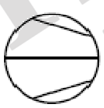
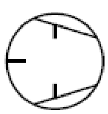
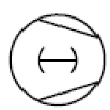
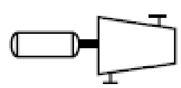
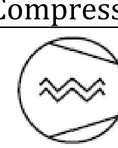
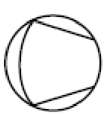
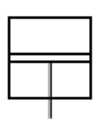
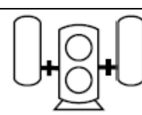
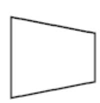
 Staggered Baffle Trays Column	 Barrel	 Tank 3	 Internal Floating Roof Tank	 Electrical Heating Vessel
 Packing Column	 Barrel (ISO)	 Tank 4	 Double Wall Tank	 Wastewater Treatment
	 Gas bottle	 Open tank	 Onion Tank	 Bin

Filters

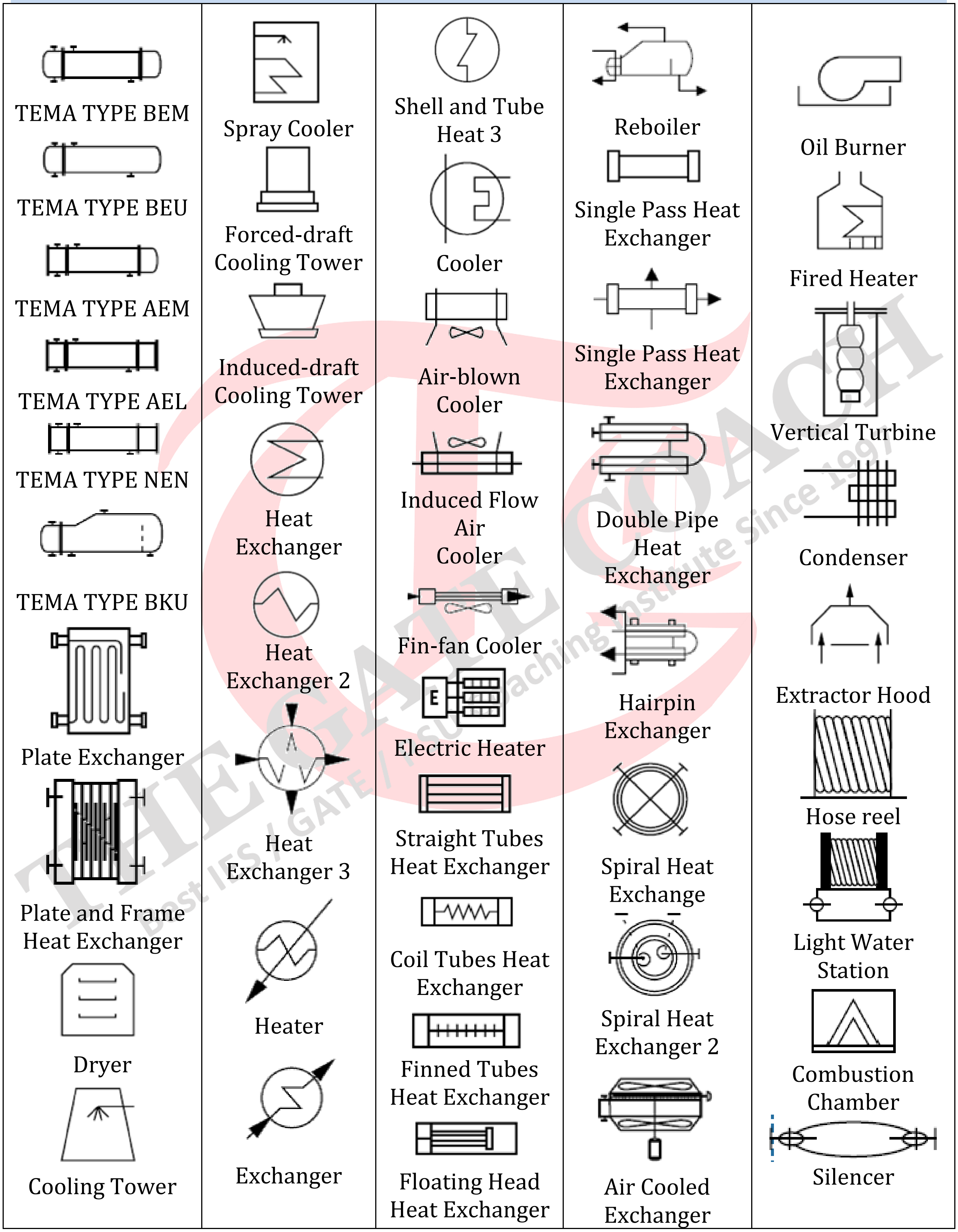
 Mode Filter	 Filter	 Fixed bed air Filter	 Biological Filter	 High efficiency Filter
 Mode Filter indication	 Filter 2	 HEPA gas Filter	 Ionexchanger Filter	 Primary Filter Mid-effect Filter
 Filter	 Gas Filter	 Liquid Filter	 Press Filter	 Oxygen-enriched Filter
 Highpass Filter	 Cartridge gas Filter	 Fixed bed liquid Filter	 Air Filter	 Filter

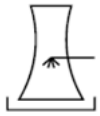
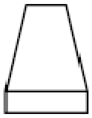
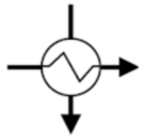
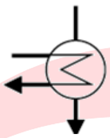
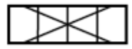
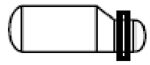
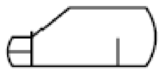
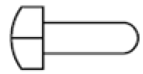
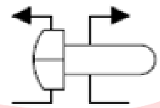
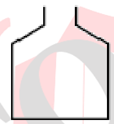
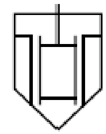
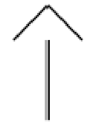
 Lowpass Filter	 Roll air Filter	 Rotary liquid Filter	 Air Filter 2	 Filter 2
 Bandpass Filter			 The Filter	 Rotary Filter
				 Suction Filter

Compressors

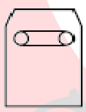
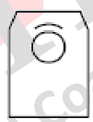
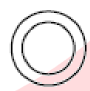
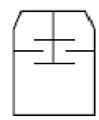
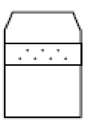
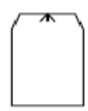
 Compressor	 Ejector Compressor	 Compressor silencers	 Liquid ring Compressor	 Axial Compressor
 Compressor 2	 Piston Compressor	 Rotary Compressor	 Centrifugal Compressor	 Air Compressor
 Compressor, Vacuum pump	 Ring Compressor	 Rotary Compressor 2	 Centrifugal Compressor 2	 AC air Compressor
 Centrifugal Compressor	 Roller vane Compressor	 Rotary Compressor 3	 Centrifugal Compressor 3	 Screw Compressor
 Diaphragm Compressor	 Reciprocating Compressor 3	 Rotory Compressor and silencers	 Selectable Compressor	 Turbo Compressor

Heat Exchanges

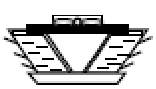
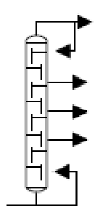


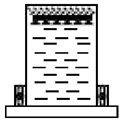
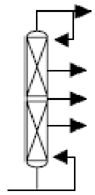
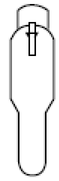
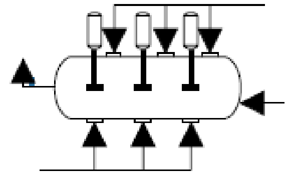
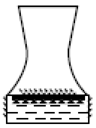
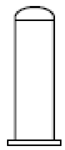
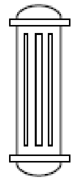
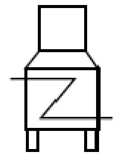
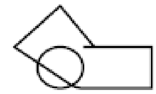
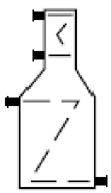
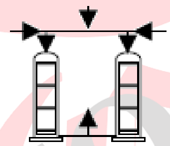
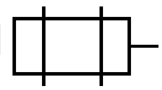
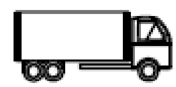
 Cooling Tower 2  Cooling Tower 3	 Condenser  Shell and Tube Heat  Shell and Tube Heat 2	 Plate Heat Exchanger  Kettle Heat Exchanger  Reboiler Heat Exchanger	 Briquetting Machine  U-Tube Heat Exchanger  U-tube Heat Exchanger  Boiler	 Thin-Film Evaporator  Vent

Dryers

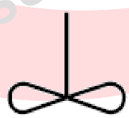
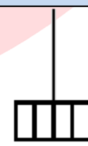
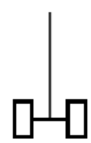
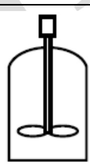
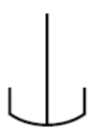
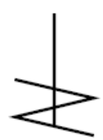
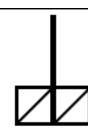
 Dryer	 Roller Conveyor Belt Dryer	 Generator	 Heat Consumer	 Moving Shelf Dryer
 Fluidized Bed Dryer	 Motor Generator	 Drying Oven	 Spray Dryer	

General

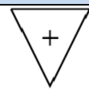
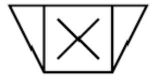
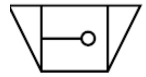
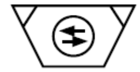
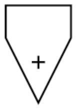
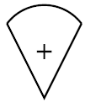
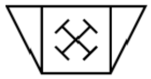
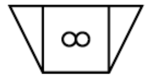
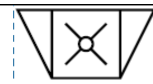
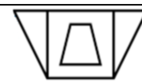
 Cross flow Inducted Draft	 Plate Tower	 Fluid Catalytic Cracking	 Fluidized Reacto	 **Screen**

 Counter flow Forced Draft	 Packed Tower	 Fluid Coking	 Alkylation	 Boom Loader
 Chimney Tower Hyperbolic	 Hydro cracking	 Tubular	 Furnace	 Automatic Stoker
 Furnace	 Hydro desulfurization		 Hydro cracking	 Electric Motor
				 Transport

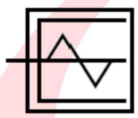
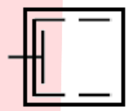
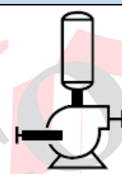
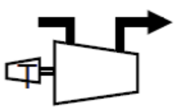
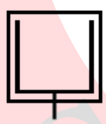
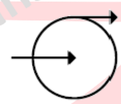
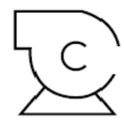
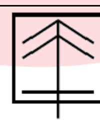
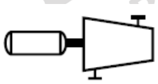
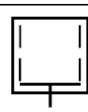
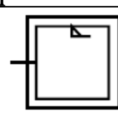
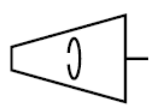
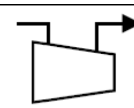
Mixers

 In-line Mixer	 Various Mixers	 Agitator, Propeller	 Agitator, Turbine	 Agitator, Disc
 Mixer	 Various Mixers 2	 Agitator, Anchor	 Agitator, Helical	 Agitator, Cross-beam
 Various Mixers	 Agitator, Stirrer	 Agitator, Impeller	 Agitator, Gat Paddle	

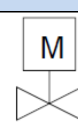
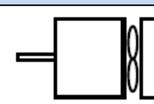
Crushers

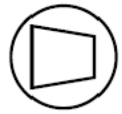
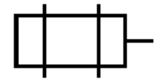
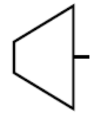
 Crusher	 Medium Crushers	 Various Crushers	 Jaw Crusher	 Vibration Crusher
 Coarse Crusher	 Fine Crushers	 Hammer Crusher	 Roller Crusher	 Hammer Crusher
		 Impact Crusher	 Cone Crusher	

Centrifuges

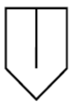
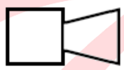
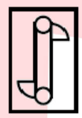
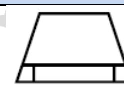
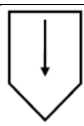
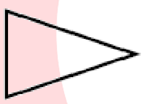
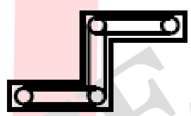
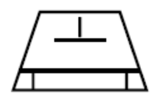
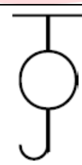
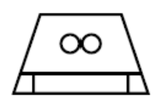
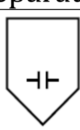
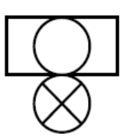
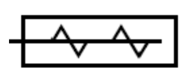
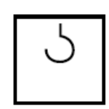
 Centrifugal Pump	 Centrifuge Screw	 Centrifuge, Pusher	 Centrifugal Blower	 Centrifugal Pump 3
 Centrifugal Compressor	 Centrifuge, Solid Shell	 Centrifuge Screw, Perforated Shell	 Centrifugal Pump	 Centrifugal Pump 4
 Centrifugal Compressor 2	 Centrifuge, High Speed	 Centrifuge, Separator disc	 Centrifugal Pump 2	 Centrifugal Fan
 Centrifugal Compressor 3	 Centrifuge, Perforated Shell	 Centrifuge, Skimmer	 Centrifuge	 Centrifugal Pump 5

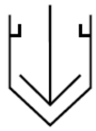
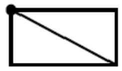
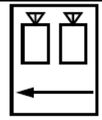
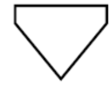
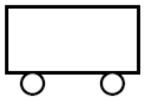
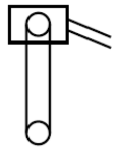
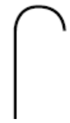
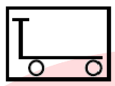
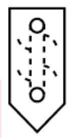
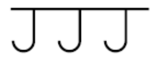
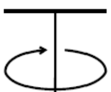
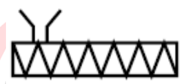
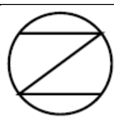
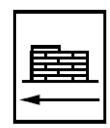
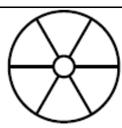
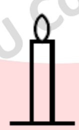
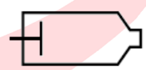
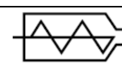
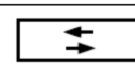
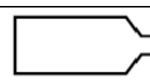
Motors

 Motor	 AC Motor	 Generator	 Motor-operated	 Diesel Motor

			Valve	
 Step Motor	 Motor Generator	 AC Generator	 Motor-driven Turbine	 Electric Motor
 DC Motor	 Gear	 DC Generator	 Motor	 Turbine

Peripheral

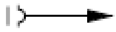
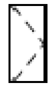
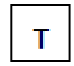
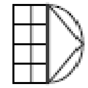
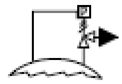
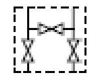
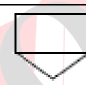
 Impact Separator	 Injector	 Elevator	 Elevator 2	 Vertical Shaping Machines
 Gravity Separator	 Reducer	 Z-form Elevator	 Skip Hoist	 Pelletizing Disc
 Cyclone Separator	 Rupture Disc	 Lift	 Conveyor	 Piston Press
 Electromagnetic Separator	 Viewing Glass	 Hoists	 Conveyor, Chain, Closed	 Roller Press
 Electrostatic Precipitator Separator	 Viewing Glass with Lighting	 Aerator with Sparger	 Conveyor, Screw, Closed	 Crane

 Solidifier	 Back Draft Damper	 Bag Filling Machine	 Roller Conveyor	 Cyclone
 Permanent Magnet	 Box Truck	 Belt Skimmer	 Conveyor	 Curved Gas Vent
 Spray Nozzle	 Manual Forklift	 Screening	 Overhead Conveyor	 Firing System
 Rotary Table Feeder	 Truck Forklift	 Bucket Elevator	 Screw Conveyor	 Flame Arrestor
 Proportional Feeder	 Industrial Truck	 Elevator 1	 Scraper Conveyor	 Palletizer
 Rotary Valve Feeder	 Rolling Bin Truck	 Gas Flare	 Piston Extruder Shaping Machines	 Chimney
 Metering Proportional Feeder	 Ship		 Screw Extruder Shaping Machines	 Conveyor, Vibrating, Closed
			 Horizontal Shaping Machines	

Piping and Connecting Shapes

Major Pipeline	Top to Top	Double Containment	Electrically Insulated	Expansion Joint
Connect Pipeline	Sonic Signal	Flange	In-line Mixer	Hose
Major Straight Line Pipe	Nuclear	End Caps	Separator	Flexible Hose
Straight Line Pipe	Pneumatic Control	End Cap 2	Bursting Disc	Flow Indicator
Battery Limit Line	Pneumatic Binary Signal Line	Breather	Flame Arrester	Bell Mouth
S Electronic Serial	Electric Signal Line	Drip Pan Elbow	Drain Silencer	Removable Spool
H Heat Trace	Electric Binary Signal Line	Flange	Exhaust Silencer	Basket Strainer
Side by Side	Electric Binary Signal Line	Union	Strainer	Breather
Top-Bottom	Sleeve Joint	Socket Weld	Exhaust Head	Damper
One-to-Many	General Joint	Screwed Connection	Triangle Separator	Breakthrough

Traced Line	Butt Weld	Orifice Plate	Triangle Separator 2	Orifice
Multi-Lines	Welded Connection	Flanged Dummy Cover	Tundish	Clamped Flange Coupling
Mid Arrow	Mechanical Link	Electrical Bounded	Open Vent	Compensate
Multi-Lines Elbow	Soldered/ Solvent	Slope Requirements Line	Syphon Drain	Coupling
Y-strainer	Blind Disc	Reducer	Hydrant	Electrically Insulated
Diverter Valve	Spectacle Blind	Pulsation Dampener	Swivel Joint	Flame Arrestor
Y-type Strainer	Interchangeable Blind	Duplex Strainer	Detonation Arrestor	Explosion-Proof Flame Arrestor
Rotary Valve	Open Disc	Vent Silencer	Flame Arrestor	Detonation-Proof Flame Arrestor
Expansion Joint 2	Orifice Plate	Basket Strainer	In-line Silencer	Fire-Resistant Flame Arrestor

 Bursting Disc		 Cone Strainer	 Steam Trap	 Fire-Resistant, Explosion-Proof Flame Arrestor
		 Pilot Operated Relief Valve with Renote Sensor	 Desuperheater	 Valve Manifold
			 Ejector or Eductor	
			 Exhaust Head	