PDHonline Course E444 (7 PDH)

Instrumentation & Process Control Automation Guidebook – Part 3

Instructor: Jurandir Primo, PE

2014

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone & Fax: 703-988-0088

www.PDHonline.org
www.PDHcenter.com

An Approved Continuing Education Provider

INSTRUMENTATION & PROCESS CONTROL AUTOMATION GUIDEBOOK – PART 3

CONTENTS:

1. INTRODUCTION
2. INSTRUMENTATION & CONTROL SYSTEMS
3. INSTRUMENTATION DESCRIPTION & APPLICATION
4. PROCESS CONTROL INSTRUMENTATION
5. CONDUCTIVITY & ANALYTICAL INSTRUMENTATION
6. CONTROL VALVES & INSTRUMENTATION
7. STANDARD & CONTROL VALVES APPLICATION
8. VALVES ACTUATORS, POSITIONERS & TRANSDUCERS
9. CONTROL SYSTEMS & FIELDBUS TECHNIQUES
10. DIAGNOSTICS & COMMUNICATION INTERFACES
11. HAZARDOUS CLASSIFICATION & PROTECTION TYPES
12. PROCESS & PIPING INSTRUMENTATION DIAGRAMS
13. PROCESS CONTROL & SOFTWARE SIMULATIONS
14. REFERENCES & LINKS

1. INTRODUCTION:

Instrumentation is the science of automated measurement and control, or can be defined as the science that applies and develops techniques for measuring and controls of equipment and industrial processes. Process control has a broad concept and may be applied to any automated systems such as, a complex robot or to a common process control system as a pneumatic valve controlling the flow of water, oil or steam in a pipe.

A basic instrument consists of three elements:

- Sensor or Input Device
- Signal Processor
- Receiver or Output Device

To measure a quantity, usually is transmitted a signal representing the required quantity to an indicating or computing device where either human or automated action takes place. If the controlling action is automated, the computer sends a signal to a final controlling device which then influences the quantity being measured. The physical components commonly measured are:

- Temperature, Pressure, Speed, Flow, Force, Movement, Velocity and Acceleration, Stress and Strain, Level or Depth, Mass or Weight Density, Size or Volume, Acidity/Alkalinity.

Sensors may operate simple on/off switches to detect the following:

- Objects (proximity switch), empty or full (level switch), hot or cold (thermostat), pressure high or low (pressure switch).

Most modern analogue equipment works on the following standard signal ranges.

- The accepted industrial standard for electronic signals is a 4 to 20 mA current signal that represents the 0% to 100% process condition.
- The standard industrial range for pneumatic signals is 20 to 100 kPa (3 – 15 psig), which corresponds to a 0% to 100% process condition.

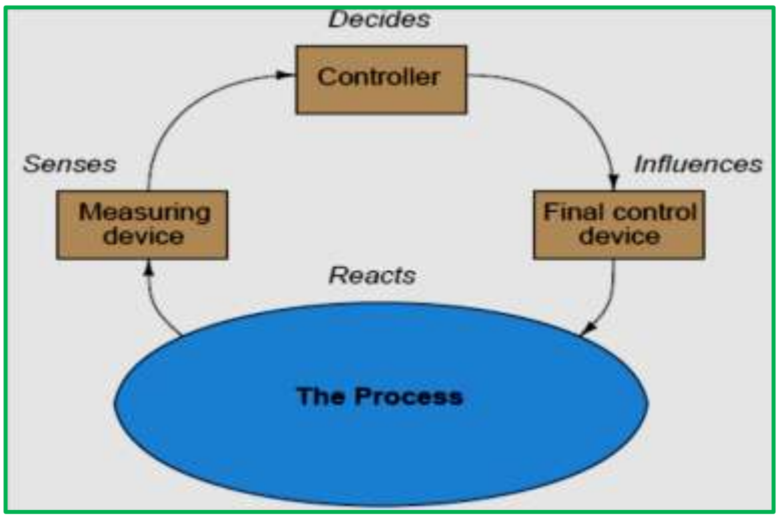
Note: The live zero (4 mA) is used to distinguish between 0% process (4 mA) and an interrupted or faulted signal loop (0 mA). The live zero (20 kPa) allows the control room personnel to distinguish between a valid process condition of 0% (or a 20 kpa(g) reading) and a disabled transmitter or interrupted pressure line (or a 0 kpa(g) reading), providing a coarse rationality verification.

The main motive that pneumatic signals are commonly used in process industries is for safe environment, especially when there is a risk of fire or explosion. The advantage of having a standard range or using digital signals is that all equipment may be purchased ready calibrated. For analogue systems the minimum signal (temperature, speed, force, pressure and so on) is represented by 4 mA or 0.2 bar (3 psig), and the maximum signal is represented by 20 mA or 1.0 bar (15 psig). Older electrical equipment use 0 to 10 V. Increasingly the instruments are digital with a binary digital encoder built in to give a binary digital output.

The control devices usually take one of the following forms:

- Control valves (example, for throttling the flow rate of a fluid);
- Electric motors;
- Electric heaters.

The measurement devices and the final control devices connect to some physical system which is called "*the process*". To show this as a general block diagram:



2. INSTRUMENTATION & CONTROL SYSTEMS:

The most common industrial instrumentation measurement and control systems have their own unique terms and standards. The most common control process terms and definitions are:

Process: Is the physical systems to control or measure. Examples: water filtration systems, steam boiler systems, oil refinery units, power generation units, molten metal casting systems, etc.

Process Variable, or PV: Is the specific quantity measured in a process. Examples: pressure level, temperature, flow, electrical conductivity, pH, position, speed, vibration, etc.

Setpoint, or SP: Is the value where a process variable is required to be maintained. In other words, is the "target" value for the process variable.

Primary Sensing Element, or PSE: Is a device sensing a process variable and translating that sensed quantity into an analog representation (electrical voltage, current, resistance; mechanical force, motion, etc.). Examples: thermocouple, thermistor, bourdon tube, microphone, potentiometer, electrochemical cell, accelerometer.

Transducer: Is a device converting one standardized instrumentation signal into another standardized instrumentation signal, and/or performing some sort of processing on that signal. Often referred to as a converter and sometimes as a “relay.” Examples: I/P converter (converts 4-20 mA electric signal into 3-15 PSI pneumatic signal), P/I converter (converts 3-15 PSI pneumatic signal into 4-20 mA electric signal), square-root extractor (calculates the square root of an input signal).

Note: in general, the “transducer” is any device converting one form of energy into another, such as a microphone or a thermocouple. In industrial instrumentation, however, is generally used “the primary sensing element” to describe this concept and reserve the word “transducer” to specifically refer to a conversion device for standardized instrumentation signals.

Transmitter: Is a device translating the signal produced by a “primary sensing element” (PSE) into a standardized instrumentation signal such as 3-15 PSI air pressure, 4-20 mA DC electric current, Fieldbus digital signal packet, etc., which may then, be conveyed to an indicating device, a controlling device, or both.

Lower and Upper-Range Values (LRV and URV): Are the values of a process measured in 0% and 100% of a transmitter’s calibrated range. For example, if a temperature transmitter is calibrated to measure a range of temperature starting at 300ºC and ending at 500ºC, its LRV would be 300ºC and its URV would be 500ºC.

Zero and Span: Are the alternative descriptions of LRV and URV for the 0% and 100% points of an instrument’s calibrated range. “Zero” refers to the beginning-point of an instrument’s range (equivalent to LRV), while “Span” refers to the width of its range (URV − LRV). For example, if a temperature transmitter is calibrated to measure a range of temperature starting at 300ºC and ending at 500ºC, its zero would be 300ºC and its “span” would be 200ºC.

Controller: Is a device receiving a process variable (PV) signal from a primary sensing element (PSE) or transmitter, compares the signal to a desired value (called the setpoint), and calculates an appropriate output signal value to be sent to a final control element (FCE), such as an electric motor or control valve.

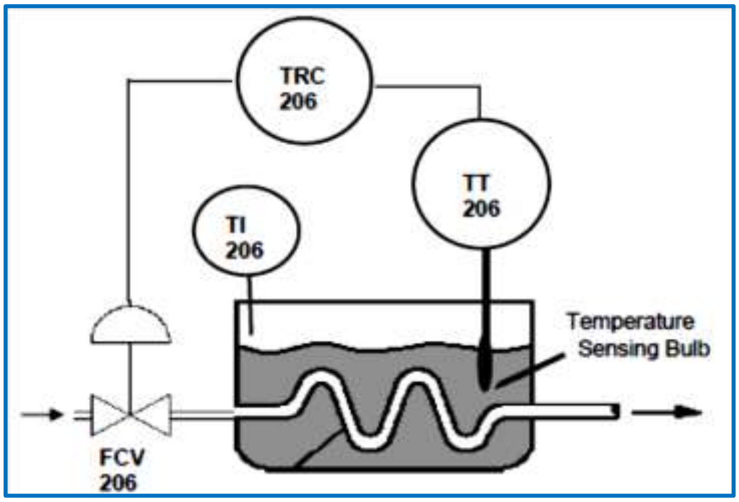
Final Control Element, or FCE: Is a device receiving the signal output by a controller that directly influences the process. Examples: variable-speed electric motor, control valve, electric heater.

Manipulated Variable, or MV: Is another term to describe the output signal generated by a controller. Is the signal commanding (“or manipulating”) the final control element to influence the process.

Automatic Mode: Is when the controller generates an output signal based on the relationship of a process variable (PV) to the setpoint (SP).

Manual Mode: Is when the controller’s decision is bypassed, to let a human operator directly determine the output signal sent to the final control element.

Tag Numbers: Are letters and numbers placed within or near the instrument to identify the type and function of the device. The letters and numbers placed within or near the instrument to identify the type and function of the device.



Pressure	**I**ndicator
Level	**R**ecorder
Flow	**C**ontroller
Temperature	**T**ransmitter

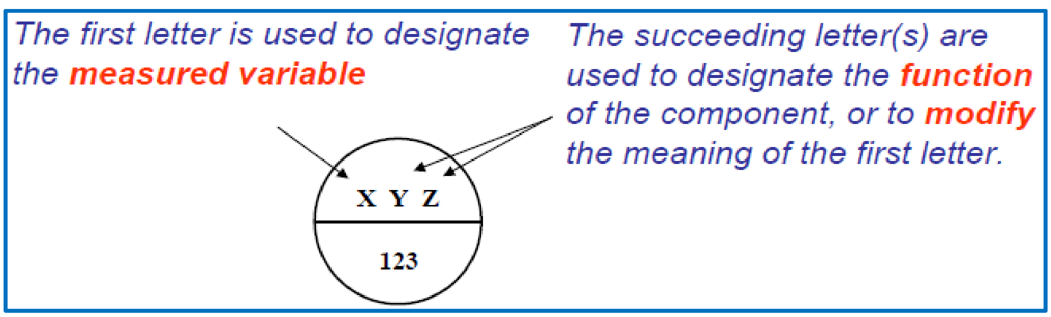
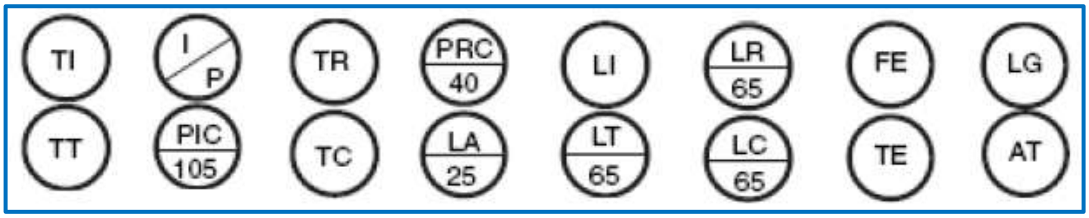
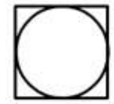
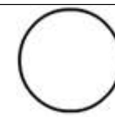
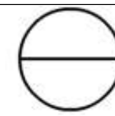
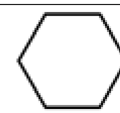
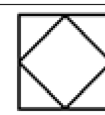
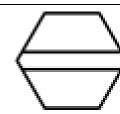
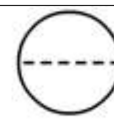


Diagram Balloon: On a process control diagram, a circle, called as "balloon", is used to indicate an instrument, as the "temperature transmitter", as shown below:

Examples of "balloons" and the respective instruments:



If the balloon is inside a square, the instrument is identified as a “shared device	
Symbols without horizontal lines indicate the instrument is installed in the field, either: At the point of measurement. Near the final control element.	
Symbols with a single line indicate the instrument is mounted on a panel board, accessible to the operator or for routine maintenance.	
If a hexagon is indicated instead of a balloon, a computer function should be used.	
A rhombus inside a square identifies the application of a PLC – Programmable Logic Controller.	
Double lines indicate the instrument is at an auxiliary location away from the process	
Symbols with a single dashed line indicate the instrument is located behind a panel and not easily accessible.	

Examples of instruments, PLC and control panels:

 Flowmeter	 PLC - Programmable Logic Controller	 Control Panel

ISA - Instrument Functions and Identifications: The ISA standard covers the identification of instruments or control functions associated with it in a loop. The user is free to apply additional identification, by serial number, unit number, area number, plant number, or by other means. For a more complete treatment, see ISA-S51.1 and the ISA-S75 series of standards. Examples:

Alarm: A device or function that signals the existence of an abnormal condition by means of an audible or visible discrete change, or both, intended to attract attention. Its operation is simply to close or open a circuit that may or may not be used for normal or abnormal interlock, start-up, shutdown, of a pilot light or an alarm device, properly designated as a level switch, a flow switch, etc.,.

Binary: A term applied to a signal or device that has only two discrete positions or states. When used in its simplest form, as in "binary signal" (as opposed to "analog signal"), the term denotes an "on-off" or "high-low" state, i.e., one which does not represent continuously varying quantities.

Board: Synonym for control panel.

Bubble: Is a circular symbol used to denote and identify the purpose of an instrument or function, synonym for balloon. It may contain a tag number.

Controller: A device having an output that varies to regulate a controlled variable in a specified manner. The automatic controller varies its output automatically in response to a direct or indirect input of a measured process. The manual controller is a manual loading station and its output is not dependent on a measured process, but can be varied only by manual adjustment.

Control Station: A manual loading station that also provides switching between manual and automatic control modes of a control loop. It is also known as an auto-manual station. The operator interface of a distributed control system may be regarded as a control station.

Control Valve: A hand-actuated on-off valve, or a self-actuated check valve that directly manipulates the flow of one or more fluid process streams. It is expected that use of the designation "hand control valve" will be limited to hand-actuated valves that are used for process throttling, or require identification as an instrument.

Converter: A device that receives information in one form of an instrument signal and transmits an output signal in another form. Typically, a temperature element (TE) may connect to a transmitter (TT), not to a converter (TY). A converter is also referred to as a transducer; however, "transducer" is a completely general term, but its use for signal conversion is not recommended.

Digital: A term applied to a signal or device that uses binary digits to represent continuous values or discrete states.

Distributed Control System: A system which, while being functionally integrated, consists of subsystems which may be physically separate and remotely located from one another.

Final Control Element: The device that directly controls the value of the manipulated variable of a control loop. Often the final control element is a control valve.

Function: The purpose of, or an action performed by, a device.

Identification: The sequence of letters or digits, or both, used to designate an individual instrument or loop.

Instrument: A device used directly or indirectly to measure and/or control a variable. The term includes primary elements, final control elements, computing devices, and electrical devices such as annunciators, switches, and pushbuttons.

Instrumentation: A collection of instruments or their application for the purpose of observation, measurement, control, or any combination of these.

Loop: A combination of two or more instruments or control functions arranged so that signals pass from one to another for the purpose of measurement and/or control of a process variable.

Manual Loading Station: A device or function having a manually adjustable output that is used to actuate one or more remote devices. The station may have integral indicators, lights, or other features. It is also known as a manual station or a manual loader.

Measurement: The determination of the existence or the magnitude of a variable.

Monitor: A general term for an instrument or instrument system used to measure or sense the status or magnitude of one or more variables for the purpose of deriving useful information. Monitor can also be used as a verb.

Monitor Light: Synonym for pilot light.

Panel: A structure that has a group of instruments mounted on it, houses the operator-process interface, and is chosen to have a unique designation. The panel may consist of one or more sections, cubicles, consoles, or desks.

Panel-Mounted: A term applied to an instrument that is mounted on a panel or console and is accessible for an operator's normal use. A function that is normally accessible to an operator in a shared-display system is the equivalent of a discrete panel-mounted device.

Pilot Light: A light that indicates which of a number of normal conditions of a system or device exists. It is unlike an alarm light, which indicates an abnormal condition. The pilot light is also known as a monitor light.

Primary Element: Synonym for sensor.

Process: Any operation or sequence of operations involving a change of energy, state, composition, dimension, or other properties that may be defined with respect to a datum.

Process Variable: Any variable property of a process. The term process variable is used in this standard to apply to all variables other than instrument signals.

Program: A repeatable sequence of actions that defines the status of outputs as a fixed relationship to a set of inputs.

Programmable Logic Controller: A controller, usually with multiple inputs and outputs, that contains an alterable program.

Relay: A device whose function is to pass on information in an unchanged form or in some modified form. Relay is often used to mean computing device. The latter term is preferred. The term "relay" also is applied specifically to an electric, pneumatic, or hydraulic switch that is actuated by a signal. The term also is applied to functions performed by a relay.

Scan: To sample, in a predetermined manner, each of a number of variables intermittently. The function of a scanning device is often to ascertain the state or value of a variable. The device may be associated with other functions such as recording and alarming.

Sensor: That part of a loop or instrument that first senses the value of a process variable, and that assumes a corresponding, predetermined, and intelligible state or output. The sensor may be separate from or integral with another functional element of a loop. The sensor is also known as a detector or primary element.

Set Point: An input variable that sets the desired value of the controlled variable. The set point may be manually set, automatically set, or programmed. Its value is expressed in the same units as the controlled variable.

Shared Controller: A controller, containing preprogrammed algorithms that are usually accessible, configurable, and assignable. It permits a number of process variables to be controlled by a single device.

Shared Display: The operator interface device (usually a video screen) used to display process control information from a number of sources at the command of the operator.

Switch: A device that connects, disconnects, selects, or transfers one or more circuits and is not designated as a controller, a relay, or a control valve. As a verb, the term is also applied to the functions performed by switches.

Test Point: A process connection to which no instrument is permanently connected, but which is intended for the temporary or intermittent connection of an instrument.

Transducer: A general term for a device that receives information in the form of one or more physical quantities, modifies the information and/or its form, if required, and produces a resultant output signal. Depending on the application, the transducer can be a primary element, transmitter, relay, converter or other device. Because the term "transducer" is not specific, its use for specific applications is not recommended.

Transmitter: A device that senses a process variable through the medium of a sensor and has an output whose steady-state value varies only as a predetermined function of the process variable. The sensor may or may not be integral with the transmitter.

Identification Designation: Based on Standard ANSI/ISA S5.1 and ISO 14617-6, the P&ID is used for the identification of measurements within the process. The identifications consist of up to 5 letters. The first identification letter is for the measured value, the second is a modifier, 3rd indicates passive/readout function, 4th - active/output function, and the 5th is the function modifier.

Letter	Measured value	Modifier	Readout/Passive function	Output/active function)	Function modifier)
A	Analysis		Alarm		
B	Burner, combustion		User choice	User choice	User choice
C	User's choice (usually conductivity)			Control	Close
D	User's choice (usually density)	Difference			Deviation
E	Voltage		Sensor		
F	Flow rate	Ratio			
G	User's choice (usually gaging/gauging)	Gas	Glass/gauge /viewing		
H	Hand				High
I	Current		Indicate		
J	Power	Scan			
K	Time, time schedule	Time rate of change		Control station	
L	Level		Light		Low
M	User's choice				Middle / intermediate
N	User's choice (usually torque)		User choice	User choice	User choice
O	User's choice		Orifice		Open

P	Pressure		Point/test connection		
Q	Quantity	Totalize Integrate	Totalize/integrate		
R	Radiation		Record		Run
S	Speed, frequency	Safety		Switch	Stop
T	Temperature			Transmit	
U	Multivariable		Multifunction	Multifunction	
V	Vibration, mechanical analysis			Valve or damper	
W	Weight, force		Well or probe		
X	User's choice (usually on-off valve as	X-axis	Accessory devices, unclassified	Unclassified	Unclassified
Y	Event, state, presence	Y-axis		Auxiliary devices	
Z	Position, dimension	Z-axis		Actuator, driver or unclassified final	

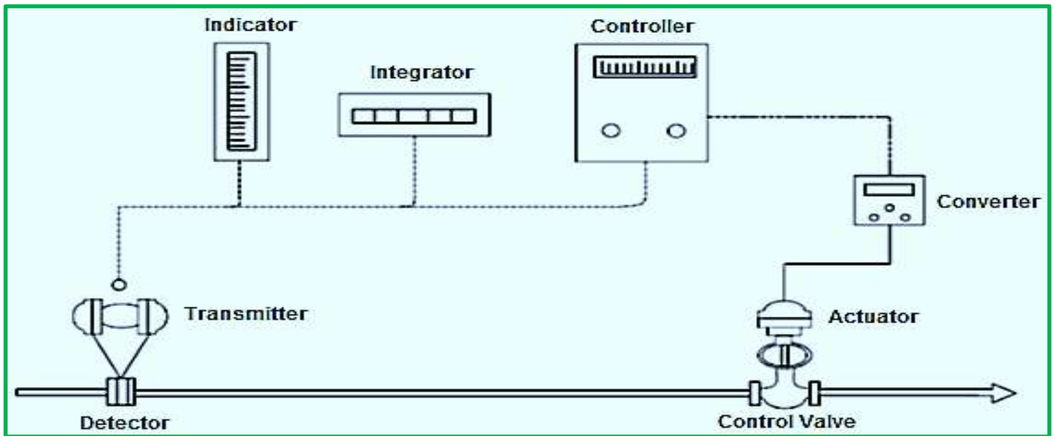
Note: For reference designation of any equipment in industrial systems the standard IEC 61346 (*Industrial systems, installations and equipment and industrial products - Structuring principles and reference designations*) can be applied. For the function *measurement,* the reference designator **B** is used, followed by the above listed letter for the measured variable.

Process Variables: Industries such as petrochemical, steel, food, paper, and so on, where the instrumentation is responsible for the maximum yield of a process, causing that all energy be transformed into a controlled work. There are many types of instrumentation, as can be seen in the table above. Our main subject is only process control. Thus, the main variables that reflect energy transfers in the process controls are: *pressure, level, flow and temperature*; called as process variables.

These systems may need to be identified on drawings and in text. As an example, the system codes for identification may be the following:

ACS = Analyzer Control System BMS = Burner Management System CCS = Computer Control System CEMS = Continuous Emissions Monitoring System	DCS = Distributed Control System FDS = Flame Detection System MMS = Machine Monitoring System VMS = Vibration Monitoring System

Loop Diagram: The instruments can be interconnected with each other to accomplish a certain task in industrial processes. The association of these instruments is called "*loop diagram"* where each instrument performs a function, as shown below:



Instrument Tag Letters: Provides the allowable loop identification letters and combinations according to the loop identification number construction schemes. The letters and combinations shall have the mandatory meanings are given by ISA S5.1 (now ANSI/ISA-5.01.01). Some examples of instrument tag letters are shown in the following list:

- **AIT** = Analytical Indicating Transmitter: Example, an oxygen concentration analyzer with a built-in display of oxygen percentage.
- **ESL** = Voltage Switch, Low: Example, a switch used to detect an under-voltage condition in an electrical power system.
- **FFI** = Flow Ratio Indicator: Example, a device indicating the ratio between air and fuel for a large industrial engine.
- **FIC** = Flow Indicating Controller: Example, a controller designed to indicate the flow to a human operator.
- **HC** = Hand Controller: Example, a device allowing a human operator to set a control signal to some desired level, usually to operate a valve or other final control element.
- **JQR** = Power Totalizing Recorder: Example, a watt-hour recorder, tracking total energy used.
- **LSHH** = Level Switch, High-High: Example, a level-sensing switch designed to detect a dangerously high liquid level and initiate an automatic shutdown in that event.
- **LT** = Level Transmitter: Example, a device sensing liquid level and reporting that level in some analog or digital form.
- **PIT** = Pressure Indicating Transmitter: Example, a Rosemount model 3051 pressure transmitter with a built-in display of measured pressure.
- **PDT** = Pressure Differential Transmitter: Example, a pressure transmitter built and installed to sense the difference of pressure between two points in a fluid system.
- **PV** = Pressure Valve: Example, a control valve installed in a loop where the process variable is only pressure.
- **TE** = Temperature Element: Example, a sensing element used to directly detect the temperature of a process material; e.g. a thermocouple, thermistor, filled-bulb, bimetallic spring.
- **TKAH** = Temperature Rate-of-change Alarm, High: Example, a device alarming when the rate of temperature change exceeds a pre-set limit.
- **TV** = Temperature Valve: Example, a control valve installed in a loop where the process variable is only temperature.
- **TY** = Temperature Converter: Example an I/P transducer in a temperature loop.

• **VSH** = Vibration Switch, High: Example, a switch used to detect a high level of vibration on motors.
• **ZXI, ZYI,** and **ZZI** = Position Indicators for X, Y, and Z axes respectively: Example, indicators showing the three axis positions for a CNC machine tool.

The main classification according to instrument function is described in this table:

INSTRUMENT	DESCRIPTION
Detector	Are devices that can detect changes in a variable process. May or may not be part of the transmitter.
Transmitter	Instrument which has the function of converting signals from the detector or otherwise capable of being sent away to a receiver, usually located in the instrument panel.
Indicator	An instrument that indicates the value of the measured quantity sent by a transmitter, detector, etc.
Recorder	Instrument that registers graphically instantaneous all values measured over time, these values are sent by the detector, transmitter, controller etc.
Converter	Instrument whose function is to receive the information in the form of a sign, change this form and send it as an output signal, proportional to the input.
Arithmetic Unit	Instrument that performs operations on input values signals according to a given expression, and provides an output resulting from the operation.
Integrator	Instrument that indicates the values obtained by integrating measurement over time.
Controller	Instrument compares the measured value with the desired and, based on the difference between them, emits a signal to fix for the variable manipulated in order that this difference is equal to zero.
Final Control Element	Device whose function is to modify the value of a variable to take the case back to the desired value.

Detectors: Its main function is to convert radiation energy into an electrical signal. Detectors are used to measure particle physics, nuclear engineering, cosmic radiation, calorimeters and other attributes such as momentum, spin, charge etc. of the particles. There are two basic mechanisms for converting this energy: excitation and ionization.

- ✓ **Ionization**: An electron is stripped from an atom and the electron and resulting ion are electrically charged. Example, 3He neutron detectors, Geiger Mueller, and other gas proportional detectors are examples of ionization detectors.

- ✓ **Excitation**: Electrons are excited to a higher energy level and when the vacant electron is filled, an electromagnetic radiation is emitted. Example, scintillation detectors such as NaI, BGO, CsI, Polyvinyl Toluene (PVT), plastic scintillator and the neutron sensitive glass fibers.

There are three categories of detectors: Thermal, pyroelectric and photoelectric – described below:

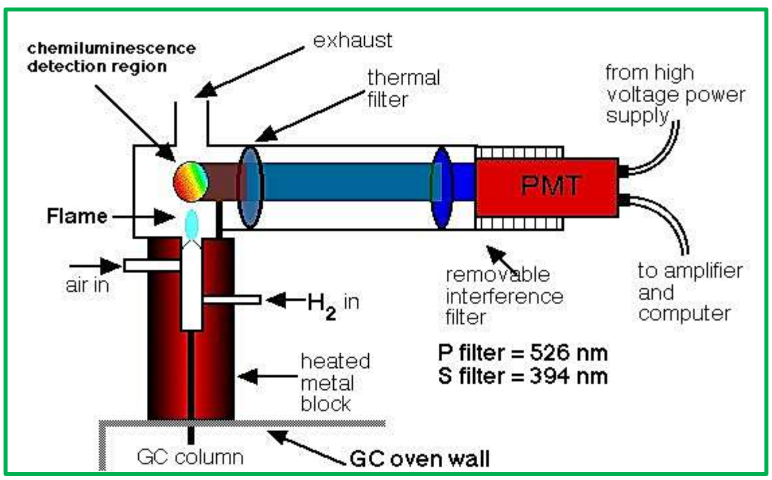
- ✓ **Thermal Detectors**: Are generally considered to be those devices that absorb the radiation, increase their own temperature, and provide a resultant electrical signal. There are several types; the oldest are bolometers and thermocouples.

- ✓ **Pyroelectric Detectors**: Are used to convert infrared light to electric signals. Pyroelectric materials are characterized by having spontaneous electric polarization, which is altered by temperature changes. The change in temperature modifies the positions of the atoms slightly within the crystal structure. This polarization change gives rise to a voltage across the crystal producing an electrical signal, in response to the changing of temperature.

- ✓ **Photoelectric Detectors**: The main function is to quickly identify a developing fire, alarms and emergency response before extensive damage occurs. Automatic fire detection systems do this by using electronic sensors to detect the smoke, heat, or flames from a fire and providing an early warning.

Thermal Detectors	Pyroelectric Detectors	Photoelectric Detectors
		

Gas Detectors: Are used to detect the presence of various gases within a plant area, combustible or toxic, always defined by its technology; *catalytic and infrared sensors* detect combustible gases and *electrochemical and metal oxide* semiconductor technologies generally detect toxic gases.



Gas chromatographic flame photometric detector

Neutron Detectors: Are used by nuclear plants to the effective detection of neutrons, and may be installed inside or outside the reactor, depending on the type of reactor. If detectors normally used by the operator are outside the reactor, these detectors must be periodically recalibrated with detectors that are also installed in the reactor core.

Scintillation Detectors: Are used to detect radiation but may also be used to detect neutrons. The basic principle is the use of a special material, which glows or "scintillates" when radiation interacts with it. The most common type of material is a type of salt called *sodium-iodide*.

Leak Detectors: Leak testing is sometimes referred to as pressure testing or vacuum testing. There are many different forms of leak test detectors that can be used, from the basic submersing of the test object under water in a tank and *watching for bubbles for leak location*, to the highly accurate *helium leak testing* required for very tight leak limits.

The most common detectors types and application is shown in the table below:

Instrument	Detection Principle	Applications
Ion chamber (IC)	Ionization of air (or other gases).	Direct measurement of exposure or exposure rates, with minimal energy dependence.
Geiger-Mueller (GM) Proportional counter (PC)	Ionization of gas with multiplication of electrons.	Detection of individual events, i.e. alpha or beta particles & secondary electrons, for measuring activity (in samples or on surfaces) & detecting low intensities of ambient x or gamma radiation.
Solid state diodes	Ionization of semi-conductor.	Detection & energy measurement of photons or particles; primarily for laboratory use.
Solid state diodes	Ionization & excitation followed by light emission.	Detection of individual events;
-Solids		- NaI (Tl) - photons; energy spectrometry; - ZnS (Ag) - alpha particles; detection only
-Liquids		Detection of low-energy beta emitters mixed with the scintillation fluid.
Photographic film	Ionization of Ag Br.	Personal exposure monitoring.
Thermo-luminescent (TLD)	Excitation of crystal light release by heating.	Personal and environmental exposure monitoring.

3. INSTRUMENTATION DESCRIPTION & APPLICATION:

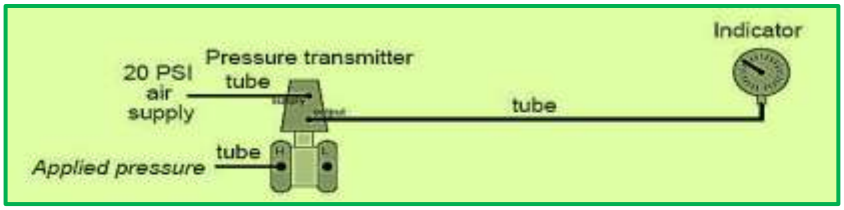
Transmitters: Are devices which convert the reading from a primary sensor or transducer into a standard signal and transmits that signal to a monitor or controller. Field instruments or smart transmitters monitor process control variables, such as temperature, pressure, level and flow. There are *three kinds of signals* that are present in the process industry to transmit the reading of a process variable from the instrument to the centralized control system. These are:

- *Pneumatic signals, analog signals and digital signals* – as described below:

- ✓ **Pneumatic Signals**: The common industrial standard is 3-15 psig (0.2-20 bar). The unit 3 psig (0.2 bar) corresponds to the lower range value (LRV) and the unit 15 psig (20 bar) corresponds to the upper range value (URV).

- ✓ **Analog Signals**: The most common standard for transmitting an analog signal is the 4-20 mA current signals, where a transmitter sends a small current through a set of wires.

- ✓ **Digital Signals**: Are discrete levels or values that are combined in specific ways to represent process variables and also carry other information, such as diagnostic information. The methodology used to combine the digital signals is referred to as **protocol**. Digital signals conditioning can be considered as changing one form of digital data to another form.



The types of transmitters used in process industries include:

- Pressure transmitters;
- Temperature transmitters;
- Flow transmitters;
- Level transmitters;
- Analytic (O2, CO), and pH transmitters.

The main types of pressure transmitters used in industries are:

- ✓ **Absolute Pressure Transmitter**: This transmitter measures the pressure relative to perfect vacuum pressure (0 psi or no pressure).
- ✓ **Gauge Pressure Transmitter**: This transmitter measures the pressure relative to a given atmospheric pressure at a given location. When the pressure gauge reads 0 PSI, it is really atmospheric pressure.
- ✓ **Differential Pressure Transmitter**: This transmitter measures the difference between two or more pressures introduced as inputs to the sensing unit, for example, measuring the pressure drop across an oil filter. The differential pressure is also used to measure flow or level in pressurized vessels.

Digital Gauge, Transmitter & Switch

Pressure Transmitter

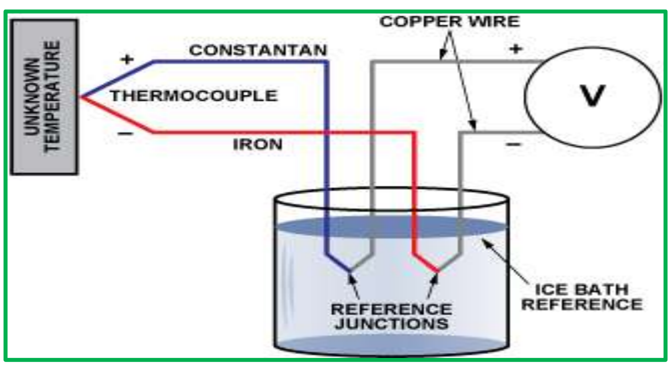
Temperature Transmitters: Are devices that capture a signal from a sensor, such as a thermocouple or RTD, calculates the temperature based on this signal and then converts it to a 4-20 mA type signal for output to a receiving device. There are some types of temperature transmitters:


Conventional Temperature Transmitters

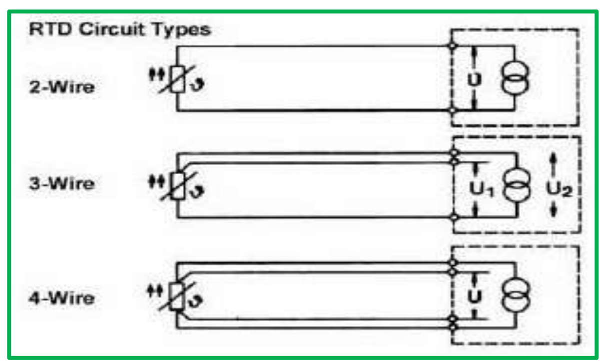

Wireless Temperature Transmitter

Thermocouples: Is when a conductor generates a voltage when subjected to a temperature variation. The voltage difference generated by the two materials can then be measured and related to the corresponding temperature gradient. The Seebeck coefficient or thermoelectric sensitivity is the material electromotive force (EMF) change with respect to a temperature raising.

Resistance Temperature Detectors (RTD): Is based on the principle that the resistance of a conductor varies with temperature. As the temperature goes up, resistance goes down. When an RTD is used, the temperature transmitter passes a very small electric current through the RTD to measure electrical resistance.



Thermocouple Circuit



RTD Circuits

Flow Transmitters: Flow is defined as the rate (volume or area per unit time) at which a substance travels through a given cross section, characterized at specific temperatures and pressures. The flow transmitter is often a *4 to 20mA* current that changes with flow, but the instruments used to measure flow are termed flow meters.

Flow transmitters have stringent power constraints, as all of the electronics for signal acquisition/processing and transmission may need to operate solely the 4-20-mA loop. Transmitters with digital connectivity features such as a process field bus *(Profibus), I/O links*, and/or wireless connectivity are increasing among industries, as they provide continuous monitoring and fault diagnostics. All these factors greatly improve productivity and efficiency of the automation loop.

The main **difference** between a *flow meter* and a *flow transmitter* is that the flow meter measures flow and displays it. Flow transmitter is the most common flow meter interface using a *4-20-mA* current, to be sent for other controllers. This current can be measured locally (near the flow) and indicated, or can also be monitored at a distance as in a control room or near operation, if necessary. However, a *flow meter* may be a *flow indicator*, or a combined *transmitter and indicator*.

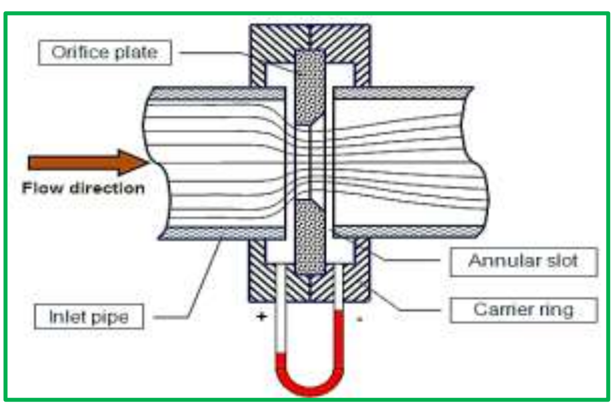
However, the main components of a flow meter may include the *sensor, signal processor and tranmitter*. The flow sensors use *acoustic waves* and electromagnetic fields to measure the flow through a given area via physical quantities, such as acceleration, frequency, pressure and volume. Flow meters are an integral tool for *measuring the flow of liquid, gas, or a mixture of both*, used in the food and beverage industry, oil and gas plants, and chemical/pharmaceutical factories.

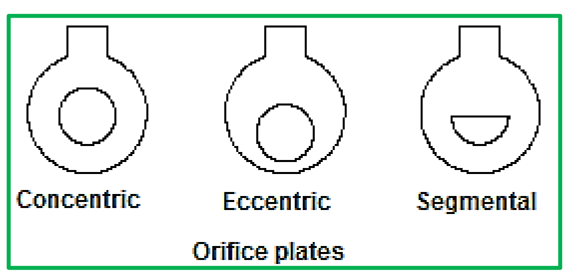
There are many different types of flow meters, according to fluid characteristics (single or double phase, viscosity, turbidity, etc.), flow profile (laminar, transitional, or turbulent, etc.). Flow range and other considerations as output-connectivity options, effects of pressure, temperature, and dynamic influences can potentially alter the measurements to be taken. The most common **flow meters** are:

- Differential-Pressure Flowmeters; Vortex Flowmeters; Coriolis Flowmeters; Ultrasonic Flowmeters; Magnetic Flowmeters and Annubar Flowmeters.

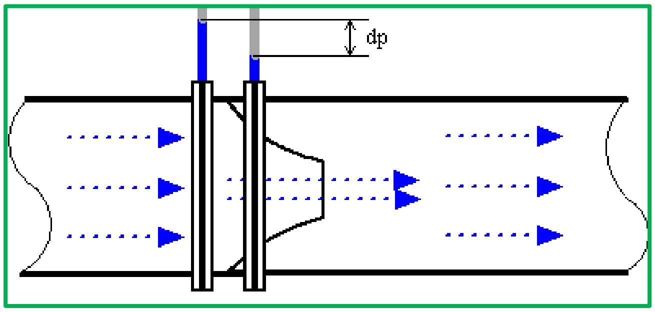
- **Differential-Pressure Flowmeters**: Based on Bernoulli's principle, measures the differential-pressure drop across a constriction in the flow's path that infer in the flow velocity. The common types are the ***Orifice***, the ***Flow Nozzle***, ***Pitot***, and ***Venturi Tubes***.

- **Orifice Flowmeters**: Are used as orifice plates in a pipe flange, which constricts the flow of the fluid inside the pipe. As the fluid flows through the hole in the orifice plate, in accordance with the law of conservation of mass, the velocity of the fluid that leaves the orifice, is more than the velocity of the fluid, before the orifice.

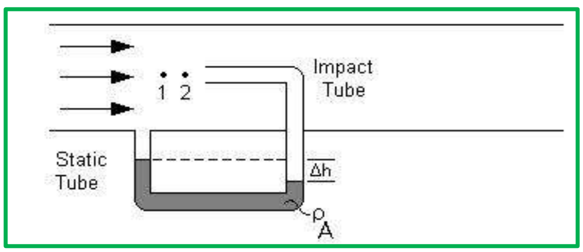


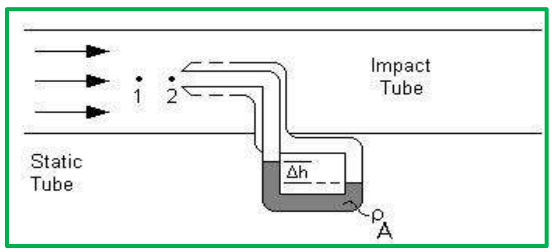


- **Flow Nozzles**: Are often used as measuring elements for air and gas flow in industrial applications, and also meter either liquids or liquids with suspended solids. Its construction makes it substantially more rigid in adverse conditions, as the flow coefficient data and high Reynolds numbers can be better documented, than using orifice plates. At high velocities, flow nozzles can handle approximately 60 percent greater liquid flow than orifice plates having the same pressure drop.

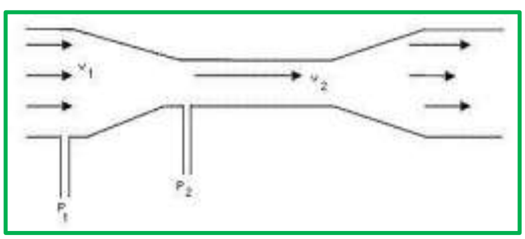


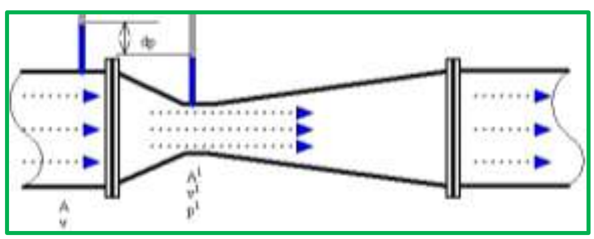
- **Pitot Tubes**: Measure the local velocity due to the pressure difference between points 1 and 2 in the diagrams below. Unlike the other differential flow meters, the pitot tubes only detect fluid flow at one point rather than an overall calculation. The first diagram shows a simple pitot tube configuration while the second shows a compact pitot tube configuration.



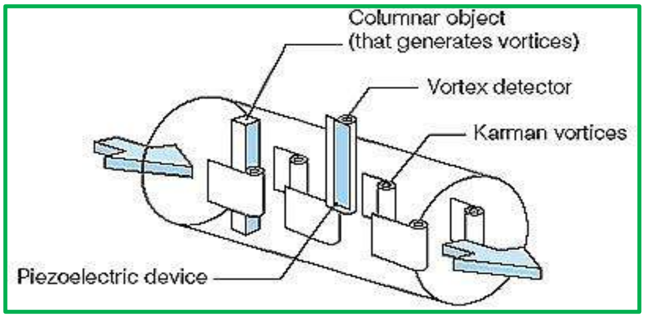


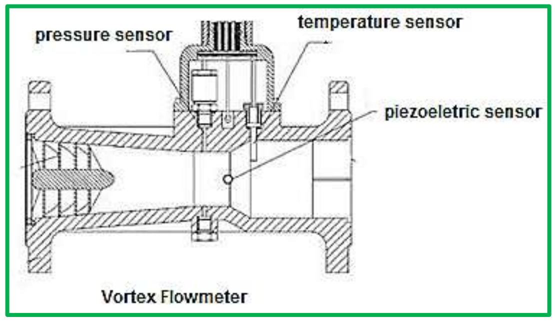
- **Venturi Tubes**: Can pass 25 – 50% more flow than an orifice meter, and the pipe design does not need to be straight like the orifice meter. There are two main types of Venturi meters. The first one, known as the classical Herschel Venturi meter, is a very long meter characterized below. Pressure readings at different points are combined to provide an average pressure reading. The second type of Venturi meter is known as the short form Venturi meter. This differs from its longer counterpart by reduced size and weight.





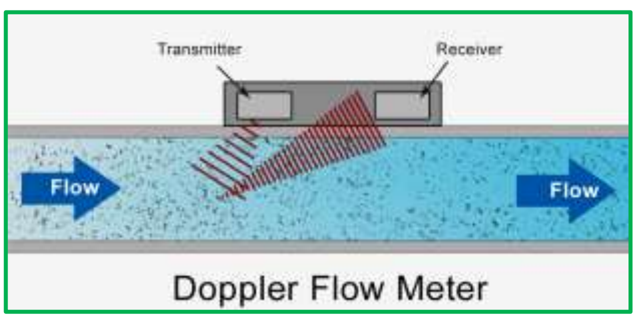
Vortex Flowmeters: Is often a piezoelectric crystal, which produces a small, but measurable, voltage pulse every time a vortex is created. Since the frequency of such a voltage pulse is also proportional to the fluid velocity, a volumetric flow rate is calculated using the cross sectional area of the flow meter. The frequency at which these vortices alternate sides is essentially proportional to the flow rate of the fluid. This vortex trail is called the Von Karman vortex street that is a mathematical description of the phenomenon.



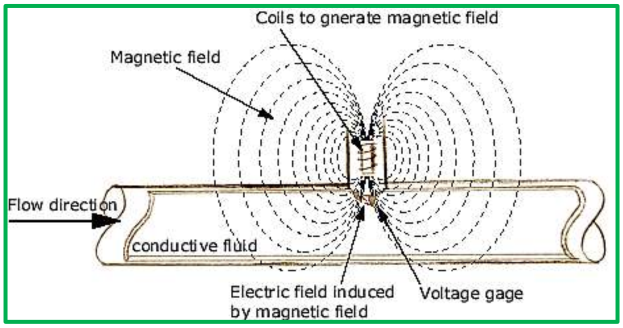


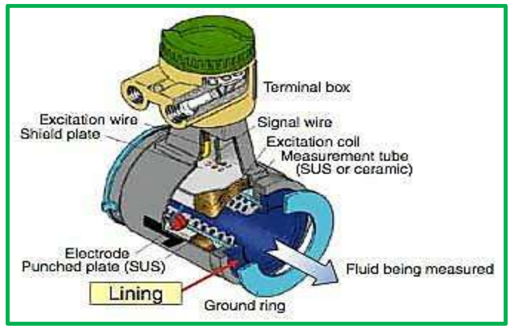
Coriolis Flowmeters: Are the most popular flow meters as directly measures the flow rate. When the fluid starts flowing through the tubes, the oscillatory motion of the tubes superimposes on the linear motion of the fluid, exerting twisting forces on the tubes, designated by coriolis. The coriolis mass flowmeter, shown aside, is one of the most compact, and can be installed in the tightest spaces as it has no up or downstream piping requirements, with a low pressure drop and a wide measurement span for numerous applications.

Ultrasonic Flowmeters: Are devices that measure the velocity of a fluid through ultrasound to calculate a volume flow, using ultrasonic transducers. The clamp-on design flow meter can measure by averaging the difference of a transit time between the pulses of ultrasound or by measuring the frequency shift from using the Doppler-shift ultrasonic meter, based on the Doppler effect. This meter consists of transmit-and-receive-node sensors, which propagates an ultrasound wave of 0.5 to 10 MHz into the fluid.



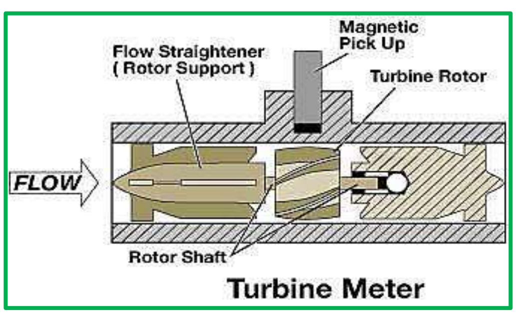
Magnetic Flowmeters: Are also technically designated as electromagnetic flow meter or more commonly as magmeter. A magnetic field is applied to the metering tube, which results in a potential difference proportional to the flow velocity perpendicular to the flux lines, through an electromagnetic induction. The magnetic flow meter requires a conducting fluid, for example, water that contains ions, and an electrical insulating pipe surface, for example, a rubber-lined steel tube.



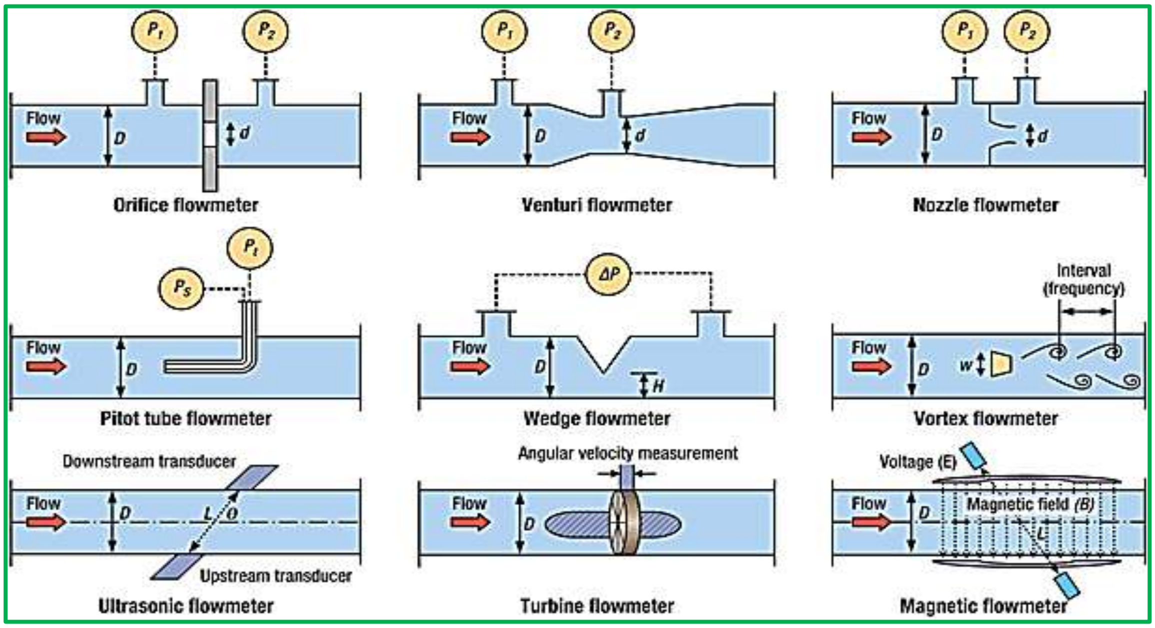


Annubar Flowmeters: Is similar to a pitot tube used to measure the flow of gas or liquid in a pipe, but provides better accuracy than pitot tubes. The biggest difference between an annubar and a pitot tube is that an annubar takes multiple samples across a section of a pipe or duct. Annubar is economical to install with negligible pressure drop but is unsuitable when dirty fluids are used. Annubar is a registered trade name with Emerson Process Management / Rosemount. Although this technology has been around for many years, only 11% are annubar type probes.

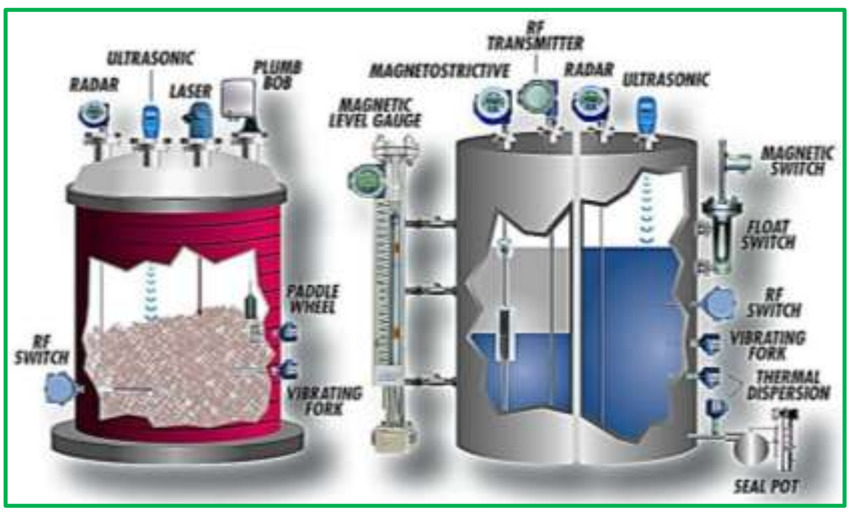
Turbine Flowmeters: Or axial turbines, translates the mechanical action of the turbine rotating in the liquid flow around an axis into a user-readable rate of flow (gpm, lpm, etc.). Turbine flow meters are commonly used for the measurement of natural gas and liquid flow. The flow direction is generally straight through the meter, allowing for higher flow rates and less pressure loss than displacement-type meters. Turbine meters are generally available for pipe sizes 4 to 30 cm (1 ½–12 in) or higher.



Below, is shown the various types of flowmeters usually applied in fluid process:

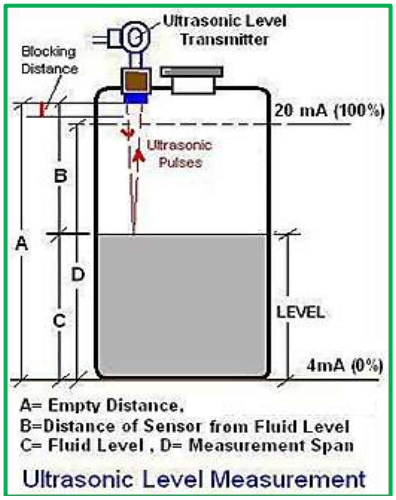


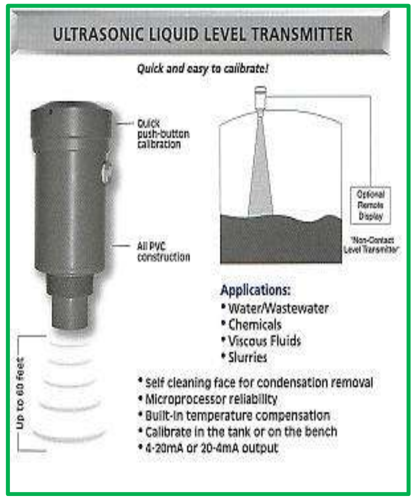
Level Transmitters: Are used for no-contact common 4-20 mA instrumentation devices, generally used to measure the level of liquids, slurries, granular materials, and powders within a confined space, and to provide information about these measurements proportional to the input level. Continuous sensors determine the exact amount of substance and measure the level, while other point-level sensors types, only indicate whether the substance is above or below the sensing point. Different types of level transmitters are shown in figure below:



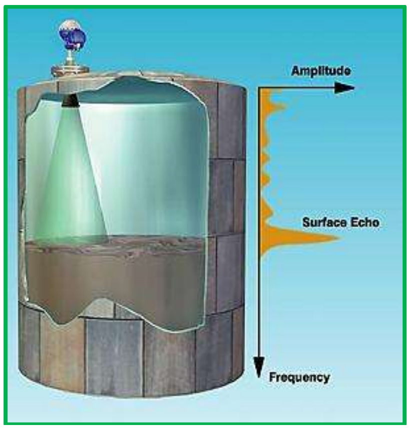
Vibrating Point Level Transmitters: Are used to provide output signal when a specific level measurement is reached; generally in the form of an *audible alarm* or an electrical charge used to turn on a switch. Continuous level transmitters measure level within a specified range and provide output as a continuous reading of the level. The most common level transmitters are described below:

Ultrasonic Level Transmitters: Are used for non-contact level sensing of highly viscous liquids, as well as bulk solids. They are also widely used in water treatment applications for pump control and open channel flow measurement.

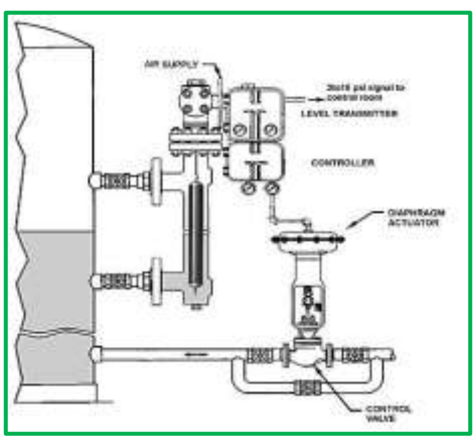




Radar Level Transmitters: These use a low-voltage, current-limited power source applied across separate electrodes. These are ideal for the point level detection of a wide range of conductive liquids such as water, and is especially well suited for highly corrosive liquids such as caustic soda, hydrochloric acid, nitric acid, ferric chloride, and similar liquids.

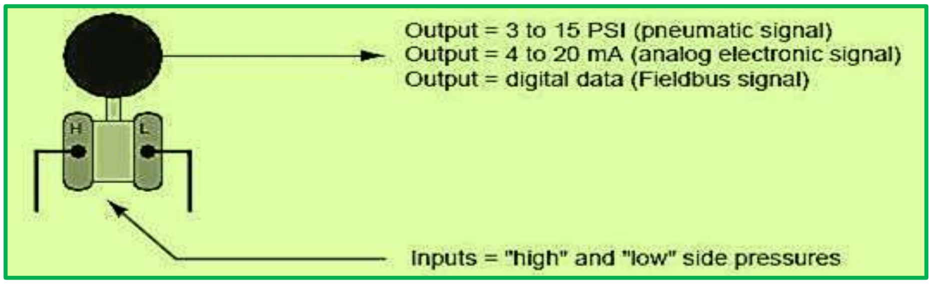


Pneumatic Level Transmitters: These transmitters are intended to be used in hazardous environments, where there is no electric power or its use is restricted, and in applications involving heavy sludge or slurry.



Other types of transmitters are:

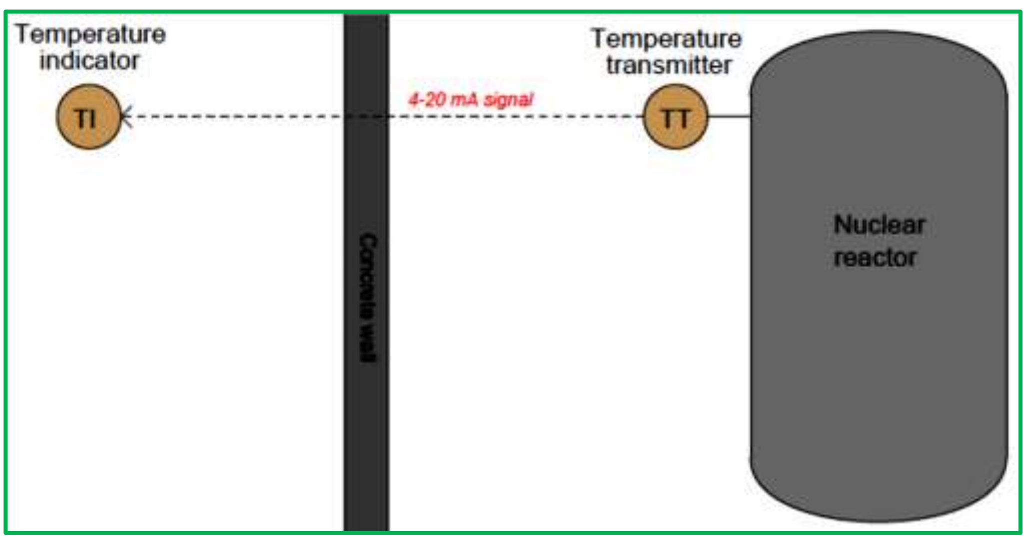
Electronic pressure transmitters, pneumatic pressure transmitters, submersible pressure transmitters, digital pressure transmitters, wireless pressure transmitters.



Telemetry: Is the reproduction, at a convenient location, of measurements made at remote points. It is the method of getting information from one point to the other. In general, a *telemetering* system consists of:

- ✓ A measuring instrument which may measure flow, liquid level, pressure, temperature or any other variable.
- ✓ A conversion element that converts the measured variable into a proportional air pressure and electrical quantity.

Indicators: An indicator gives a human operator a convenient way of seeing what the output of the transmitter is without having to connect test equipment (pressure gauge for 3-15 PSI, ammeter for 4-20 mA) and perform conversion calculations. Moreover, indicators may be located far from their respective transmitters, providing readouts in locations more convenient than the location of the transmitter itself.



A numerical Bargraph Indicator, as shown below, may be mounted in the face of a metal panel inside of a control room. It is directly wired in series with the same 4-20 mA current signal sent to the gate actuator. Aside, can be seen a less sophisticated style of Panel Indicator that shows only a numeric display.

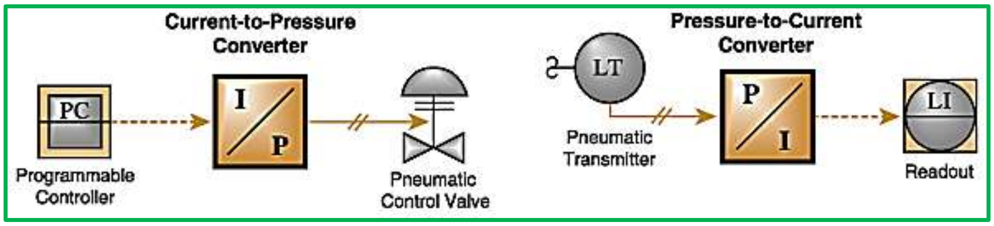
Indicators may also be used in "field" (process) areas to provide direct indication of measured variables if the transmitter device lacks a human-readable indicator of its own. This Field Indicator, shown below, also operates directly from the electrical power available in the 4-20 mA loop. The numerical display of this indicator uses a LCD technology rather than the red-glowing LEDs, in order to use less electrical power.

Bargraph and Panel Indicator	Field Indicator
	

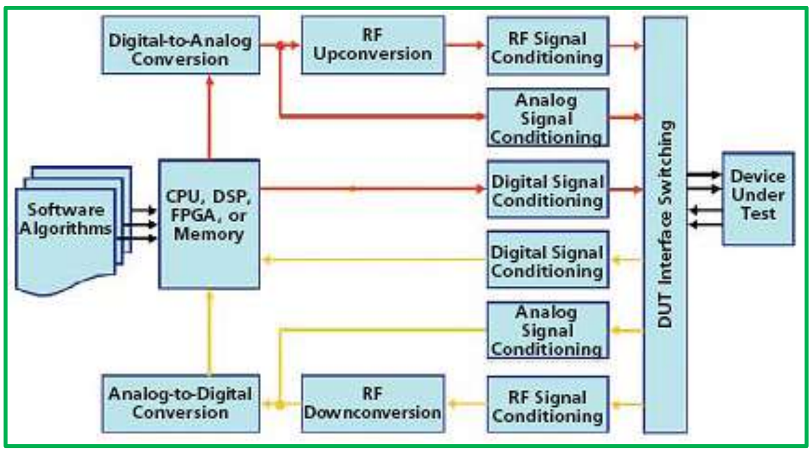
Recorders: Sometimes referred to as a chart recorder or a trend recorder, draw a graph of process variable over time. Recorders usually have indications built into them for showing the instantaneous value of the instrument signal simultaneously with the historical values, and for this reason are usually designated as indicating recorders. The Temperature Indicating Recorders, shown below, would be designated as "TIR" where a circular chart recorder uses a round sheet of paper, rotating slowly beneath a pen moved side-to-side by a servo-mechanism driven by the instrument signal.

Two more chart recorders are shown, a strip chart recorder on the right and a paperless chart recorder on the left. The strip chart recorder uses a scroll of paper drawn slowly past one or more lateral-moving pens, while the paperless recorder does away with paper entirely by plotting graphic trend lines on a computer screen:

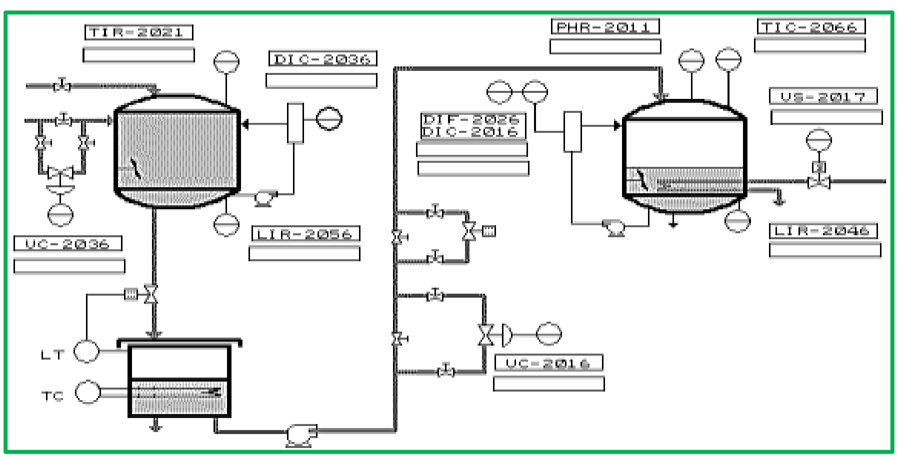
Converters: Instruments, whose function is to receive the information in the form of a sign, change this form and send it as an output signal, proportional to the input. The typical transducer measurement system block diagram is shown below. The transducer converts the data into an electrical signal adequate for processing by the circuitry that follows the transducer. The output of the transducer is an electrical signal representing the measured variable.



Integrators: Instruments that integrate the instruments and other devices, as the PLC/DCS/scada systems, provide some basic programming and also indicate the values obtained by integrating measurements over time. The acceptance of the fieldbus technology and the technology between the analogic 4-20 mA and digital devices makes the information relevant to the process that can be monitored, manipulated and used to control or be easily changed. Integrators are used to provide a great amount of information over every aspect of the process plant operation.



Controllers: Instruments that compares the measured value with the desired and, based on the differences between them, emits a signal to fix for the variable manipulated in order that this difference is equal to zero.

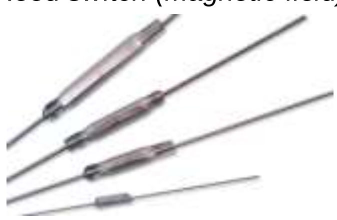


Switches: Are devices that may be operated by process variables such as pressure, temperature, flow, current, voltage, and force, acting as sensors in a process, used to automatically control a system. For example, a thermostat is a temperature-operated switch used to control a heating process.

Relay is a switch that is operated by another electrical circuit; however, large switches may be remotely operated by a motor drive mechanism. Some switches are used to isolate electric power from a system, providing a visible point of isolation that can be padlocked if necessary to prevent accidental operation of a machine during maintenance, or to prevent electric shock.

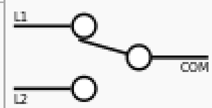
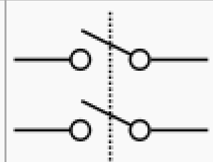
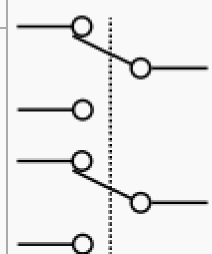
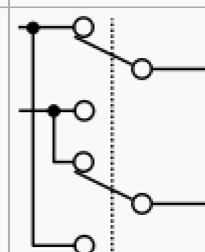
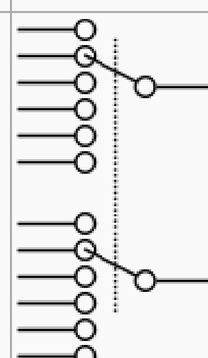
The most familiar form of switch is a manually operated electromechanical device with one or more sets of electrical contacts, which are connected to external circuits. Each set of contacts can be in one of two states: either "***closed or normally closed***" (NC) meaning the contacts are closed and electricity can flow between them, or "***open or normally open***" (NO), meaning the contacts are separated and the switch is nonconducting. The mechanism actuating the transition between open or closed, can be either a "*toggle*" (flip switch for continuous "on" or "off") or "*momentary*" (push-for "on" or push-for "off") type.

Types of Switches: Are designed to respond to any type of mechanical stimulus: for example, vibration (*trembler switch*), tilt, air pressure, fluid level (*float switch*), the turning of a key (*key switch*), linear or rotary movement (*limit switch or microswitch*), or presence of a magnetic field (*reed switch*). Many switches are operated automatically by changes in some environmental condition or by motion of machinery. The *limit switch* is used, for example, in machine tools to interlock operation with the proper position of tools. In heating or cooling systems the *sail switch* ensures that air flow is adequate in a duct. *Pressure switches* respond to fluid pressure.

Trembler switch(vibration)	*Float switch (fluid level)*	*Limit switch or Microswitch*
		
Reed switch (magnetic field)	*Sail switch (duct air flow)*	*Pressure switch (fluid pressure)*
		

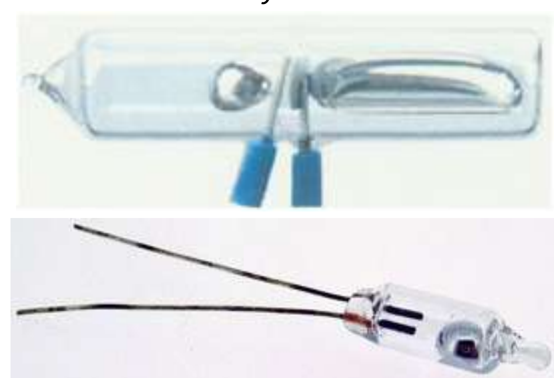
Contact Terminology: Terms as *pole* and *throw* are always used to describe switch contact variations. The number of "*poles*" is the number of separate circuits, controlled by a single switch. For example, a "*2-pole*" switch has two separate identical sets of contacts controlled by the same switch. The number of "*throws*" is the number of separate wiring path choices other than "open" adapted for each pole of a switch.

The *single-throw switch* has one pair of contacts, either *closed or open*. The *double-throw switch* has a contact that can be connected to any of other two contacts. The *triple-throw* has a contact which can be connected to any of three other contacts, and so on. The table below indicates the usual types of electro-electronic contacts in industry:

Electronic Specification	Type	British	American	Description	Symbol
SPST	Single pole, single throw	One-way	Two-way	A simple on-off switch:	
SPDT	Single pole, double throw	Two-way	Three-way	A simple changeover switch connected to L1 or to L2 inputs.	
SPCO SPTT, c.o.	Single pole changeover *or* Single pole, center off *or* Single Pole, Triple Throw			Similar to *SPDT*. *SPCO/SPTT* are switches with a stable off position in the center and *SPDT* for those without	
DPST	Double pole, single throw	Double pole	Double pole	Equivalent to two *SPST* switches controlled by a single mechanism	
DPDT	Double pole, double throw			Equivalent to two *SPDT* switches controlled by a single mechanism.	
DPCO	Double pole changeover *or* Double pole, center off			Schematically equivalent to *DPDT*. *DPCO* are switches with a stable center position and *DPDT* without center position. A DPDT/DPCO switch with a center position can be "off" in the center, not connected to either L1 or L2, or "on", connected to both L1 and L2 at the same time.	
		Intermediate switch	Four-way switch	*DPDT* switch internally wired for polarity-reversal applications: only four rather than six wires are brought outside the switch housing.	
2P6T	Two pole, six throw			Changeover switch with a (COM, Common) which can connect to L1, L2, L3, L4, L5, or L6; with a second switch (2P, two pole) controlled by a single mechanism	

Electronic Switches: Since the advent of digital logic in the 1950s, the term *switch* has spread to a variety of ***digital active devices*** such as transistors and ***logic gates*** whose function is to change an output state between two logic levels or connect different signal lines. As an example, the main function of computer active switches is to provide connections between different ports of computer networks. The power transistors in a switching voltage regulator, such as a power supply unit, are used like a switch to alternately let power flow and block power from flowing.

A *relay* is an electrically operated switch. The *mercury switch* consists of a drop of mercury inside a glass bulb with 2 or more contacts. A *rotary switch* operates with a twisting motion of the operating handle with at least two positions. A *toggle switch* is a class of electrical switches that are manually actuated by a mechanical lever, handle, or rocking mechanism. The term "*switched*" is also applied to telecommunications networks, and signifies that a network is circuit switched, providing dedicated circuits for communication between end nodes, such as the public switched telephone network.

Relays	*Mercury switches*
	
Rotary switches	*Toggle switches*
	

A *network switch* is a device used to create a computer network. A *network hub* creates a LAN, or Local Area Network. Ethernet is the most common technology used for Local Area Networks.

Network switch	*Network hub*
	

4. PROCESS CONTROL INSTRUMENTATION:

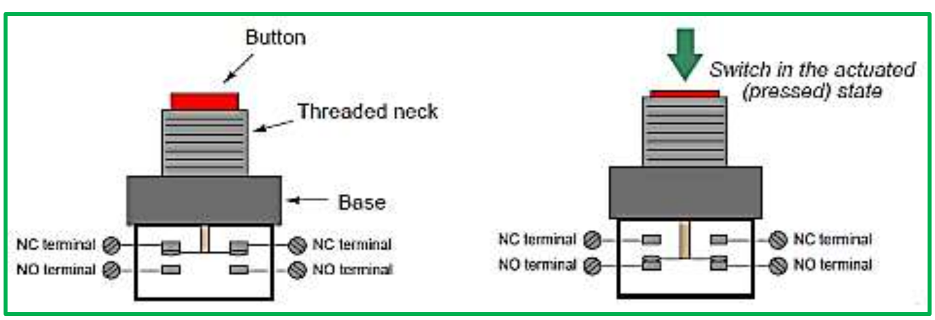
Process Control Switches: Process switches generate an *on* or *off* output based on a change in variable phenomenon, commonly used in the process control industry to monitor physical quantities such as flow, speed, temperature and pressure. Process switches can be characterized by switching technology used such as electro-mechanical or solid state, available in Normally Open (NO) or Normally Closed (NC) or both configurations.

A typical example is a pressure switch, when the pressure in a chamber has to be controlled with a certain value, 50 psi, as an example. The pressure switch controls the range of this temperature sending a high output when pressure is almost below 50 psi and a low output when pressure reaches almost above 50 psi. The range is defined by the process control of the chamber.

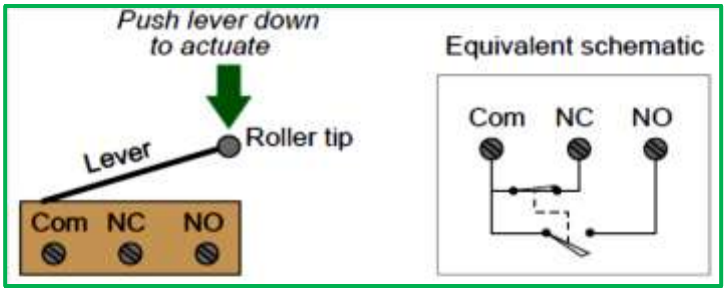
The difference between installing transmitters instead of process switches is that transmitters generally are more expensive. The switch output is typically a voltage free contact, e.g. SPDT Switches - 120 VAC when *on* and 0 volts when *off.* The transmitter has a variable output signal, and 4 to 20 mA current loop is the most common. The most common process switch types are:

- ✓ Hand switches: To be actuated by a person's hand motion;
- ✓ Limit switches: To prevent a machine go on or off, according to process;
- ✓ Proximity switches: To detect the proximity of an object;
- ✓ Pressure switches: For measuring low or high pressure (or even a vacuum);
- ✓ Level switches: For measuring high or low level;
- ✓ Temperature switches: For measuring high or low temperature;
- ✓ Flow switches: For measuring high or low flow rate.

Hand Switches: Are electrical devices actuated by a person's hand motion. These may take the form of toggle, pushbutton, rotary, pull-chain, etc. When pressed, the downward motion of the actuator breaks the electrical bridge between the two NC contacts, forming a new bridge between the NO contacts, as shown below:



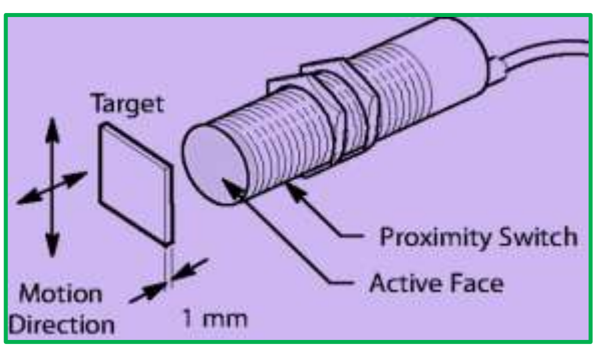
Limit Switches: Are switches operated by the motion of a machine part or presence of an object, used for control of a machine, as safety interlocks, or to count objects passing a point. Consist of an actuator mechanically linked to a set of contacts, when an object comes into contact with the actuator, the device operates make the electrical connection go on or off, according to process. Limit switches can determine the presence or absence, passing, positioning or end of travel of an object.



For example, the axis controls on a CNC machine tool such as a lathe or mill all return to their "home" positions upon start-up, so the machine computer can know with confidence the starting locations of each piece. These home positions are detected by means of limit switches. Other application examples are shown below:

Proximity Switches: Are devices that emit an electromagnetic field or a beam to detect the proximity of an object. The object being sensed is often referred to as the proximity sensor's target, as different proximity sensor targets demand different sensors. For example, a capacitive or a photoelectric sensor might be suitable for a plastic target; as well, an inductive proximity sensor always requires a metal target.

The maximum distance that this type of sensor can detect is defined as "nominal range". Some sensors have adjustments of the nominal range or means to report a graduated detection distance. Proximity sensors can have a high reliability and long functional life because of the absence of mechanical parts and lack of physical contact between sensor and the sensed object. Thus, by definition, these switches are non-contact sensors, using magnetic, electric, or optical means to sense the proximity of objects.



Pressure Switches: A pressure switch is a form of switch that closes an electrical contact when a certain set pressure has been reached on its input that often use diaphragms or bellows as the pressure-sensing element, which actuates one or more switch contacts. The switch may be designed to make contact either on pressure rise or on pressure fall.

The pressure switch will be in its "normal" status when it senses minimum pressure, that is, an applied pressure, or in some cases a vacuum condition. The following figure below shows two pressure switches sensing the same fluid pressure and an electronic pressure transmitter (left):

One of the settings on this switch is the "*deadband*" or "*differential pressure*" setting to determine the amount of pressure change required to re-set the switch to its normal state after it has tripped. For example, a high-pressure switch with a trip point of 67 PSI increasing, that re-sets back to its normal state at a pressure of 63 PSI decreasing, then this pressure switch has a "*deadband*" or "*differential*" pressure setting of 4 PSI (67 PSI − 63 PSI = 4 PSI).

Level Switches: A level switch is also a device instrument used to indicate the level of liquid or solid either in a tank or a vessel. Level switches often use floats as the level-sensing element, the motion of which actuates one or more switch contacts. The "normal" status of a level switch is when the fluid level is below the trip threshold of the switch.

Comparing with level transmitters, actually, level transmitters are relatively inexpensive, but according to experienced engineers, no level transmitter is 100% reliable, then it is preferable to have an additional level switch installed as a secondary backup to prevent overfills.

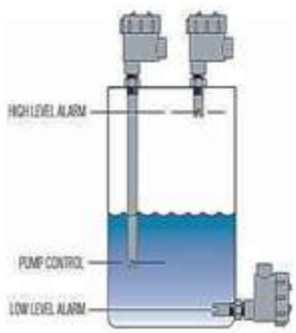
The most common types and application of level switches is according to table below:

Types:	Ultrasonic	Vibration	Buoyancy	Optic	Capacitance
Media:	Chemical	Wastewater	Water	Various	Various

Contact:	SPST	SPDT
Voltage:	12-36 VDC	120 VAC/VDC

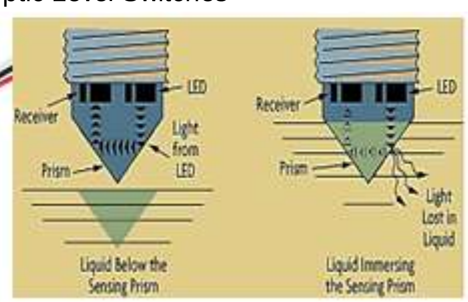
Ultrasonic Level Switches: Are devices that provide reliable high or low-level measurement in a wide variety of liquids. Installation requires mounting the sensor (threaded or flanged) to the vessel, connecting the power control wires, and there is no additional set-up or calibration required. Since it is an electronic instrument with no moving parts, preventive maintenance is limited to an annual visual inspection. A technician with basic electrical skills (wiring) can service the instrument.

Vibrating Level Switches: Are used in liquids, as well as, in granular and powdery bulk solids consisting of a rod or a fork set for vibrating. When the vibrating probe comes into contact with the medium, the vibration changes and the device outputs a switching command. Vibration rods are easy to clean and measure reliably regardless of grain size and position. The switching accuracy of vibrating level switches with tuning forks is not influenced by material deposits or buildup.

Ultrasonic Level Switches:	Vibrating Level Switches:
 	 

Buoyancy Level Switches: Are commonly used to detect reliable liquid level of relatively clean water and chemical solutions with a 15VA reed switch output, to switch pumps, valves, PLCs relays and alarms. Media examples may include boric acid and ultrapure water. The submersible polypropylene (PVDF liquid level sensor) is mounted vertically inside the tank, to actuate as a high level alarm or low level alarm.

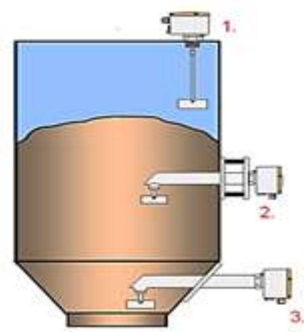
Optic Level Switches: Are instruments that work by emitting a beam of infrared light within a prism and measuring the amount of light received. When the measured fluid reaches the sensor the amount of emitted light received drops, thus triggering the contacts.

Buoyancy Level Switches	Optic Level Switches
 	 

These instruments are suitable for high, low or intermediate level detection in practically any tank, large or small and the installation is simple over the tank, bottom or side, including water, oil, CO2, etc. However, optic level switches are not recommended for use in any liquid that crystallizes or leaves a solid residue.

Capacitance Level Switches: Are instruments that use the RF (radio frequency signals), which is a technique applied to the capacitance circuit. When the material level changes, inside the contained space, the electrical capacitance between the electrodes also changes. This change is evaluated and converted into an output signal, as the rod versions cover a variety of applications, and also measure aggressive liquids, oils, or powdered and granular bulk materials. The sensor and the wall of a container (tank or vessel) form the two electrodes of a capacitor.

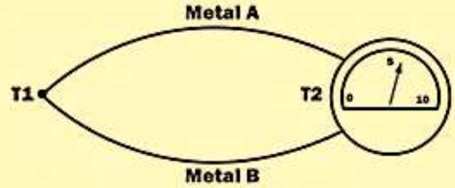
Paddle-wheel Level Switches: This type of switch uses an electric motor to slowly rotate a metal paddle inside the process vessel. If solid material rises to the level of the paddle, the material's bulk will place a mechanical load on the paddle. A torque-sensitive switch mechanically linked to the motor actuates when enough torsional effort is detected on the part of the motor. Many switches of this design have been supplied in the United States under the trade-name Bindicator (so-called because detects the level of solid material in storage bins), a more primitive variation of the "tuning fork" level switch, commonly used to detect the level of powder or granular solid materials.

Capacitance Level Switches	Paddle-wheel Level Switches
 	 

Temperature Switches: Are instruments used to measure temperature, based upon the temperature variations in an enclosed space or in an open area. In many switch designs, the temperature sensing element either rise or drop according to temperature variations, increasing or decreasing the internal pressure of liquid or gas of the temperature switches. This variation in pressure is used to actuate a switching mechanism.

Temperature can be measured via a diverse array of sensors. These sensors are induced by temperature realizing changes in physical characteristics of the switches. Six types of temperature switches are the most common; *thermocouples, resistive temperature detectors (RTDs and thermistors), bimetallic devices, liquid filled devices, infrared radiators, and change-of-state devices*.

Thermocouples: Consist of two wires composed of dissimilar metals, joined at both ends. One of the ends is heated, and there is a continuous current which flows in the thermoelectric circuit (Seebeck effect). The junctions can be exposed, grounded or ungrounded. The thermocouple is normally directly connected to a standard temperature controller. Thermocouples are among the easiest temperature sensors used in science and industry and very cost effective.



Basic thermocouple circuit with instrument

Thermocouples can measure temperatures up to 5000°F, and are used in high temperature furnaces, rocket engines and ammunitions, and must be selected to meet application conditions, such as:

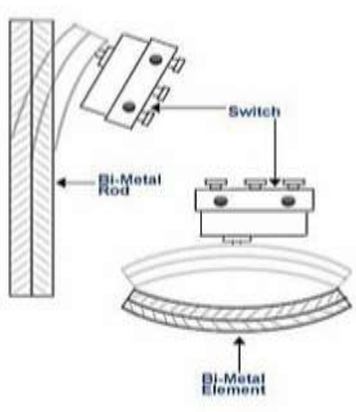
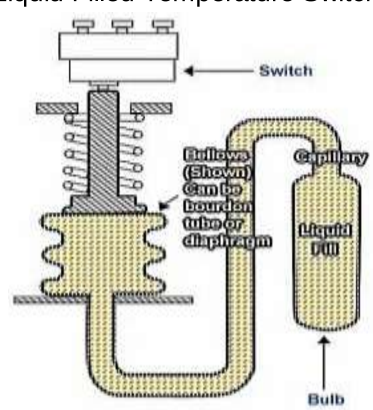
Select type J, K, M, T or other;
Response time (larger diameter reduce response time);

Resistive Temperature Detectors (RTD): Is used to measure temperature by correlating the resistance of the RTD element with temperature. The most common metal is Platinum, which is the RTD element used in a resistance thermometer, besides Nickel alloys, consisting of a wire wound or thin film element, conforming to DIN standard and with a 0.00385 temperature coefficient. The RTD is a more accurate temperature sensor and more linear than a thermocouple with a wider temperature range than a *thermistor*.

Thermistors: Are temperature sensitive resistors, constructed of semiconductor materials especially sensitive to temperature. The resistance of a thermistor decreases with increasing temperature, have small voltage outputs, but not the millivolt outputs of thermocouples. Thermistors are not used for high temperatures (up to 200 °F) and only for very limited temperature ranges, however, are more accurate than thermocouples and RTD's. The disadvantage is the loss of linearity.

Bimetallic Temperature Switches: These instruments consist of a thin rectangular strip formed by two diverse metals, bonded back to back. When the temperature increases, one metal expands faster than the other metal, resulting that the bending effect of the metal, activates another switching temperature device. Thus, the metal strip, shown below, is one of the most commonly used methods to determine temperature.

Liquid Filled Temperature Switches: Consist of a brass bulb filled with a chemical fluid (sometimes gas) including a small tube which lifts up the bulb to a pressure sensing mechanism with bellows, a bourdon tube or a diaphragm. When the temperature inside the bulb increases, it causes the liquid or gas inside the bulb to spread out. This expansion increases the pressure inside the bulb, resulting in the activation of the pressure switch connected to the bulb.

Bimetallic Temperature Switches	Liquid Filled Temperature Switches
	

Infrared Measurement Instruments: Infrared sensors are non-contacting devices, commonly used to indicate the surface temperature of workpieces, also called as laser thermometers, non-contact thermometers or temperature guns, to describe the device's ability to measure temperature from a distance. The infrared temperature sensor infers temperature by measuring the thermal radiation emitted by any type of material. With the infrared instrument, rapid temperature measurement on site is possible.

The distance-to-spot ratio (D:S) is the ratio of the distance to the object and the diameter of the temperature measurement area. For instance, if the D:S ratio is 12:1, measurement of an object 12 inches (30 cm) away, averages the temperature over a 1-inch-diameter (25 mm) area. The sensor may have an adjustable emissivity setting to measure the temperature of reflective and non-reflecti-ve surfaces. The most common infrared thermometers are the:

- **Spot Infrared Thermometer** or **Infrared Pyrometer**: Measures the temperature at a spot on a surface (actually a relatively small area determined by the D:S ratio).

- **Infrared Scanning Systems:** Scan a larger area, widely used in manufacturing involving conveyors or "web" processes, such as large sheets of glass or metal exiting an oven, fabric and paper, or continuous piles of material along a conveyor belt.

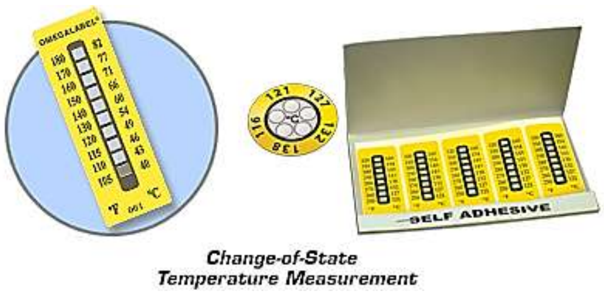
- **Infrared Thermal Imaging Cameras or Infrared Cameras:** Measure the temperature at many points over a relatively large area to generate a two-dimensional image, called as thermograms, with each pixel representing a temperature. This technology is more pro-cessor and software, than spot or scanning thermometers, used for monitoring large areas.

Spot Infrared Thermometer	Infrared Scanning	Infrared Cameras
		

Change-of-State Measurement Devices: Consist of labels, pellets, crayons, lacquers or liquid crystals whose appearance changes once a certain temperature is reached. They are used, for in-stance, with steam traps, when a trap exceeds a certain temperature, a white dot on a sensor label attached to the trap will turn black. Response time typically takes minutes, and often does not re-spond to transient temperature changes. Accuracy is lower than with other types of sensors.

Thermostats: Are instruments commonly used in the regulation of heating and cooling. One end of the bimetal strip is mechanically fixed and attached to an electrical power source, while the other end carries an electrical contact. In adjustable thermostats another contact is positioned with a regulating knob or lever. The position controls the regulated temperature, called the *set point*.

Some thermostats use a mercury switch connected to both electrical leads. The angle of the entire mechanism is adjustable to control the set point of the thermostat. Depending upon the application, a higher temperature may open a contact (as in a heater control) or it may close a contact (as in a refrigerator or air conditioner).

Change-of-State Measurement Devices	Thermostats
	

Fluid-Expansion Measurement Devices: Are common instruments typified by the household thermometer, generally come in two main classifications: the *mercury type* and the *organic-liquid type*. Versions employing gas or vapor pressure (the gas or vapor pressure changes with temperature and operates a pressure switch), are also available.

Bimetallic Thermometers: Are direct indicating dials (outdoor thermometers or meat thermometers), that use a bimetallic strip wrapped into a coil. One end of the coil is fixed to the housing of the device and the other drives an indicating needle. A bimetallic strip is also used in a recording thermometer. The Breguet's thermometer consists of a tri-metallic helix.

Fluid-Expansion Measurement Devices	Bimetallic Thermometers
	

Digital Temperature Indicators: Are instruments with digital displays, built-in easy programmable, Windows-based software, and ideal for monitoring, testing and process control applications. Complete configuration of the instrument can be quickly performed from the front panel, including designating sensor input type, sampling rate, limit settings and resolution. Process and min/max. values can also be selected for display from the front panel.

Pyrometers: Are used to measure high temperatures. The first pyrometer was invented to measure the temperature in kilns, to compare the color of clay, fired at known temperatures. Later examples used the expansion of a metal bar. Various forms of pyrometers have historically existed. In the modern usage, it is a non-contacting device that intercepts and measures thermal radiation, a process known as *pyrometry*.

Digital Temperature Indicators	Pyrometers
 	 

Platinum Resistance Thermometers (PRTs): Are instruments that offer excellent accuracy over a wide temperature range from 200 to 850°C (~390 to 1560ºF). The principle of operation is to measure the resistance of a platinum element. The most common type is the very well-known PT100, with a resistance of 100 ohms at 0°C (32ºF) and 138.4 ohms at 100°C (212ºF). There are also PT1000 sensors that have a resistance of 1000 ohms at 0°C. Unlike thermocouples, it is not necessary to use special cables to connect to the sensor.

Limitations: RTDs in industrial applications are rarely used above 660°C (1100ºF), as at temperatures above 660°C it becomes increasingly difficult to prevent the platinum from becoming contaminated by impurities from the metal sheath of the thermometer. This is why laboratory standard thermometers replace the metal sheath with a glass construction.

Industrial PRTs: Are designed to withstand industrial environments. They can be almost as durable as a thermocouple. Depending on the application industrial PRTs can use thin film elements or coil wound elements. The internal lead wires can range from PTFE insulated stranded nickel plated copper to silver wire, depending on the sensor size and application. Sheath material is typically stainless steel; higher temperature applications may demand Inconel.

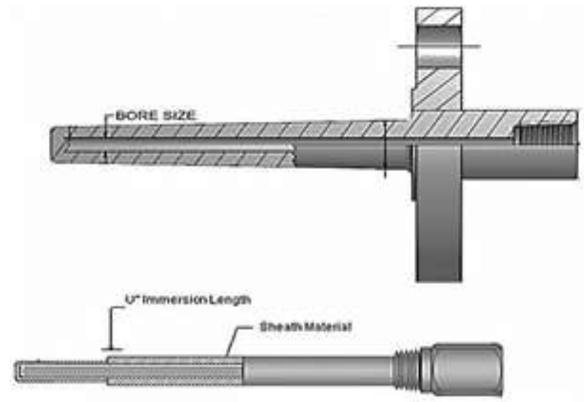
Thermowells: Consist of a tube closed at one end and mounted in the process stream using a temperature sensor such as a thermometer, thermocouple or resistance temperature detector (RTD) inserted in the open end of the tube. Commonly, are tubular fittings used to protect temperature sensors installed in industrial processes, usually in open air outside the process piping or vessels with a thermal insulation.

The process fluid transfers heat to the thermowell wall, which in turn transfer heat to the sensor. If the sensor fails, it can be easily replaced without draining the vessel or piping. To be representative of the average temperature of fluid, the thermowell must extend a few per cent of the inside diameter of the process pipe or vessel.

In many applications the transverse component of the fluid forces resulting from vortex shedding tends to govern the onset of flow-induced resonance, with a forcing frequency equal to the vortex shedding rate. A thermowell is typically mounted into the process stream by way of a threaded, welded, sanitary cap or flanged process connection.

PRT – PT 100 sensor

Thermowells



Flow Switches: Are mechanical devices that can be switched *on* or *off*, in response to flow (or lack of flow) of a liquid or a gas, and widely used in domestic air conditioning, heating, hot-water systems, chilled water cooling circuits, or to provide alerts when the flow rate exceeds or falls below a certain level. Flow switches typically send a trip signal to another device, such as to connect or disconnect a pump, or any other attached instrument.

Sail switches, *vane switches* or *flow switches* are also mechanical switches that are switched *on* or *off* in response to the flow or non-flow of a fluid such as air or water and typically operates through the use of paddles which gets displaced due to the force of moving fluid. Sail switches also find application in the measurement of fan speeds; protect an electric heating element from being energized before the air flow from the blower is established or to be used to alarm if a ventilation fan in a hazardous location fails and air flow has stopped.

Flow Meters: Measure the rate at which a liquid moves through a structure (liquid flow rate). There are two flow rates that can be measured by a liquid flow meter: *volumetric or mass flow rate*. Volumetric flow rate is measured in *cubic meters per second*. Mass flow rate is measured in *kilograms per second*. Mass flow rate is sometimes measured by directing a fluid through a pair of tubes.

Flow Switches

Flow Meters

The most common types of flow meters, as defined before, are *differential pressure flow meters*, *positive displacement flow meters*, *velocity flow meters*, *mass flow meters and open channel flow meters*. Each type has several different versions that operate under the same concept. *Orifice* *plates, venturi tubes and flow tubes* are all examples of *differential pressure flow meters*. *Reciprocating pistons and rotary vanes* are both examples of *positive displacement flow meters*. *Turbines and Doppler meters* are both common types of *velocity flow meters*. *Coriolis and thermal* are both mass flow meters.

Velocimeters: Flow meters are also called velocimeters when are used to measure the velocity of fluids flowing through them. The *laser-based interferometry* is often used for air flow measurement. The Doppler-based methods are used for flow measurement. *Hall effect sensors* may also be used, on a flapper valve, or vane, to sense the position of the vane, as displaced by fluid flow.

Ultrasonic Flow Meters: Consist of a pair of transmitters fitted to the termination points on a tube. A short burst of sound travels through the tube, and is measured by the flow meter as it passes through the liquid in the tube. Using a transmitter-receiver method is useful for testing the way a fluid flows through another medium, such as a metal or plastic pipe. Generally, *ultrasonic flow meters* test the velocity in a liquid (particularly useful in *waste water management*, where testing for particles and solids in water is a matter of public health).

Velocimeters	Ultrasonic Flow Meters
	

Flow Sensors: Are devices for sensing the rate of fluid flow. Typically a flow sensor is the sensing element used in a flow meter, or flow logger, to record the flow of fluids. Absolute accuracy of a measurement requires functionality for calibration of all sensors. There are various kinds of flow sensors, including some that have a *vane pushed by the fluid to drive a rotary potentiometer*, or similar devices. Other flow sensors are based on sensors which measure the transfer of heat caused by the moving medium. This principle is common for micro-sensors to measure flow.

Gas Flow Meters: Are used to measure the flow of the moving gas. There are several analyzers and sensors used to detect the quantity of gas flowing in the given area under specific conditions. It is used to measure the temperature, pressure and velocity of the gas. This is usually done with a help of flow sensors which also include detectors, switches, meters and flow controllers.

At times, the measurement of gas flow becomes so vital that a wrong assessment may lead to disaster. There are several types of gas flow meters available, such as rotary meters, turbine meters, orifice meters, ultrasonic meters and diaphragm meters. Another popular use of gas flow meters is in welding machines, where the meter is enclosed in plastic or glass cylinder.

Propane is mostly used for this purpose and it is very essential to measure the amount of gas that runs through the gas pipe into the house. The gas flow meter is put on these gas pipes to measure the temperature as well as the quantity of the gas flowing through the pipes. These meters also help the gas companies to ascertain the quantity of gas being consumed.

Flow Sensors	Gas Flow Meters
	

Load Cells: Are used in several types of measuring instruments, commonly used as weight-based level instruments to directly measuring the weight of a vessel or a support structure, through transducers used to convert a force into an electrical signal. This conversion is in two stages. Through a mechanical arrangement, the force being sensed deforms a strain gauge. The strain gauges measure the deformation (strain) as an electrical signal, changing the electrical resistance of the wire.

A load cell usually consists of four strain gauges called Wheatstone bridge configuration, with one strain gauge (quarter bridge), or two strain gauges (half bridge), are available. The electrical signal output is typically in the order of a few millivolts and requires amplification by an instrumentation amplifier before it can be used. The various types of load cells are; Hydraulic load cells, Pneumatic load cells and Strain-gauge load cells. *Hydraulic load cells, Pneumatic load cells and Strain-gauge load cells, Piezoelectric Load Cells, Vibrating Wire Load Cells, S-beam Load Cells, Capacitive Load Cells and Button Load Cells*.

Hydraulic Load Cells: Are devices that use conventional piston and cylinder arrangement, placed in a thin elastic diaphragm, and the load cell is completely filled with oil. When a load is applied on the piston, the movement of the piston and the diaphragm arrangement result in an increase of oil pressure which in turn produces a change in the pressure on a Bourdon tube connected with the load cells. Typical hydraulic load cell applications include tanks, bins and hoppers weighing.

Pneumatic Load Cells: Use air pressure applied to one end of the diaphragm and automatically regulates the balancing pressure, when air escapes through the nozzle placed at the bottom of the load cell. A pressure gauge is attached to measure the pressure inside the cell. The deflection of the diaphragm affects the airflow through the nozzle, as well as, the pressure inside the chamber.

Strain-gauge Load Cells: Work with the principle that the strain gauge (a planar resistor) deforms/stretches/contracts when the material of the load cells deforms appropriately. These values are extremely small and are relational to the stress and/or strain that the material load cell is undergoing at the time. The change in resistance of the strain gauge provides an electrical value change that is calibrated to the load placed on the load cell.

Hydraulic Load Cell:	Pneumatic Load Cell:	Strain-gage Load Cell:
		

Piezoelectric Load Cells: These electronic instruments are used to measure strain and forces inside machine parts. The sensor is installed into the industry-standard 8-mm bore which runs perpendicular to the direction of the force to be measured. The sensor can be fitted in a recessed way in deeper bores.

Vibrating Wire Load Cells: These types of load instruments are ideally suited for measuring loads in rock bolts, cable anchors and tendons, structural beams, piles, loads between tunnel supports and loads in pull-out tests on trial anchors. Consist of a high strength steel alloy cylindrical housing with three to six vibrating wire gauges for measuring the compression of the cylinder under load. The readings are averaged minimizing the effects of eccentric or uneven loadings.

S-beam Load Cells: These load cells use the shear principles to amplify the effects of the load on strain gauges within the load cell and can be used in tension or compression. Typical uses are in test machines, platforms, conveyors, overhead track scales and for general in-line load measurement applications.

Capacitive Load Cells*:* Is based on a capacitive measurement principle where a non-contacting ceramic sensor is mounted inside the load cell body and can tolerate shocks, torsion, and very high overloads and side loads. The capacitance changes, as the signal from the non-contacting sensor is directly converted when the load presses two plates close together.

Button Load Cells: Are small sensors that measure compression loads, used in applications that require a thin form factor. The bottom of the load cell is bolted, and force applied to the button on the top. By loading only the button, which is slightly rounded, the load cell is less sensitive to errors, resulting the load may not be pushing down exactly straight on the load cell.

Piezoelectric Load Cells	Vibrating Wire Load Cells	S-beam Load Cells	Capacitive Load Cells
			

5. CONDUCTIVITY & ANALYTICAL INSTRUMENTATION:

Conductivity: Is the measure of the ease at which an electric charge or heat can pass through a material. Electrical conductivity is when a material will easily allow electricity to travel through it. A conductor is a material that gives very little resistance to the flow of an electric current or thermal energy. Materials are classified as metals, semiconductors, and insulators. Metals are the most conductive in nature, and insulators (ceramics, wood, plastics) the least conductive.

Thermal Conductivity: Is the measure of the ease at which thermal energy (heat for most purposes) can move through a material. Some materials like metals allow heat to travel through them quite quickly. For example, metal has a higher heat transferability, or thermal conductivity than wood. Ceramics, and polymers are usually good insulators, however, polymers usually have a very low melting temperature.

Conductivity in Water: Is the measurement of the electrical conductivity of water, when is passed an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge).

Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore, have a low conductivity when in water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25 degrees Celsius (25 C).

Conductivity in Metals: Is the measurement of the electrical conductivity of a metal object, when is passed an electrical current. When a voltage is applied across two points of a liquid solution, *negative ions* will drift toward the *positive pole (anode)* and *positive ions* will drift toward the *negative pole (cathode)*. Negative ions are sometimes called *anions* (attracted to the anode), while positive ions are sometimes called *cations* (attracted to the cathode).

Conductivity in Gases: Is much the same, *ions* are the charge carriers. However, with gases at room temperature, ionic activity is virtually nonexistent. A gas must be superheated into a plasma state before substantial ions exist which can support an electric current. However, the thermal conductivity of a gas is a specific physical quantity. Then, when a gas mixture is composed of two components, the concentration of each of the components through its property can be known.

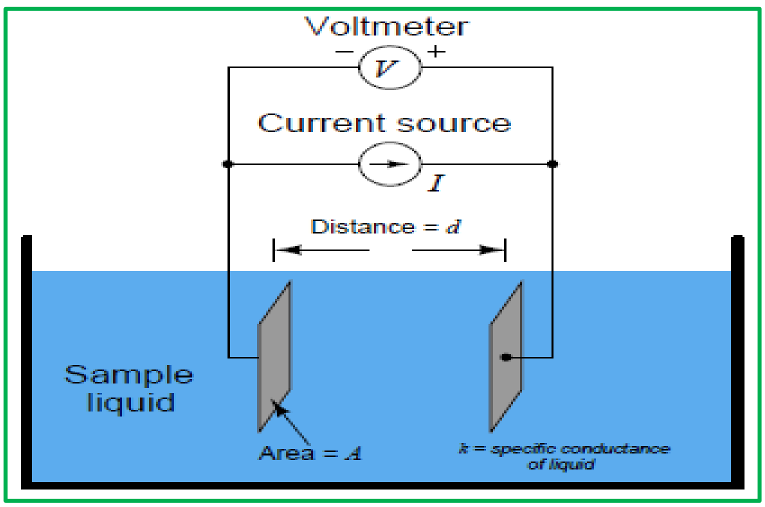
Conductivity Measurement: Is generally measured with a probe and a meter. Voltage is applied between two electrodes in a probe immersed in a sample water. The drop in voltage caused by the resistance of the water is used to calculate the conductivity.

The meter converts the probe measurement to *micromhos per centimeter (µmhos/cm)* or *microsiemens per centimeter (µs/cm)* and displays the result for the user. Distilled water has conductivity in the range of 0.5 to 3 µmhos/cm. Conductivity of rivers in the United States generally ranges from 50 to 1500 µmhos/cm.

Electrolyte: Is any substance that enhances electrical conductivity when dissolved in water. This enhancement of conductivity occurs due to the molecules of the *electrolyte* separate into *positive and negative ions*, and serve as electrical charge carriers. If the electrolyte is an *ionically-bonded compound,* (example, table salt), the ions forming that compound naturally separate in solution, and this separation is called *dissociation*.

If the electrolyte is a *covalently-bonded compound*, (example hydrogen chloride), the separation of those molecules into *positive and negative ions is called ionization*. Both *dissociation and ionization* refer to the separation of formerly joined atoms upon entering a solution. The difference between these terms is the type of substance that splits: "*dissociation*" refers to the division of ionic compounds (table salt), while "*ionization*" refers to covalent-bonded (molecular) compounds such as HCl which are not ionic in their pure state.

The most primitive form of conductivity sensor (or a conductivity cell) consists of two metal electrodes inserted in the solution, connected to a circuit designed to measure conductance, the reciprocal of resistance. Two-electrode conductivity cells are not very practical in real applications, because mineral and metal ions attracted to the electrodes tend to "foul" the electrodes over time forming solid, insulating barriers on the electrodes.



pH Measurement: Is the measurement of the *hydrogen ion* activity in a liquid solution. The pH is also a significant factor in the corrosion of metal pipes and vessels carrying aqueous (water-based) solutions. Food processing, water treatment, pharmaceutical production, steam generation (thermal power plants), and alcohol manufacturing are just some of the industries making extensive use of pH measurement (and control).

The measurement of pH can be divided broadly into two methods: *Method of electro-electronic measurement and measurement method for color comparison*. The industrial area, employs the method of *electrical measurement* due to its ease of handling and ease in instrumentation.

- ✓ **Electronic Meter:** Is a device used for measuring the pH (acidity or alkalinity) of a liquid (though special probes, used to measure the pH of semi-solid substances) and consists of a special measuring probe (glass electrode) connected to an electronic meter that measures and displays the pH reading. The probe is a rod type usually made up of glass. At the bottom of the probe there is a bulb that also contains a sensor. The probe is dipped to measure the pH of a solution.

- ✓ **Glass Electrode Measuring Probe**: The glass electrode probe contains a liquid inside that is standard solution with a pH equal to 7 and the liquid medium uses potassium chloride (KCL) for the differential electrode. The KCL is used because it presents the smallest difference of electrical potential between the liquids measured.

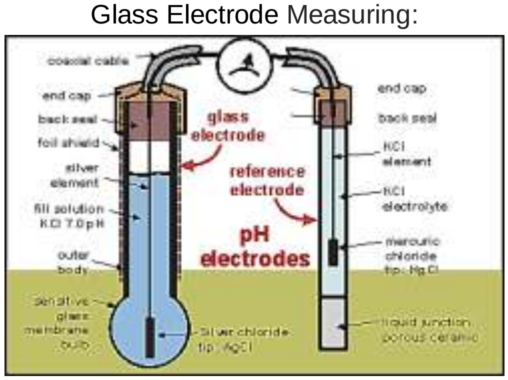
- ✓ **Colorimetric Measurement**: One of the simplest ways to measure the pH of a solution is by color. Some chemical compounds dissolved in an aqueous solution, change their colors if the pH value of that solution falls within a certain range. The colorimetric method employs the use of complex orga- nic dyes which change to distinctive colors through a specific pH range. These dyes are known as indicators; with a pH range from 4.0 to 8.4 can be reached. The main dyes are:

pH test range, indicator dyes and their color change range

	Indicator	From pH	To pH
	Optimum pH range for hydroponics	5.6	6.2
A	Brom-thymol blue	6.0	7.6
B	Brom-cresol green	4.0	5.6
C	Chlorophenol red	5.2	6.8
D	Phenol red	6.8	8.4

pH Meters: Range from simple and inexpensive pen-like devices to complex and expensive laboratory instruments with computer interfaces and several inputs for indicator and temperature measurements. There are also holographic pH sensors, which allow the measurement pH colorimetrically.

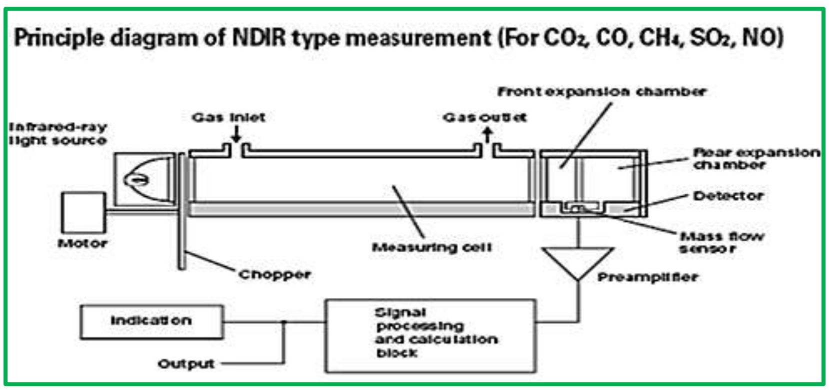
pH - Colorimetric and Electrometric: As a general rule, *electrometric methods* are more precise than *colorimetric methods*, simply because it is easier to measure a change in voltage, current, and/or electrical resistance than it is to see some color vs. a reference. A pH meter using a glass electrode is not the "best" method. Electrical conductivity is better because electrical conductivity can be measured with higher accuracy.

pH – Electronic Digital Meter:	Glass Electrode Measuring:	pH –Pen-like Devices:
		

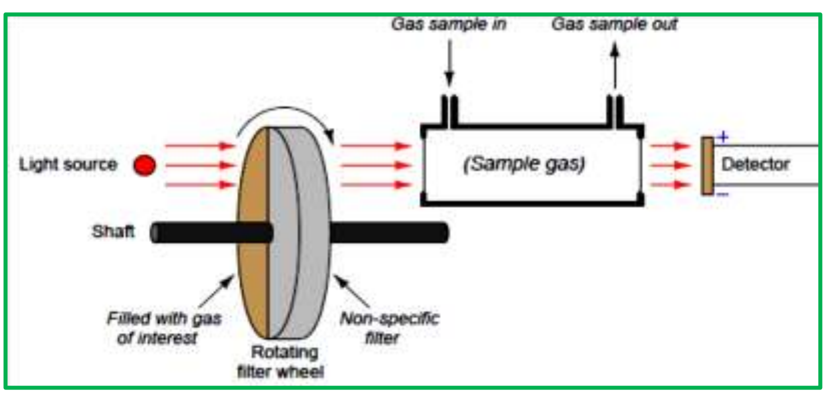
Non-Dispersive Analysis: Industrial non-dispersive analyzers typically use either infrared or ultra-violet light sources, because most substances of interest absorb wavelengths in those regions rather than in the visible light spectrum. Non-dispersive analyzers employ the principle of spectrographic absorption to measure how much of a particular substance exists within a sample.

Gas analysis is the more common application of non-dispersive spectroscopy in industry, as opposed to liquid analysis. Non-dispersive spectroscopy using infrared light is usually abbreviated NDIR, while non-dispersive spectroscopy using ultraviolet light is abbreviated NDUV and non-dispersive spectroscopy using visible light is abbreviated NDVIS. Historically, NDIR is more prevalent of these three technologies.

Single-beam Analyzer: Is the simplest style of non-dispersive analyzer that uses a single light source, shining continuously through a single gas cell, and eventually falling on a small thermopile (converting the received infrared light into heat, and then into a voltage signal). An example would be the measurement of carbon dioxide (CO2) concentration in the exhaust gas of a combustion furnace; however, most of the gases exiting the furnace do not absorb infrared light as Nitrogen. Carbon monoxide (CO), water vapor (H2O), and sulfur dioxide (SO2) absorb infrared light, and are all normally present in the exhaust gas of a furnace.



Gas Filter Correlation (GFC): Is called positive filtering in the field of spectroscopy using filter cells to eliminate wavelengths associated with interfering gases where the analyzer filters out all wavelengths associated with all interfering species. The gas filter analyzers use a single gas cell rather than dual cells (sample and reference), through which a light beam of alternating spectrum is passed. A rotating filter wheel creates this alternating spectrum, as seen below:



Safety Gas Analyzers: Measure the concentration of specific substances for the purpose of measuring and/or controlling those concentrations in a process stream. Safety analyzers detect the presence of dangerous concentrations of specific substances to personnel threats to life or health. There are no ends to the different types of process analyzers to meet the needs of process industries, but applications, sometimes, rather restricted to those substances known to human health hazards.

There are analysers that measure a wide range of gases, wall mounted or highly portable to be suitable for an extensive range of geoscience applications. Fast response high-precision analyzers are widely used to measure gas emissions and ecosystem fluxes using eddy covariance methods (atmospheric measurement technique to measure and calculate air turbulent fluxes, when used together with sonic anemometers.

Safety gas analyzers are made for many applications, such as, motor vehicles, utilities, energy, environmental, research, and petroleum industries. Environmental and gas analyzers include *diode laser analyzers, oxygen analyzers, infrared gas analyzers, stack gas analyzers, dust monitors, process gas chromatographs, gas density analyzers, clean room gas monitors* to bulk analyzers that measure over 270 different gases; several can operate in hazardous environments. The most used industrial gas analyzers are:

Katharometers: Are thermal conductivity analyzers (TCD) for measuring levels of some gas in a binary or pseudo-binary mixture, commonly used in gas chromatography. For example, air is composed of many gases; therefore hydrogen is a pseudo-binary mixture, measured with a katharometer. Hydrogen, helium, dissociated ammonia, sulphur hexafluoride and noble gases, such as, krypton and xenon are all well suited to this technique.

Infrared Gas Analyzers: Measure gas traces by determining the absorption of an emitted infrared light source. Modern analyzers use the Non-dispersive Infrared Technology (NDIR) to detect a certain gas by detecting the absorption of infrared wavelengths, characteristic of that gas. By optically filtering the energy, the radiation spectrum is limited according to the absorption band of the gas being measured.

Stack Gas Analyzers: Consist also of a Non-dispersive Infrared (NDIR) gas analyzer using a highly sensitive and stable double beam system and a zirconia or paramagnetic oxygen analyzer to simultaneously measure up to 5 components, NOx, SO_2, CO_2, CO and O_2, commonly used for measuring and monitoring emissions from various boilers and waste incinerators.

Katharometers	Infrared Gas Analyzers	Stack Gas Analyzers
		

Upper/Lower Explosive Sensors: Measure the maximum or minimum concentration of flammable gases in air capable of igniting. These sensors are specially designed to detect the dangerous presence of combustible gases, also called "UEL or LEL sensors". Gases and vapors are not the only substances with potential to explode in sufficient concentrations. Certain dusts (such as grain) and fibers (such as cotton) may also present explosion hazards, when in sufficient quantity. However, the majority of analytical technologies only function with gases and vapors (Class I), not dusts or fibers (Class II and Class III, respectively).

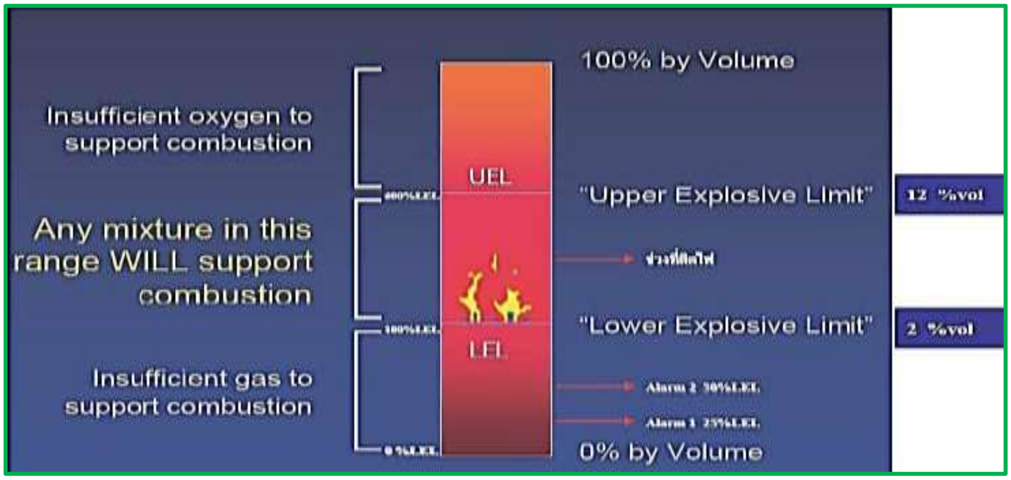
Catalytic Bead Combustible Detector

Gas Alarms and Detectors

Hydrogen Sulfide (H2S): Is a highly toxic gas that has a pungent "rotten eggs" odor at low concentrations, but no visible color. Seems odorless, and at higher concentrations, this gas acts as a nerve agent to de-sensitize human smell, so that it causes a paralytic effect, extending to the more important bodily functions such as breathing, and rapid loss of consciousness and asphyxiation. The below photograph of a safety chart shows just how toxic hydrogen sulfide gas is:

Note: Note how concentrations in the parts per million are hazardous, and how little H2S concentration is required to paralyze one's sense of smell. Hydrogen sulfide also happens to be flammable, its LEL value in air being 4.3%. However, the toxic properties of H2S are more concerning when released into the atmosphere.

Carbon Monoxide (CO): Is a colorless, odorless, and toxic gas principally generated by the incomplete combustion of carbon-based fuels. At significant concentrations of carbon monoxide gas in air, the hemoglobin in your blood latches on to CO molecules instead of oxygen (O2) molecules, and remains bound to the hemoglobin, preventing it from transporting oxygen. The result is that your blood rapidly loses its oxygen-carrying capacity, and your body asphyxiates from within.



Like hydrogen sulfide, carbon monoxide is also flammable (LEL = 4%), but its toxic properties are generally the larger concern when released into the atmosphere. Carbon monoxide is not to be confused with carbon dioxide (CO2) gas, which is almost completely inert to the human body. Carbon dioxide is principally produced by complete combustion of carbon based fuels. Its only safety hazard potential is the capacity to displace breathable air in an enclosed area if rapidly released in large volumes.

Chlorine (Cl2): Is a strong-odored, toxic gas used as a biological disinfectant, bleaching agent, and as an oxidizer in many industrial processes. Colorless in low concentrations, it may appear green in color when mixed in very high concentrations with air. Water and wastewater treatment operations frequently use chlorine for disinfection of water. Pulp mills use either chlorine or chlorine compounds as a bleaching agent to whiten the wood pulp process.

Chlorine is highly reactive, presenting a distinct hazard to mucous membranes (eyes, nose, throat, lungs) by creating hypochlorous acid (HOCl) and hydrochloric acid (HCl) upon contact with water: Cl2 + H2O → HOCl + HCl. The following table correlates levels of chlorine gas concentration with degree of hazard. The unit of measurement for chlorine concentration in air – parts per million (ppm) equivalent to just 0.0001 percent:

Concentration in air	Hazard
1 ppm to 3 ppm	Mild mucous membrane irritation
5 ppm to 15 ppm	Upper respiratory tract irritation
30 ppm	Immediate chest pain, cough, and difficulty breathing
40 ppm to 60 ppm	Toxic pneumonitis and pulmonary edema
430 ppm	Lethal over 30 minutes
1000 ppm (0.1%)	Lethal within a few minutes

6. CONTROL VALVES & INSTRUMENTATION:

Control Valves: Regulate the rate of fluid flow as the position of the valve plug or disk is changed by force from *actuators* or signals of *positioners,* commonly used to control conditions such as flow, pressure, temperature, and liquid level by fully or partially opening or closing. Automatic control valves actuate in response to signals received from controllers that compare a "setpoint" to a "process variable", whose values are provided by sensors that monitor the condition changes.

- **Actuators**: The opening or closing of control valves is usually done automatically by electric, hydraulic or pneumatic actuators.
- **Positioners**: Are devices used to control the opening or closing of actuators based on either electric or pneumatic control signals.

These control signals, are traditionally based on 3 – 15 psi (0.2 - 1.0 bar), or the well-known electro-electronic 4 - 20 mA signals for industry, 0 - 10V for HVAC systems and the introduction of *smart systems,* or either *analogic or digital protocols*, such as, HART, Fieldbus Foundation and Profibus, the most common protocols. The following summary describes some special control valve styles:

Relief and Safety Valves: These types of valves have the main function to prevent process equipment damage by relieving excess pressure in a fluid system. The main difference between a *relief valve* and a *safety valve* is the extent of opening at the setpoint pressure, as described below:

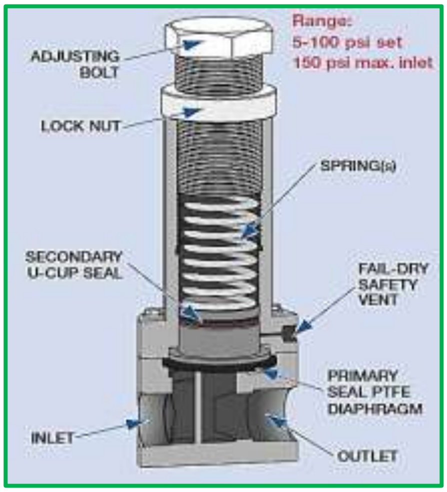
- ✓ **Relief Valves**: *Open gradually*, when the *inlet pressure* increases above the defined process setpoint, and open only the necessary to relieve the over-pressure condition. Relief Valves are typically used for *incompressible fluids such as water or oil*.

- ✓ **Safety Valves**: *Open immediately*, when the defined pressure setpoint is reached, and stay fully open until the process pressure drops below a reset point. The reset pressure, normally, is lower than the actuating pressure setpoint. Safety Valves are typically used for *compressible fluids such as steam or other gases*.

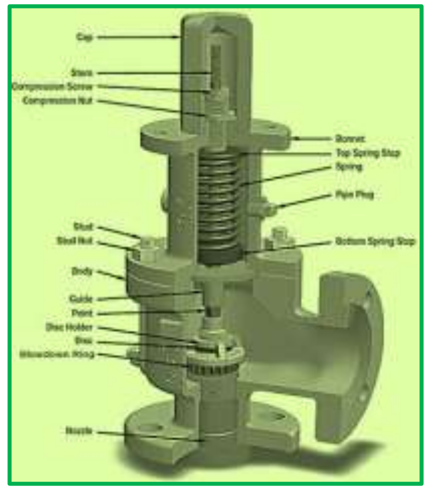
The difference between the *actuating pressure setpoint* and the *pressure of resetting* is called blow-down, expressed as a percentage of the *actuating pressure setpoint*. The defined *pressure setpoint* is adjusted by turning the adjusting nuts on top of the valve yoke to increase or decrease the spring compression in both Relief and Safety valves, as can be seen in the pictures below:

Pilot-Operated Valves: Are designed to keep the pressure in balance, through a small passage at the top of a piston connected to the stem, and are typically *solenoid-operated valves*, with the energizing signal originating from pressure measuring systems. When the small valve pilot opens, the pressure is relieved, keeping the balance of the system.

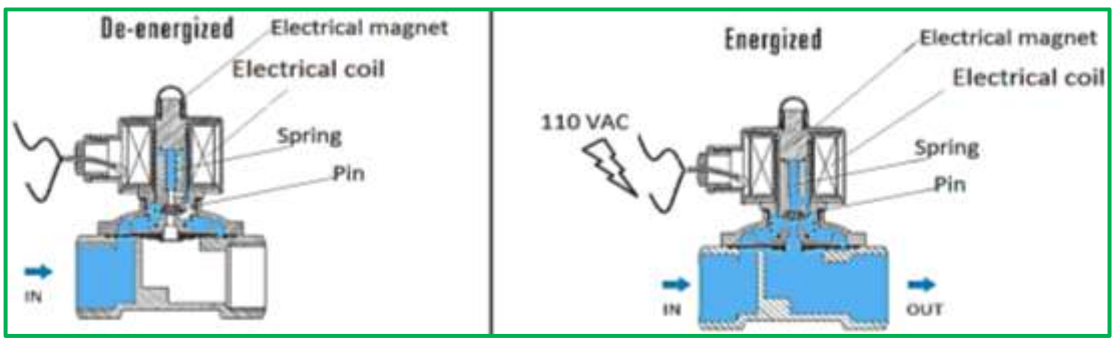
Note: Safety valves can often be *distinguished* by the presence of an *external lever* at the top of the valve body, which is used as an operational check. Both Safety and Relief Valve open by spring compression, when the system pressure overcomes the spring characteristics.



Relief Valves


Safety Valves

Solenoid Valves: The solenoid is an integrated device, which actuates either a pneumatic or a hydraulic valve. The solenoid is an electromechanical coil wound into a tightly packed helix, a specific type of relay that operates as an electrical switch. The term solenoid refers specifically to a magnet designed to produce a uniform electric field in a volume of space. The term solenoid may also refer to a variety of transducer devices that convert energy into linear motion.



Solenoid Valves Parts: Are the most frequent devices used for control in fluid flow, to shut off, release, dose, distribute or mix fluids. The solenoid valve has *two main parts*: the solenoid and the valve. The solenoid converts *electrical energy* into *mechanical energy* which, in turn, opens or closes the valve mechanically. In the case of a *two-port valve* the flow is switched *on* or *off*; the *three-port valve*, the outflow is switched between the two outlet ports. *Multiple solenoid valves* can be placed together on a manifold.

Rotary Solenoid Valves: The rotary solenoid is a round design electromechanical device, used to rotate a ratcheting mechanism when power is applied, suited in industrial applications to convert linear force into rotary motion, or rotary snap-switch automation in electromechanical controls, which range is commonly 25/35/50/60/75 & 100mm diameter. The solenoid coils are 3.5 VDC to 462 VDC.

Pneumatic Solenoid Valves: A pneumatic solenoid valve is a switch for routing air to any pneumatic device, usually an actuator up to 120 psi, and is an efficient method of converting electrical signals into pneumatic functions. Pneumatic solenoids valves are also referred to as: 3/2 valves, or 3-way pneumatic valves. The single solenoid models are a 2-position normally closed, spring return operation, and the double solenoid models is a 2-po-sition open/closed operation, 24 VDC or 120 VAC solenoid coils.

Hydraulic Solenoid Valves: Hydraulic solenoid valves are similar to pneumatic solenoid valves, except that the flow is a hydraulic fluid often at around 3000 psi. The hydraulic valve properly directs the flow of a liquid medium, usually oil, through a hydraulic system. The hydraulic solenoid valves are heavier than pneumatic, and generally have metal-to-metal seating surfaces, subdivided into three main categories: directional control valves, pressure control valves, flow control valves, and the servo control hydraulic valves as a separate category.

Rotary Solenoid Valves	Rotary Solenoid Valves	Hydraulic Solenoid Valves
		

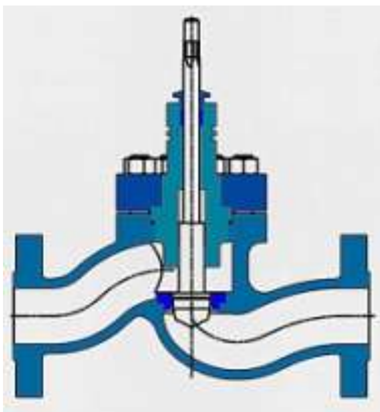
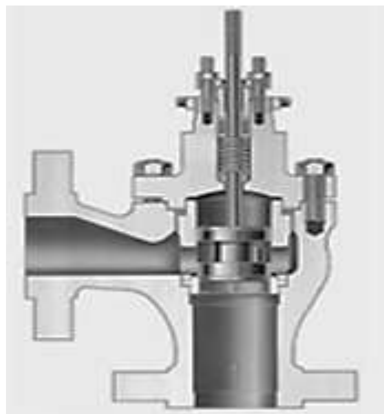
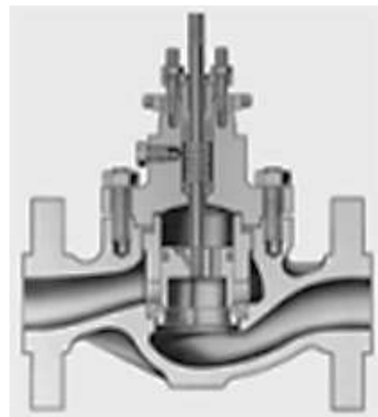
Solenoid Valves Types: The 2-way valve, for example, has 2 ports; when the valve is **open**, the two ports are connected and fluid may flow between the ports; when the valve is **closed**, the ports are isolated. When the valve is open, the solenoid is not energized, then the valve is termed **normally open** (N.O.). However, when the valve is closed, the solenoid is not energized, then the valve is termed **normally closed** (N.C)**.**

Solenoid Valves Application: Solenoid valves are used in fluid power pneumatic and hydraulic systems, to control cylinders, fluid power motors or larger industrial valves, irrigation sprinkler systems, domestic washing or dishwasher machines, dentist chairs to control air and water flow, compressed air or CO_2, water purifiers (RO systems), etc.

Single-Ported Globe Valves: Is a type of valve used for regulating flow in a pipeline, consisting of a movable disk-type element and a stationary ring seat in a spherical body and is the most common valve body style, available in various forms, such as*, angle, bar stock, forged, and split constructions* and can handle most service requirements, commonly used in 4-inch to 8-inch sizes with high-thrust actuators, specified for applications with stringent shut-off requirements.

Single-Ported Angle Valves: Are also always single-ported, commonly used in boiler feedwaters, heater drain services and piping schemes, where these types can also serve as elbows. The valve shown, has a cage-style construction or may have screwed-in seat rings, expanded outlet connections, restricted trim, and outlet liners for reduction of erosion damage.

Balanced-Plug Cage-Style Valves: Provide the advantages of a balanced valve plug often associated only with double-ported valve bodies. The cage-style trim provides the valve plug guiding, seat ring retention, sliding piston ring-type seal between the upper parts of the valve. The wall of the cage cylinder type can virtually eliminate the vortex of an upstream high pressure fluid to a lower pressure downstream system.

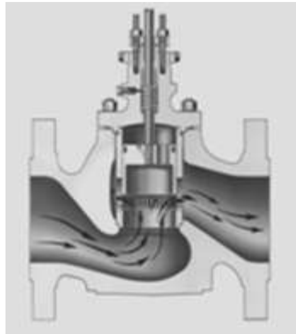
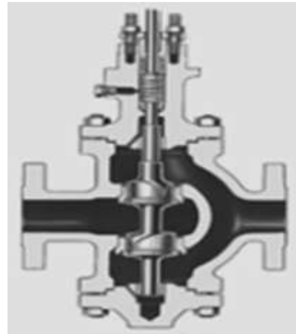
Single-Ported Globe Valves	Single-Ported Angle Valves	Balanced-Plug Cage-Style Valves
		

High Capacity Control Valves: Generally, globe-style valves larger than 12-inch, ball valves over 24-inch, and high performance butterfly valves larger than 48-inch fall in special category. Normally maximum allowable *pressure drop is reduced on large valves* to keep design and actuator requirements within reasonable limits, as well, lowered working pressure ratings.

High Capacity Cage-Suppress Noise Valves: Designed to *suppress noise applications*, such as, high *pressure gas reducing station,* where sonic gas velocities are often hazardous at the outlet of conventional valves. The design incorporates oversize end connections with a streamlined flow path and the ease of maintenance, inherent with cage-style constructions. Use of noise abatement reduces overall noise levels, as much as, 35 decibels.

Double-Ported Globe Valves: Are often used for *on-off* or *low-pressure throttling service*. Top-and-bottom-guided valve plugs furnish stable operation for severe service conditions. Reduced dynamic forces acting on plug, permit choosing a smaller actuator than would be necessary for a single-ported valve body with similar capacity.

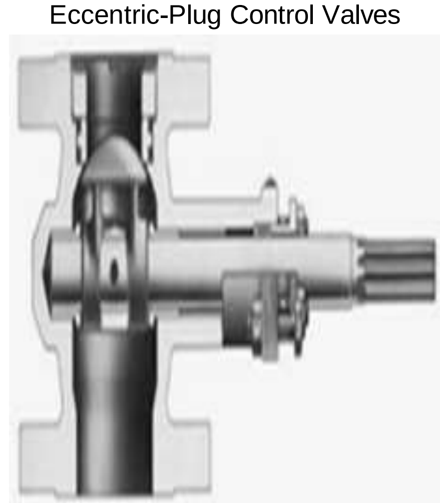
Balanced Plug Three-Way Valves: Manufactured with cylindrical valve plugs in the down position to open the bottom common port to the *right-hand port* and shuts off the *left-hand port*. The application is *for use with three pipeline connections* providing general converging (flow-mixing) or diverging (flow-splitting) service. Actuator selection demands careful consideration, particularly for constructions with unbalanced valve plug.

High Capacity Control Valves	**High Capacity Cage-Suppress Noise Valves**	**Double-Ported Globe Valves**	**Balanced Plug Three-Way Valves**
			

High-Performance Butterfly Valves: Require high-output or large actuators when the pressure drop is high, so, operating torques may be quite large, used *for throttling service* or for *on-off* control. Streamlined disks suit applications with 90-degree disk rotation, with standard raised-face pipeline flanges, provide high capacity with *low pressure loss* and offer economy, particularly in larger sizes.

Eccentric-Disk Control Valves: Are intended for *general service applications* not requiring precision *throttling control*, for applications requiring *large sizes and high temperatures*, using standard pneumatic diaphragm or piston rotary actuators. Commonly offer effective throttling control and provide linear flow characteristic through 90° of disk rotation. The eccentric mounting of disk pulls it away from seal after it begins to open, minimizing seal wear.

Eccentric-Plug Control Valves: Are suited for erosive, coking and other hard-to-handle fluids, providing either *throttling or on-off operation* for service in *slurry applications*. Mining and petroleum refining, power pulp and paper industries use these valves, and can handle temperatures up to 800 °F (427 °C) and shut-off at 1500 psi (103 bar). Seat ring and rugged plug allow *forward or reverse flow* with tight shutoff in either direction, including ceramics, for selection of erosion resistance.

High-Performance Butterfly Valves	Eccentric-Disk Control Valves	Eccentric-Plug Control Valves
		

Valves for Slurry and Mining Applications: Use valves also commonly manufactured by a large variety of materials and types since common carbon steel through super alloys, sizes 1/2" through

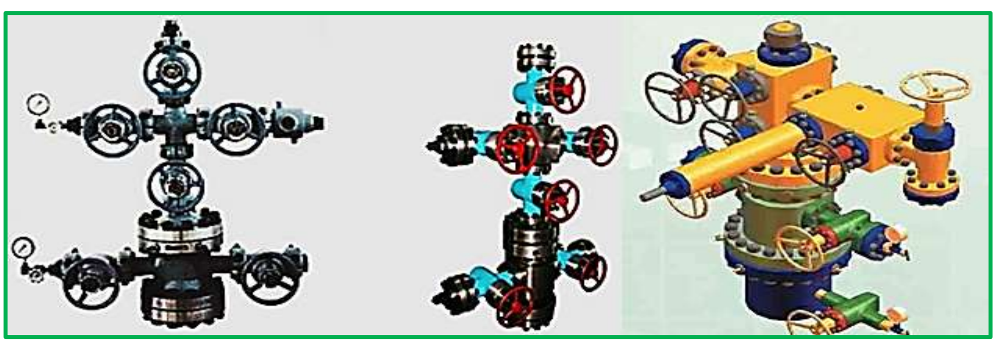
60”. The corrosive and abrasive matters managed during mining processes quickly wear pipelines and valve arrangements, requiring frequent repairs. Advanced technologies include automated Knife Gate Valves, Butterfly Valves and Slurry Isolation Valves that help automate processes, including Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA), to estimate future wear of a mining application product.

Valves for Power, Fuel and Steam Generating Plants: Use valves commonly manufactured in carbon steel to low alloy, sizes 2" to 16", for high temperature and high pressure operations and extreme quality assurance requirements, as total traceability of materials and manufacturing processes. ASME “N Stamp” required for nuclear valves, Stainless steels and Cobalt-based hard-facings are usually used.

Valves for Oil, Gas and Refining: Use valves commonly manufactured by a large variety of materials and types since common carbon steel through super alloys, sizes 1/2” through 48", operating conditions cryogenic (below -150° F) to more than 1000° F, low to high pressures, from water to strong acid to sour service, such as, hydrofluoric acid and hydrogen sulfide (H2S).

Christmas Tree Valves: Are commonly used on *both surface* and *subsea wells*, also identified as "*subsea tree" or "surface tree*". The primary functions of Christmas Tree Valves are to control the flow, usually oil or gas, or to control *injection of gas or water* into a non-producing well in order to enhance production rates of oil from other wells. This leads to a *processing facility, storage depot and/or other pipeline* eventually leading to a *refinery or distribution center* (for gas).

Flow lines on subsea wells usually lead to a fixed or *floating production platform* or to a *storage ship or barge*, known as a *Floating Storage Offloading (FSO), Floating Processing Unit (FPU), or Floating Production and Offloading (FPSO).* Wellheads and Christmas Trees are under quality standards of API Specification 6A, for application from *2,000 psi up to 20,000 psi* and their specification levels is PSL3, high-pressure bearings, no spillage and reliable quality, especially the anticorrosion to H2S and CO2. The maximum working pressure depends on the connection methods of the product.



Blowout Preventers Valves (Bops): Are safety valves used in *petroleum processes and oil & gas* to "prevent" the uncontrolled flow of liquids and gases during well drilling operations capable of being remotely controlled. When the driller closes the valve, a pressure-tight seal is formed at the top of the well, preventing the *fluids from escaping*. The two major types are Annular (also known as Spherical) and RAM.

Reset Relief Valves: Reset Relief Valves, Shear Relief Valves and Float Valves are the top of the refinery and petroleum line for the oil and gas industry. The primary functions of these valves are to protect the *oil well drilling equipment*. Reset Relief Valves were designed to protect pumps from high pressure spikes and automatically snaps to a full open position when the set pressure is reached. It is easy to adjust set pressure and reset, and allows pressure limitations to be increased while under pressure.

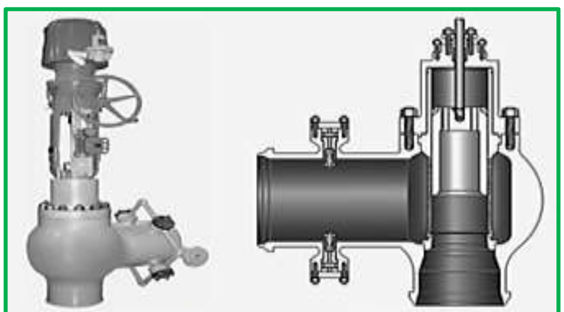
Drill Pipe Float Valves: The drill pipe float valves provide *blowout protection* at the bottom of the drill string, to prevent flow back and bit plugging, keeping cuttings out of the drill pipe while making connections.

Plug Valves: Are valves for use with *portable flowline oil drilling equipment* available manufactured according to API 6A specification, suitable for Temperature Classification P through to U as standard or K, L or X, to client order, also available with hammer union ends pressure ratings, sizes and hydraulically balanced for the Oil & Gas application.

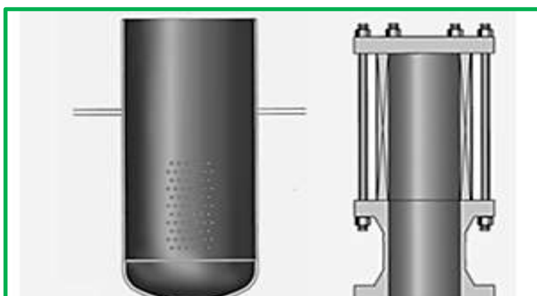
Blowout Preventers Valves (Bops)	*Reset Relief Valves*	*Drill Pipe Float Valves*	*Plug Valves*
			

Steam Conditioning Valves: Are used in steam processes for the simultaneous reduction of steam pressure and temperature to the level required for a given application. The steam conditioning valve injects the spray water towards the center of the pipeline, and varies according to applications, around the circumference of an outlet manifold for a more complete distribution of the spray water.

Steam Spargers: Are also used in steam processes as pressure-reducing devices used to safely discharge steam into a condenser or turbine exhaust duct to provide backpressure to the turbine bypass valve, limit steam velocity and allow reduced pipe size between the bypass valve. Flow-induced noise, steam spargers design and installation are key elements considering system noise.



Steam Conditioning Valve & Cross-Section



Steam Sparger With Drilled-Hole & Multi-Stage

7. STANDARD & CONTROL VALVES APPLICATION:

Standard Control Valves: Are generally used for applications encompassed by: atmospheric *pressure up to 6,000 psig (414 bar), temperature from -150 °F (-101 °C) to 450 °F (232 °C)*, flow coefficient C values from 1.0 to 25,000, and the limits imposed by common industrial standards. The viscosity, leakage rates, corrosiveness, and many other factors demand consideration when used for standard applications.

High-Temperature Control Valves: Are valves for service at temperatures above 450 °F (232 °C) designed according to specified temperature conditions. At elevated temperatures, such as, in boiler feedwater and superheater systems, all plastic materials, elastomers or standard gaskets are unsuitable and must be replaced by metal-to-metal seating materials, as well, semi-metallic, laminated flexible graphite packing materials and spiral-wound stainless steel and flexible graphite gaskets.

Valve Body Materials: Carbon steel castings are generally used for temperatures between 1000 °F (538 °C) and 1500 °F (816 °C). The ASTM A217 grade C12A steel castings and ASTM A182 grade F91, are always used at temperatures up to 1200 °F (650 °C). The ASTM A217 Grade WC9, Cr-Mo casting steels are usually used up to 1100 °F (593 °C). For above temperatures, up to 1500 °F (816 °C) the materials types 316 or 317 stainless steels are usually selected.

Cryogenic Service Valves: Cryogenics is the science dealing with *materials and processes at temperatures below -150 °F (-101 °C)*. For control valve applications in cryogenic services, many of the same issues need consideration as with high temperature control valves. Plastic and elastomeric components often cease to function appropriately at temperatures below 0 °F (-18 °C). Materials for cryogenic applications are generally CF8M body and 300 series stainless steel for trims.

Control Valves for Nuclear Service: Components for nuclear power plants are subject to the requirements of Appendix B, Title 10, Part 50 of the Code of Federal Regulations entitled Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants. Then, most nuclear power plant components are always specified in accordance with Section III of the ASME Boiler and Pressure Vessel Code with an ASME code nameplate with an “N” stamp symbolizing service acceptability in nuclear power plant applications.

Valves Subject to Sulfide Stress Cracking: Are valves subject to material failure in contact with Hydrogen Sulfide (H_2S) containing environments in Oil & Gas production”. NACE (National Association of Corrosion Engineers) is responsible for a large number of standards. The MR0175, formerly entitled “Sulfide Stress Cracking Resistant Metallic Materials for Oilfield Equipment”, issued in 1975, provide guidelines for the selection of materials that are resistant to stress cracking.

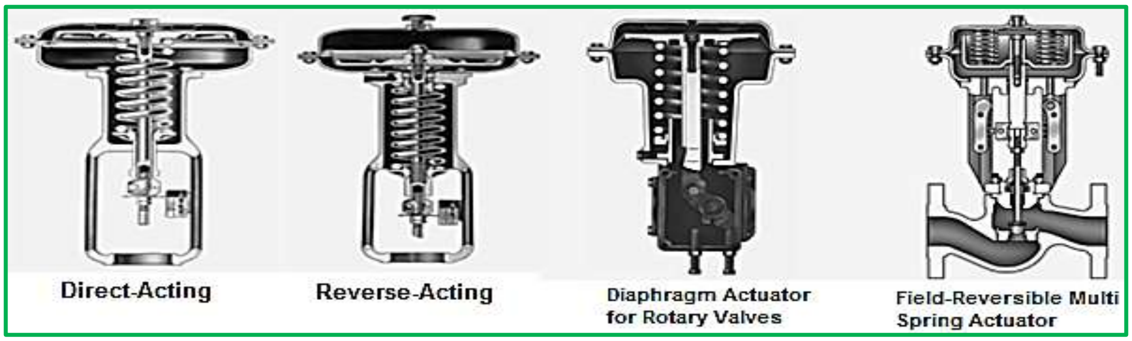
Valves Materials Weldments: The NACE MR0103 procedure requires that carbon steels should be welded per another NACE document called RP0472 “Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments”, to ensure that both the weld deposit and heat affected zone (HAZ) will be soft enough to resist the SSC (sulfide stress cracking).

8. VALVES ACTUATORS, POSITIONERS & TRANSDUCERS:

Pneumatic Actuators: Are automated devices that use a *spring-and-diaphragm pneumatic actuator* is the most commonly specified due to its dependability and simplicity of design. The other type is the *pneumatic piston actuator* that provides a high stem force output in many applications. These are the most popular types in use, but electric, hydraulic and manual actuators are also widely used.

Electric and Electro-Hydraulic Actuators: Are used where *air supply source* is not available or *low ambient temperatures* could freeze condensed water in pneumatic supply lines or when unusually large stem forces are needed. These types are much more complex and more expensive than pneumatic actuators. The various types are as following:

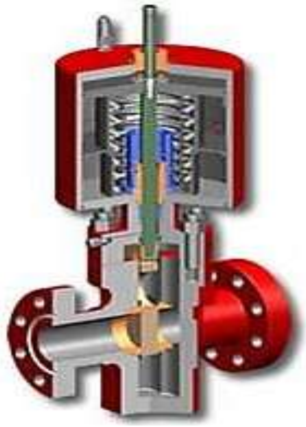
Diaphragm Actuators: Pneumatically operated diaphragm actuators use *air supply* from controllers, positioners or other sources. Various diaphragm styles include: *direct acting* (increasing air pressure pushes down diaphragm and extends the actuator stem); *reverse-acting* (increasing air pressure pushes up diaphragm and retracts the actuator stem); *reversible* (actuators are assembled for either direct or reverse action); *direct-acting unit* for rotary valves (increasing air pressure pushes down on diaphragm).



Piston Actuators: Are pneumatically operated using high-pressure air up to 150 psig, often eliminating the need for supply pressure regulator. The advantages are that piston actuators furnish maximum thrust output and fast stroking speeds; double acting types give maximum force in both directions and spring return types provide fail-open or fail-closed operations. Various accessories can be incorporated to position a double-acting piston in the event of *supply pressure failures*, including *pneumatic trip valves, lock-up systems, hydraulic snubbers, handwheels, and units without yokes* used to operate butterfly valves.

Electrohydraulic Actuators: Are ideal for isolated locations where *pneumatic supply pressure is not available* but where precise control of valve plug position is needed. Require only an electrical power to the motor and an electrical input signal from the controller. These actuators units are normally reversible by making minor adjustments and might be self-contained, including motor, pump, and a double-acting hydraulically operated piston within a weather-proof or explosion-proof casing.

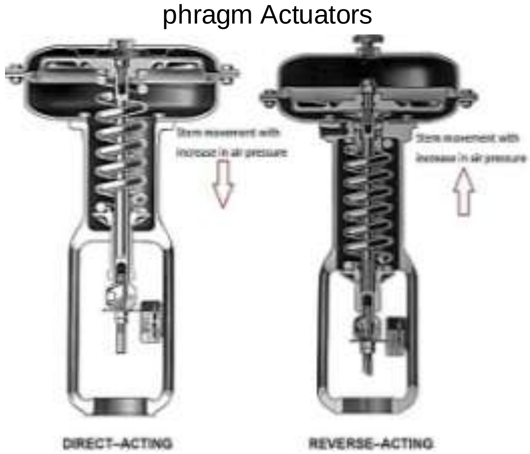
Rack and Pinion Actuators: Are typically used for *on-off applications* or where process variability is not a concern. These types provide compact and economical solutions for rotary shaft valves.

Piston Actuators	Electrohydraulic Actuators	Rack and Pinion Actuators
		

Direct-Acting and Reverse-Acting Diaphragm Actuators: Direct-Acting actuator is designed to operate from a *normally open position (NO)*, when air pressure enters *on top of the actuator*, the diaphragm closes the valve. When the air is released the spring opens the valve. Reverse-Acting actuator is designed to operate from a normally closed position (NC), when air pressure enters on the *bottom side of the actuator*, the diaphragm opens the valve. When air is released spring closes the valve.

Electric Actuators: Electric actuator designs use an electric motor and a gear reduction to move the valve to open or close position, the way these mechanisms are used for continuous control. Electric actuators have been much more expensive than pneumatic for the same performance levels. However, this is an area of rapid technological change, and future designs may cause a shift, towards greater use of electric actuators.

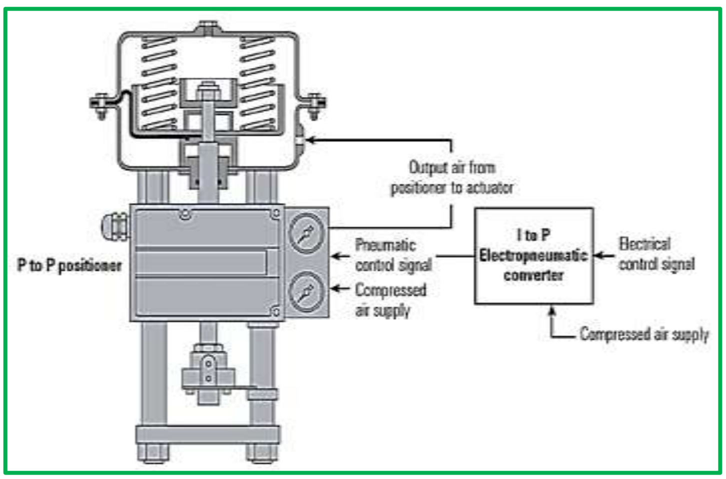
Manual Actuators: Manual actuators are useful when automatic process control is not required, ease of operation and good manual control is still necessary. They are often used to *bypass a valve* in a three-valve loop around control valves during maintenance or *shutdown the automatic system*. Manual actuators are available in various sizes for all models to permit accurate repositioning of the valve plug or disk. Manual actuators are much less expensive than automatic actuators.

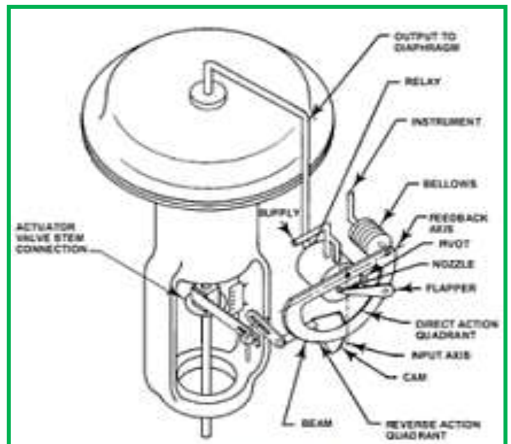
Direct-Acting and Reverse-Acting Diaphragm Actuators	Electric Actuators	Manual Actuators
		

Positioners: Are devices that use a pneumatic signal (usually 3 - 15 psig) or an electro-pneumatic signal (4 - 20 mA). Pneumatic and electro-pneumatic positioners are often used as servo-booster as they convert low-energy signals into strong proportional signal pressures up to the maximum supply pressure (6 bar/90 psi). The force balanced devices, may be operated with a cam characterized by air pressure control, utilizing a low friction spool valve to accurately drive the rotary or linear pneumatic actuators. The main types are:

Type 1 positioners use a *pneumatic input* (3 – 15 psig) to control the pneumatic output. *Type 2* positioners are *electro-pneumatic*, using an I/P (current-to-pneumatic) converter to accept a 4 - 20 mA input signal and *convert it to a pneumatic output*. *Type 3* positioners use a P/I to convert a *pneumatic input signal to an electrical output* signal.

Difference between Actuators and Positioners: *Actuators* accept a signal from the control system and in response, moves the valve to a *fully-open or fully-closed* position, or a *more open or a more closed* position (depending on whether the *on or off* or *continuous* control action is used). *Positioners* include an additional item (see below), which is usually fitted to the yoke or pillars of the valve, linked to the spindle of the actuator, in order to monitor the valve position. It requires its own pneumatic or electro-pneumatic input (as described above), used to position the valve.





Positioner for Diaphragm Actuator

Pneumatic and Electro-pneumatic Positioners: Depending on the input signal, a distinction must be made between the pneumatic (P/P) and electro-pneumatic (I/P) positioners:

Pneumatic Positioners (P/P): Accept an input signal of 0.2 to 1 bar (3 to 15 psi) and issue an output signal pressure of maximum 6 bar (90 psi). When an actuator is used, the actuator is connected to a valve stem, a damper or a lever. The actuator is then used to set the position of the connected valve (or a device), by moving a stem or shaft up and down corresponding to the pressure applied by the converter output.

Electro-pneumatic Positioners (I/P): Also called as analogic I/P or E/P positioners, accept an electrical current signal usually of 4 to 20 mA @ 24 VDC (or 1 to 5 mA as input variable), and converts into a pneumatic output signal pressure usually 3 - 15 or 6 - 30 psi, up to maximum 6 bar (90 psi).

Note: The IP or E/P positioners mean devices that convert a voltage or electronic input signal to a pneumatic output signal. The P/I converter *does the reverse* and converts a pneumatic input signal to an electrical or electronic output signal.

Digital Positioners: Replace, with many advantages, both the analog I/P and the P/P pneumatic positioners and provide accurate, repeatable signals, simplifying the control circuit and eliminating other components, with a positive feedback indication at the control room. The main difference is that digital positioners work with *digital electronic signal conversions* rather than analogic.

Digital positioners can also provide communication capabilities through either PROFIBUS-PA™, HART® communication protocols, FOUNDATION™ field bus networks, or even be operated through a Microsoft® Windows®-based HMI (Human Machine Interface) with a simple PC software. When manual operations are preferred, simple configuration can also be accomplished using an interface with an intuitive menu, push buttons, and an LCD display. The main digital controllers are:

Pneumatic (P/P) Positioners	Electro-pneumatic (I/P) Positioners	Digital Positioners
		

Limit Switches: Are electromechanical devices, adjusted individually for either alternating current or direct current with NC or NO contacts that consist of an actuator mechanically linked to control systems, signal lights, small solenoid valves, electric relays, or alarms, operated by the motion of a machine part or presence of an object. When an object contacts the actuator, the switch operates making or breaking an electrical connection for control of a machine, as safety interlocks, or to count objects passing a point.

Solenoid Valves: Convert binary signals issued by an electric control equipment into binary pneumatic control signals which *close or open a control valve* (or any other control device, as a damper). The principle of operation is similar to an electro-pneumatic converter (I/P converter), used for controlling purposes, automation equipment and fieldbus systems.

Supply Pressure Regulators: Provide pneumatic control with a constant air supply, commonly called air sets; have the function to reduce and controls the pressure of a compressed air network to the pressure adjusted at the set point of valve positioners and other control equipment. Many versions are available for installation in pipelines, control panels or direct attachment to positioners or actuators. The air pressure station consists of a supply pressure regulator and an upstream filter with condensate drain. Common reduced-air-supply pressures are 20, 35 and 60 psig.

Valve Limit Switches	Solenoid Valves	Supply Pressure Regulators
		

Pneumatic Remote Adjusters: The remote adjuster is a precision pressure regulator which can be manually adjusted. It is designed for use in pneumatic control loops as a set point adjuster or a manual remote adjuster, and can be used as a precision pressure regulator for measuring, calibration and testing equipment. These devices are designed for the following pressure ranges; 0 to 0.6 bar, 0 to 1.6 bar, 0 to 4.0 bar, 0 to 6.0 bar. The maximum supply pressure for all versions is 7 bar.

Reversing Pressure Amplifiers: These devices have the function to allow *double-acting pneumatic actuators* to operate as *single-acting pneumatic/electro-pneumatic positioners or limit switches*. The positioner creates an output signal pressure, and the reversing amplifier uses this supply pressure as an auxiliary power.

Pneumatic Volume Boosters: Are used together with positioners to increase the positioning speed of pneumatic actuators. These devices supply the actuator with an air flow output, *whose pressure corresponds exactly to the signal pressure*, except that it has a much higher volume output.

Pneumatic Remote Adjusters	Reversing Pressure Amplifiers	Pneumatic Volume Boosters
		

Pneumatic Lock-Up Valves: Have the function to shut off the signal pressure line when the *air supply falls below an adjusted value*, or are used with control valves to lock an existing actuator in the event of *supply pressure failure*. As a result, the pressure in the actuator is blocked and remains in its last position until the defect is eliminated. These devices can be used with volume tanks to move the valve to the fully open or closed position on loss of pneumatic air supply. Normal operation resumes automatically with restored supply pressure.

Fail-Safe Pneumatic Actuators: In these systems, the actuator piston moves to the top or bottom of the cylinder when supply pressure falls below a pre-determined value. The volume tank, provides loading pressure for the actuator piston when supply pressure fails, moving the piston to the desired position. Automatic operation resumes, and the volume tank is recharged when supply pressure is restored to normal.

Rotary Actuators: These devices have the function to drive rotary action valves, such as ball and butterfly valves. The commonest is the piston type, which comprises a central shaft, two pistons and a central chamber all contained within a casing. The pistons and shaft have a rack and pinion drive system. Air or hydraulic oil can be fed into either side of the pistons to cause movement in either direction. As with diaphragm type actuators, they can also be fitted with positioners.

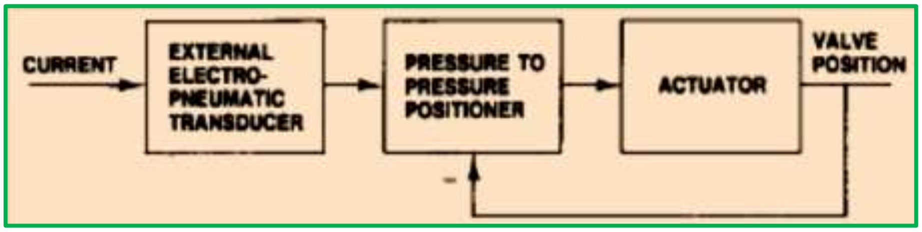
Pneumatic Lock-Up Valves	Fail-Safe Pneumatic Actuators	Rotary Actuators
		

Transducers: Are devices that convert a signal in one form of energy to another form of energy, or, are used in electronic communications systems to convert signals of various physical forms to electronic signals, and *vice versa*. Energy types include electrical, mechanical electromagnetic chemical, acoustic and thermal energy. While the term *transducer* commonly implies the use of a sensor/ detector, any device which converts energy can be considered a transducer. Transducers are widely used in measuring instruments.

Difference between Sensors and Transducers: Sensors are devices that only *measure* a physical quantity and then convert it into signals that can be read by the user or by any other instrument. Transducers are physical devices (electrical, electro-mechanical, electromagnetic, photonic or photovoltaic) that converts a type of energy into another (most electromagnetic), for the purposes of measurement or transfer of information.

Transducers Applications: For valves, the transducers reduce a supply pressure to a regulated output pressure directly proportional to an electrical input signal, with a wide range, from a minimum of 3 psig (0.2 bar) to 100 psig (6.9 bar). Thus, transducers are commonly used to convert an electrical signal to a pneumatic output which can be used to operate the valve positioners.

Electro-Pneumatic Transducers: Use a patented converter module that converts a 4 to 20 mA input signal to a proportional 0.2 to 1.0 bar (3 to 15 psig) pneumatic output signal. The transducer receives a DC analog input signal from the control system and converts it to a proportional pneumatic signal, which is then sent to the conventional positioner. Almost every positioner has the option of adding an integrated electro-pneumatic transducer, as shown below:



Note: In some applications, an *electro-pneumatic transducer* and a *common pneumatic* valve positioner, connected together in series, can be used as an equivalent substitute for the *electro-pneumatic positioner*. An actuator without a spring, such as a piston actuator, always requires the use of a positioner.

For various reasons, a valve may be installed *without a positioner*. In this case, the valve may be fitted with an *electro-pneumatic transducer*, an "I – to - P," that takes the 4 - 20 mA current signal from the control system and, based on the signal value, provides a 3 - 15 psi signal to the valve actuator. An example of a valve with an electro-pneumatic transducer is shown below.

Electro-pneumatic Transducers with diaphragm/bellows-actuated control valves	Electro-pneumatic transducers types
	

Guidelines: The following application guidelines apply, for open loop and closed loop systems:

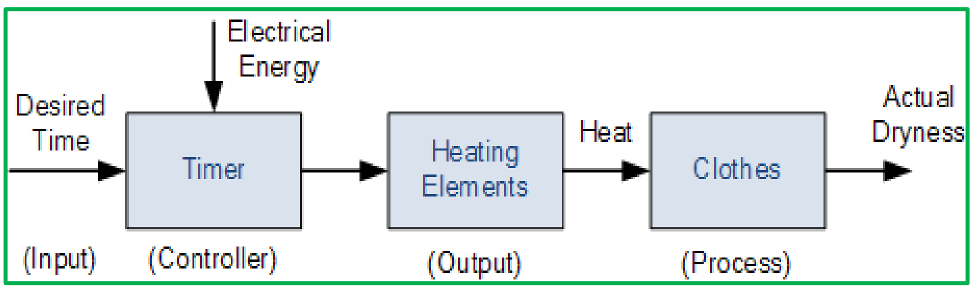
- For *open loop control*, always use an *electro-pneumatic valve positioner*. If the *loop system* is *relatively slow*, such as, liquid level, blending, select an *electro-pneumatic valve positioner*.
- For *closed loop control*, if the system is *relatively fast*, such as liquid pressure, and small volume of gas, use an *electro-pneumatic transducer* (and not use a *valve positioner*).

9. CONTROL SYSTEMS & FIELDBUS TECHNIQUES:

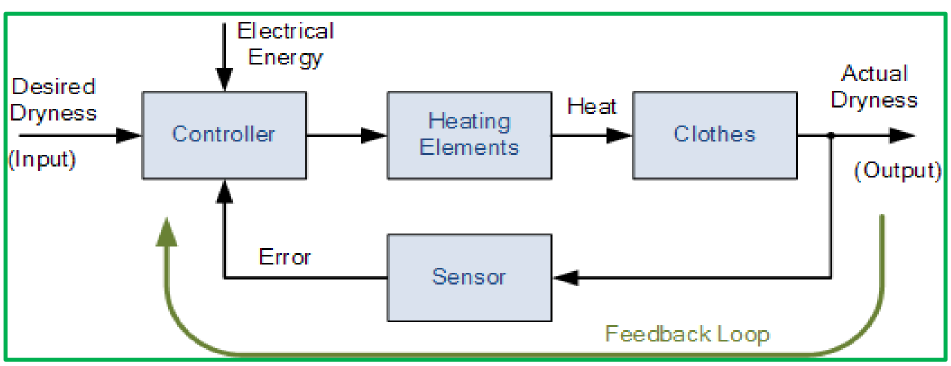
Control Systems: Are a set of devices that manages, commands, directs or regulates the behavior of other devices or systems and may be applied and completed by five elements: *Detectors, Transducers, Transmitters*, *Controllers, and a Final Control Element*. These functions may be implemented electronically by a proportional control, a *PI controller*, *PID controller, bistable, hysteretic control or Programmable Logic Controller (PLC)*. The final control changes an input or output that affects the manipulated or controlled variables.

The most common classes of control systems are: *the open loop control systems and the closed loop control systems*. The open loop control systems mean there are no feedbacks from the controlled condition; in other words, no information is sent back from the process or system. In closed loop control systems current output takes into consideration the adjustments and corrections based on *feedbacks*. A closed loop system is also called a feedback control system.

Open-loop system: Is a type of continuous control system in which the output has no influence or effect on the control action of the input signal, also referred to as non-feedback system, is. Then, an open-loop system is expected to faithfully follow its input command or set point, regardless of the final result, as example below:

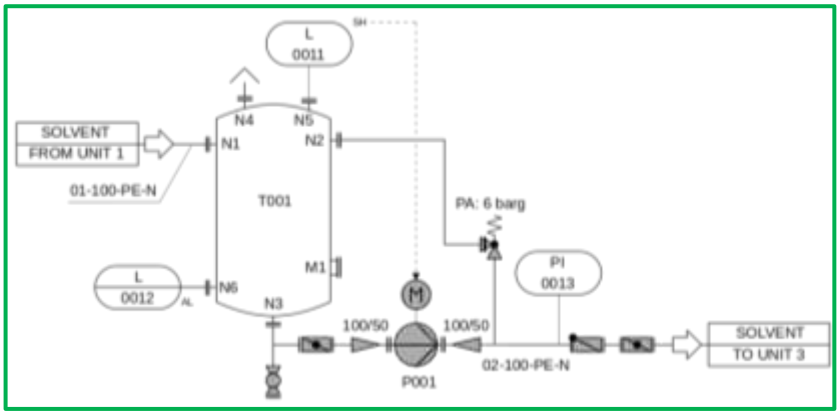


Closed-loop Systems: Are designed to automatically achieve and maintain the desired output condition by comparing it with the actual condition. In other words, a "closed-loop system" is a fully automatic control system in which its control action, gives feedbacks from the controlled condition.



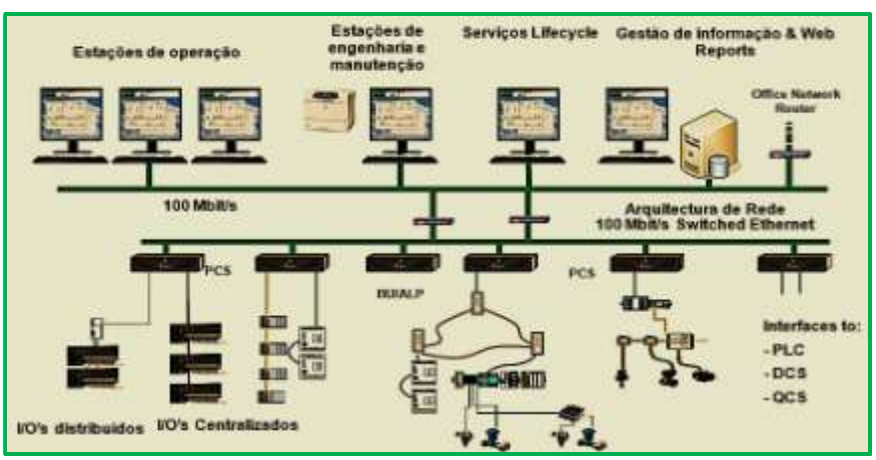
Proportional-Integral-Derivative (PID) Controller: Is a control loop feedback mechanism (controller) widely used in industrial control systems. The PID controller calculates an *error* value as the difference between a measured process variable and a desired setpoint, also called as PI, PD, P or I controller whereas the absence of an integral term may prevent the system from reaching its target value due to the control action.

Piping and Instrumentation Diagram - P&ID: Is a schematic illustration of the functional relationship of piping, instrumentation and system equipment components. The P&ID are used to operate the process system, and shows all of the piping installation through diagrams with standardized symbols, including the physical sequence of branches, reducers, valves, equipment, instrumentation and control interlocks, also allowed for further safety and operational investigations, such as a "Hazard and Operability Study" commonly pronounced as HAZOP.



Fieldbus: Is an industrial network system, of a family of industrial *computer network protocols* for real-time distributed control, as a way to connect instruments in a manufacturing plant, standardized as IEC 61158. A complex automated industrial system, such as a manufacturing assembly line, usually needs a distributed control system or an organized hierarchy of pneumatic, hydraulic and electro-electronic instrumentations and controller systems, to operate faithfully.

The meaning of *Field* is defined as in industrial limited area. The term *Bus* is a well-known word in computer science as a set of common lines that electrically (or even optically) connect various units (circuits) in order to transfer data. The main function of the fieldbus system is to link the PLCs (Programmable Logic Controllers) to the components that actually do the work, such as, sensors, actuators, electric motors, alarms, console lights, switches, valves, contactors, etc.



Human Machine Interface (HMI): Is typically local to one machine or piece of equipment, and is the interface method between the human and the equipment/machine, where an operator can monitor or operate the system. This is typically linked to a middle layer of programmable logic controllers (PLC) via a non-time-critical communications system (Ethernet). Fieldbus control techniques offers flexible and easy solutions, as network gateways.

Bus Technology Family: In most cases *Fieldbus and Ethernet* networks use the same application layer, that is, the same data types, object structure, and functions. Fieldbus and Ethernet complement each other, thus, all major bus technology organizations have both Fieldbus and Ethernet. To be clear, the table below shows only a small Fieldbus selection of what is available.

Organization	Fieldbus Level	Remote I/O Level	Ethernet Level
ODVA	DeviceNet	ControlNet	EtherNet/IP
Modbus-IDA	-	Modbus/RTU	Modbus/TCP
PNO	Profibus-PA	Profibus-DP	PROFINET
Fieldbus Foundation	FF H1	-	FF HSE
	-	SERCOS	SERCOS-III

There are about 20 industrial network systems that can be called industrial fieldbus and ethernet protocols, so an exhaustive description is not this scope. The table below lists a number of popular (serial) fieldbus protocols and their corresponding Ethernet-based industrial protocols, and described only the most known and broadly recognized in international standards:

Popular Industrial Fieldbus and Industrial Ethernet Protocols:	
Serial Protocols	**Ethernet-Based Protocols**
DeviceNet/ControlNet	Ethernet/IP
PROFIBUS	PROFINET
Modbus-RTU	Modbus-TCP
SERCOS I/II	SERCOS III
Fieldbus Foundation FF H1	FF HSE
LonWorks	Lon over Ethernet
CANopen	EtherCAT/ Ethernet Powerlink

DeviceNet / ControlNet: DeviceNet and ControlNet were originally developed by *Rockwell Automation* and actually are managed by the Open Device Vendor Association (ODVA) using the Common Industrial Protocol, called CIP, for upper protocol layers. Both DeviceNet/ControlNet use a trunk-line/drop-line topology with selectable communication rates, and are the *world leading systems for industrial automation,* very popular network for time critical applications. The configuration process is based on electronic data sheets (EDS-Files) provided by the device manufacturers, and contain relevant communication parameters, both commonly described as:

- ✓ **DeviceNet** is a digital, multi-drop network, used in Ethernet I/P layer, serving as a communication network between industrial controllers offering a single point of connection for configuration by supporting both I/O and explicit messaging.

- ✓ **ControlNet** offers good real-time capabilities, also used in Ethernet I/P layer, providing high-speed deterministic transmission for time-critical I/O data and messaging data.

PROFIBUS: Is the abbreviation for Process Field Bus and is the standard for field bus communication. Through the years, this system has gained wide acceptance in both production and process automation. The *PROFIBUS* communication protocol was created in 1989 by a consortium of companies and institutions and promoted by the BMBF (German department of education and research). Profibus is divided into two variations:

- ➢ **DP (Decentralized Peripheral) Version**: Is the more commonly used that replaced the first complex communication protocol version FMS (Fieldbus Message Specification) in 1993. *PROFIBUS DP* is the high speed solution, designed and optimized especially for communication between automation systems and decentralized devices. It can operate at data rates of up to 12 Mbit/s over twisted pair cables or fiber optic links.

- ➢ **PA (Process Automation) Protocol Version**: Is the lesser-used and is commonly provided for monitoring measurement equipment. *PROFIBUS PA* is used to monitor measuring equipment via a process control system. The disadvantage of this protocol is its slow data rate of only 31.25 kbit/s. Weak current flow through the bus lines makes it intrinsically safe and ideal for use in explosion-hazardous areas.

Modbus-RTU: Is an open, royalty-free serial communications protocol developed for Programmable Logic Controllers (PLC) applications. Modbus allows many devices to connect to the same network, such as interfacing a supervisory computer with a *Remote Terminal Unit (RTU)* through the Supervisory Control and Data Acquisition (SCADA) systems. The Modbus infrastructure is managed by the Modbus-IDA, a group of independent users and suppliers of automation devices, seeking to drive the adoption of this protocol standard.

SERCOS (Serial Real-time Communication System): Provides a standard, real-time, high-performance communications interface between motion controls, digital servo drives, and input/output (I/O) devices, ideal for applications where the precise coordination of movement along multiple axes of motion control is critical. An industrial Ethernet version, SERCOS III, is also available.

Fieldbus Foundation: This system is used as a Local Area Network (LAN) for automation devices and process automation, created in 1994, by the French ISP (Interoperable Systems Project) and the World FIP (Flux Information Processus) to form the Fieldbus Foundation. The aim was to create a single, international fieldbus standard for hazardous environments which will find widespread use as IEC (International Electrotechnical Committee) standardized fieldbus. There are two systems:

- ✓ **The H1 (Low-Speed Ethernet) Communication**: Runs at 31.25 kbit/s, provide an open and interoperable solution for most field instruments including intrinsically safe networks.

- ✓ **The HSE (High-Speed Ethernet) Communication**: Runs at 100 Mbit/s, the high speed connection between various H1 segments and host systems, including PLCs with a "back-bone" network.

The ability to embed *software commands* into the memory of the device, represents the real difference between *digital and analog I/P* segments. This allows automatic configuration and setup of the valve when equipped with a digital controller. The Fieldbus networks exchange data have two methods, *Cyclic or Acyclic data*:

- ➢ **Cyclic data**: Is information that is pre-configured to pass from one device to another at a known rate. Cyclic data is the sender and the receiver end of the message. Therefore if this cyclic data is not delivered with the proper timing, faults will occur on the network to be monitored for reliability assurance.

- ➢ **Acyclic data**: Are messages sent and received at any time as they are generated by the sender and generally have a lower priority than cyclic messages. The system incorporates a "request" and "response" communications scheme where the message sender waits to receive a response from the target before generating another message.

LonWorks: Is a popular protocol standard used in building automation control applications, such as, lighting and HVAC. LonWorks networks devices over a variety of media including twisted pair, power line, Ethernet, fiber optics, and RF.

Controller Area Network (CAN): The Controller Area Network (CAN) was developed by Bosch in the 1980s to provide simple, highly reliable, prioritized communication between intelligent devices, sensors and actuators in automotive applications. Today, CAN is used a variety of applications, as robust, electromechanically (noisy) environments. CANopen builds over CAN (data link and physical layers) in automation applications, where Ethernet may not be suitable.

Hart Protocol: This protocol makes use of the Bell 202 Frequency Shift Keying (FSK) standard to superimpose digital communication signals at a low level on top of the 4-20mA. The HART Protocol was developed in 1980 by Rosemount, for application in a wide range of smart measuring instruments. "Hart" is an acronym for *Highway Addressable Remote Transducer*. In 1993, the registered trademark and all rights of the protocol were transferred to the HART Communication Foundation (HCF). The protocol remains open and free for all, to use without royalties.

10. DIAGNOSTICS & COMMUNICATION INTERFACES:

Digital Controllers: Utilizing Distributed Control System (DCS), PC software tools, or handheld communicators, process professionals can diagnose the health of instrumentations while it is in the line. Digital controllers incorporate predefined system devices for maintenance diagnostics to provide alerts if there are problems with instruments, electronics, hardware and valves performances.

HART-based Handheld Field Communicators: When connected to the digital valve controllers it enables user-configured alerts and alarms, providing notification of current status and potential valve and instrument problems, including travel deviation, travel limit, cycle count accumulation.

AMS ValveLink Software: Control valves can be evaluated while the valve is fully operational before failure, without disrupting the process, testing all problems with the entire control valve assembly, using the valve stem travel feedback, the actuator pressure sensor and other sensors.

DeltaV System: The DeltaV is a Distributed Control System (DCS) developed to protect and improve plant performance. The safety integrity is provided by continuously monitoring sensors, logic solvers and final elements, with faults diagnosed, before causing process failures.

Flow Scanner: Can diagnose the health of valves through a series of off-line tests. The Flow Scanner system consists of a portable computer with pressure sensors that can be connected to valves to enable diagnostic tests. It is possible to diagnose the health of a valve remotely via HART or Foundation fieldbus, which enable predictive maintenance without disrupting the process.

Fieldvue Instruments: Enable new diagnostic capabilities that can be accessed remotely. This single element requires a look at the potential impact of the technology as it applies to control valves.

Valve Types and Characterization: Are electronic devices that attempt to produce valve characterization by electronically shaping the I/P positioner input signal ahead of the positioner to recalibrate the input signal 4-20 mA, using a pre-programmed table to produce the desired valve characteristics. Some of the most important design considerations include:

- **Dead Band**: Dead band is a phenomenon where a range or band of controller output (CO) values fails to produce a change in the measured process variable (PV) when the input signal reverses direction and the process variable (PV) deviates from the set point. This deviation initiates a corrective action through the controller and back through the process.

- **Actuator-Positioner Design**: Actuators and positioners must be considered together, for precise positioning accuracy and faster response to process upsets when used with a conventional digital control system. These microprocessor-based positioners provide dynamic performance equal to the best conventional two-stage pneumatic positioners.

- **Valve Response Time**: A quick response to small signal changes (1% or less) is one of the most important factors in providing optimum process control, used in many systems.

11. HAZARDOUS CLASSIFICATION & PROTECTION TYPES:

Hazardous Areas: The National Electrical Code (NEC) defines hazardous locations as those areas "where fire or explosion hazards may exist due to flammable gases or vapors, flammable liquids, combustible dust, or ignitable fibers or flyings." Hazardous areas procedures are classified by class, division, and group. The zone method is common in Europe and most other countries.

Class: Defines the general nature of the hazardous material in the surrounding atmosphere.

- ✓ Class I. Locations in which flammable gases or vapors are, or may be, present in the air in quantities sufficient to produce explosive or ignitable mixtures.
- ✓ Class II. Locations considered hazardous because of the presence of combustible dusts.
- ✓ Class III. Locations in which easily ignitable fibers or flyings may be present but not likely to be in suspension in sufficient quantities to product ignitable mixtures.

Division: Defines the probability of hazardous material being present in an ignitable concentration in the surrounding atmosphere.

- ✓ Division 1: Locations in which the probability of the atmosphere being hazardous is high due to flammable material being present continuously, intermittently, or periodically.
- ✓ Division 2: Locations that are presumed to be hazardous only in an abnormal situation.

Group: Defines the hazardous material in the surrounding atmosphere.

- ✓ Group A: Atmospheres containing acetylene.
- ✓ Group B: Atmospheres containing hydrogen, fuel and combustible process gases containing more than 30 percent hydrogen by volume, or gases or vapors of equivalent hazard such as butadiene, ethylene oxide, propylene oxide, and acrolein.
- ✓ Group C: Atmospheres such as ethyl ether, ethylene, or gases or vapors or equivalent.
- ✓ Group D: Atmospheres such as acetone, ammonia, benzene, butane, cyclopropane, ethanol, gasoline, hexane, methanol, methane, natural gas, naphtha, propane, gases or equivalent.
- ✓ Group E: Atmospheres containing combustible metal dusts, including aluminum, magnesium, and their commercial alloy, or other combustible dusts whose particle size, abrasiveness, and conductivity present similar hazards in the use of electrical equipment.
- ✓ Group F: Atmospheres containing combustible carbonaceous dusts, including carbon black, charcoal, coal, or dusts that may present explosion hazards.
- ✓ Group G: Atmospheres containing combustible dusts not included in Group E or F, including flour, grain, wood, plastic, and chemicals.

Electrical Protection Techniques: Various methods have been developed and employed, to reduce or minimize the potential risks of explosion or fire from *electrical equipment* including instrumentations and electrical motors, located in hazardous locations. The types of protection commonly used for instruments are:

Dust Ignition-proof: A type of protection that excludes ignitable amounts of dust will not allow arcs, sparks or heat otherwise generated or liberated inside the enclosure to cause ignition of exterior accumulations or atmospheric suspensions of a specified dust.

Explosion-proof: A type of protection that utilizes an enclosure that is capable of withstanding an explosion of a gas or vapor within it and of preventing the ignition of an explosive gas or vapor that may surround it.

Intrinsically Safe: A type of protection in which the electrical equipment under normal or abnormal conditions is incapable of releasing sufficient electrical or thermal energy to cause ignition of a specific hazardous atmospheric mixture.

Non-Incendive: A type of protection where the equipment is incapable, under normal conditions, of causing ignition of a specified flammable gas or vapor-in-air mixture due to arcing or thermal effect.

Temperature Codes: A mixture of hazardous gases and air may be ignited by coming into contact with a hot surface. The conditions under which a hot surface will ignite, depend on surface area, temperature and gas concentration. Tested equipment indicates the maximum surface temperature, as shown below:

Class 1	Division 1	Groups ABCD	T4
Hazard Type	Area Classification	Gas or Dust Group	Temperature Code

North American Temperature Codes

TEMPER-ATURE CODE	MAXIMUM SURFACE TEMPERATURE	
	°C	°F
T1	450	842
T2	300	572
T2A	280	536
T2B	260	500
T2C	230	446
T2D	215	419
T3	200	392
T3A	180	356
T3B	165	329
T3C	160	320
T4	135	275
T4A	120	248
T5	100	212
T6	85	185

Note: The NEC states that any equipment that does not exceed a maximum surface temperature of 100 °C (212 °F) is not required to be marked with the temperature code. Therefore, when a temperature code is not specified, it is assumed to be T5.

NEMA Enclosure Rating: Is used for the normalization of enclosing instrumentation and control devices. Enclosures may be tested to determine their ability to prevent the ingress of liquids and dusts. In the United States, equipment is tested to NEMA 250, defined as follows:

- **Type 3R (Rain-proof, Ice-resistance, Outdoor enclosure)**: Intended for outdoor use primarily to provide a degree of protection against rain, sleet, and external ice formation.
- **Type 3S (Dust-tight, Rain-tight, Ice-proof, Outdoor enclosure)**: Intended for outdoor use primarily to provide a degree of protection against rain, sleet, windblown dust, and ice.
- **Type 4 (Water-tight, Dust-tight, Ice-resistant, Indoor or outdoor enclosure)**: Intended for indoor or outdoor use primarily to provide a degree of protection against windblown dust and rain, splashing water, hose-directed water, and external ice formation.
- **Type 4X (Water-tight, Dust-tight, Corrosion resistant, Indoor or outdoor enclosure)**: Intended for indoor or outdoor use primarily to provide a degree of protection against corrosion, windblown dust and rain, splashing water, and hose-directed water, and ice formation.

Hazardous Locations: Two of the four enclosure ratings for hazardous (classified) locations are described as follows in NEMA 250:

- **Type 7 (Class I, Division 1, Group A, B, C or D, Indoor hazardous location, Enclosure)**: For indoor use in locations classified as Class I, Division 1, Groups A, B, C or D as defined in the NEC and shall be marked to show class, division, and group. Capable of withstanding the pressures resulting from an internal explosion of specified gases.

- **Type 9 (Class II, Division 1, Groups E, F or G, Indoor hazardous location, Enclosure)**: Intended for use in indoor locations classified as Class II, Division 1, Groups E, F and G as defined in the NEC and shall be marked to show class, division, and group. Enclosures shall be capable of preventing the entrance of dust.

IP Code or **Ingress Protection Marking:** The IEC standard 60529 classifies and rates the degree of protection provided against the intrusion (including body parts such as hands and fingers), dust, accidental contact, and water by mechanical casings and electrical enclosures.

Ingress Protection (IP) Codes

First Numeral Protection against solid bodies	Second Numeral Protection against liquid
0 No protection	0 No protection
1 Objects greater than 50 mm	1 Vertically dripping water
2 Objects greater than 12.5 mm	2 Angled dripping water (75° to 90°)
3 Objects greater than 2.5 mm	3 Sprayed water
4 Objects greater than 1.0 mm	4 Splashed water
5 Dust-protected	5 Jetting
6 Dust-tight	6 Powerful jetting
- -	7 Temporary immersion
- -	8 Permanent immersion

Example: IP 54, first number means “dust protected”, second number “water jetting” protected.

NEMA and IEC Enclosure Rating Comparison: The following table provides an equivalent conversion from NEMA to IEC IP designations. The NEMA types meet or exceed the test requirements for the associated IEC classifications.

Conversion of NEMA Types to IEC IP Codes

NEMA Type	IEC IP
3	IP54
3R	IP14
3S	IP54
4 and 4X	IP65

IEC Temperature Codes

TEMPERATURE CODE	MAXIMUM SURFACE TEMPERATURE	
	°C	°F
T1	450	842
T2	300	572
T3	200	392
T4	135	275
T5	100	212
T6	85	185

The German standard DIN 40050-9 extends the IEC 60529 rating system described above with an **IP 69K** rating for high-pressure, high-temperature wash-down applications. The IP69K test specification was initially developed for road vehicles, especially those that need regular intensive cleaning (dump trucks, cement mixers, etc.), but it also finds use in other areas (for example, the food industry and car wash centers). The NEMA rating can also show the following classifications:

IP Code	Min. NEMA Enclosure rating to satisfy IP Code
IP20	1
IP54	3
IP	4, 4X
IP67	6
IP68	6P

IPXX Code: The letter X is used in any place where specifying a digit is meant to be avoided (or indicates irrelevance based on the common application). As an example, IPX7 rating specifies that the device has water protection up to limited immersion, but deliberately gives no information as to whether the device has any protection against dust. IP2X is frequently used on electrical items to specify that the item must prevent finger access to live terminals, i.e., electrical sockets, IP2X.

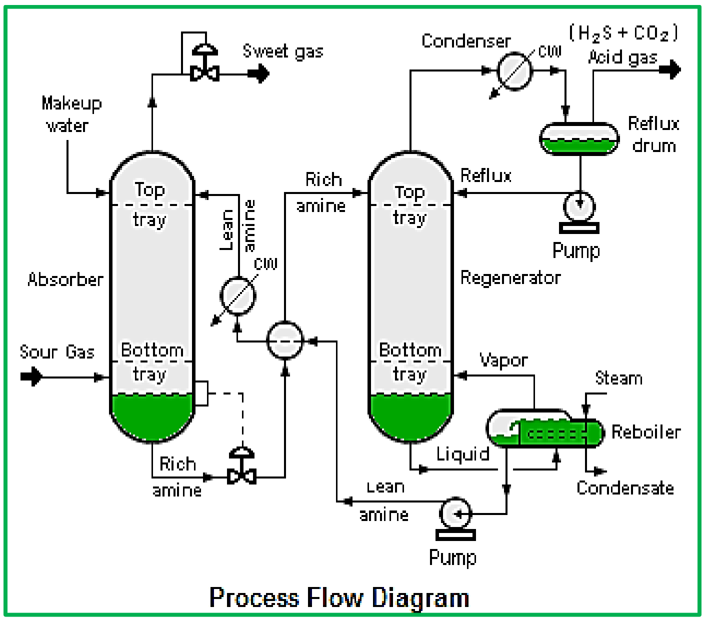
Examples:

IPX0	No special protection
IPX3	Protected against spraying water - Water spraying up to 60 degrees from vertical at 10 liters/min at a pressure of 80-100 kN/m² for 5 min.
IPX5	Protected against water jets - Water projected at all angles through a 6.3mm nozzle at a flow rate of 12.5 liters/min at a pressure of 30 kN/m² for 3 minutes from a distance of 3 meters.

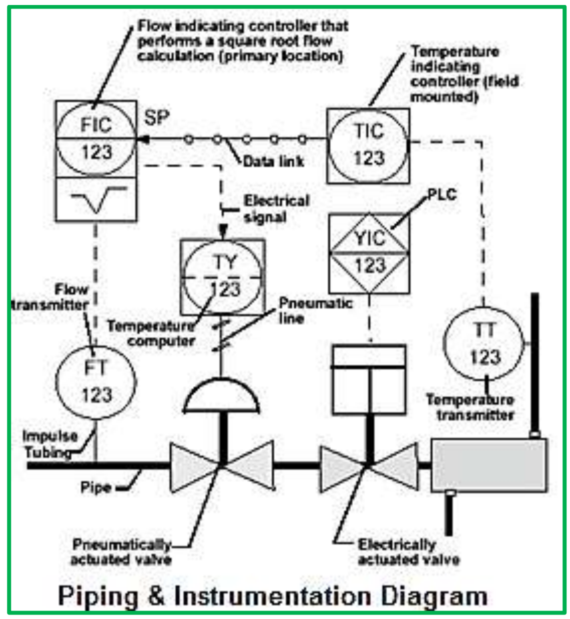
12. PROCESS & PIPING INSTRUMENTATION DIAGRAMS:

Process Flow Diagrams (**PFD´s**): Are also designated as flowsheets, commonly used in chemical and process engineering to indicate the general flow of plant processes and equipment. The PFD displays the relationship between *major* equipment of a plant facility and does not show minor details such as piping details and designations. PFD can be computer generated from process simulators (see chemical process simulators), CAD packages, or flow charts, using the engineering symbols, available from standardization organizations such as DIN, ISO or ANSI.

Difference between PFD and P&ID: The Process Flow Diagrams (PFD) contains fewer details, and may be called *block flow diagrams* or *schematic flow diagrams.* The Piping and Instrumentation Diagram (P&ID) shows all of the piping installation, including symbols and physical sequence details of *valves, branches, curves, reducers, equipment, instrumentation, control interlocks* and information.

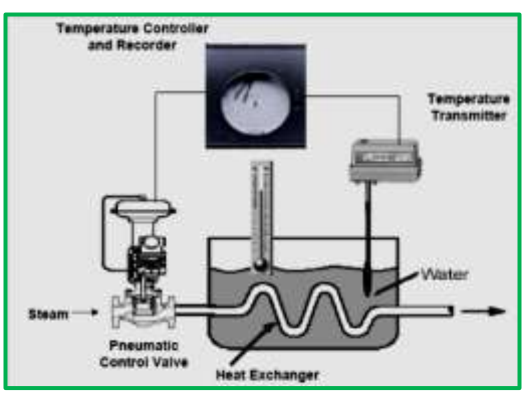


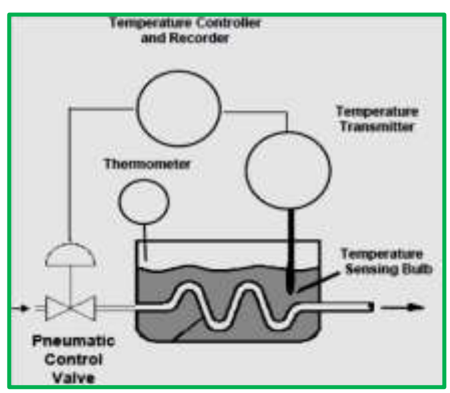
Process Flow Diagram



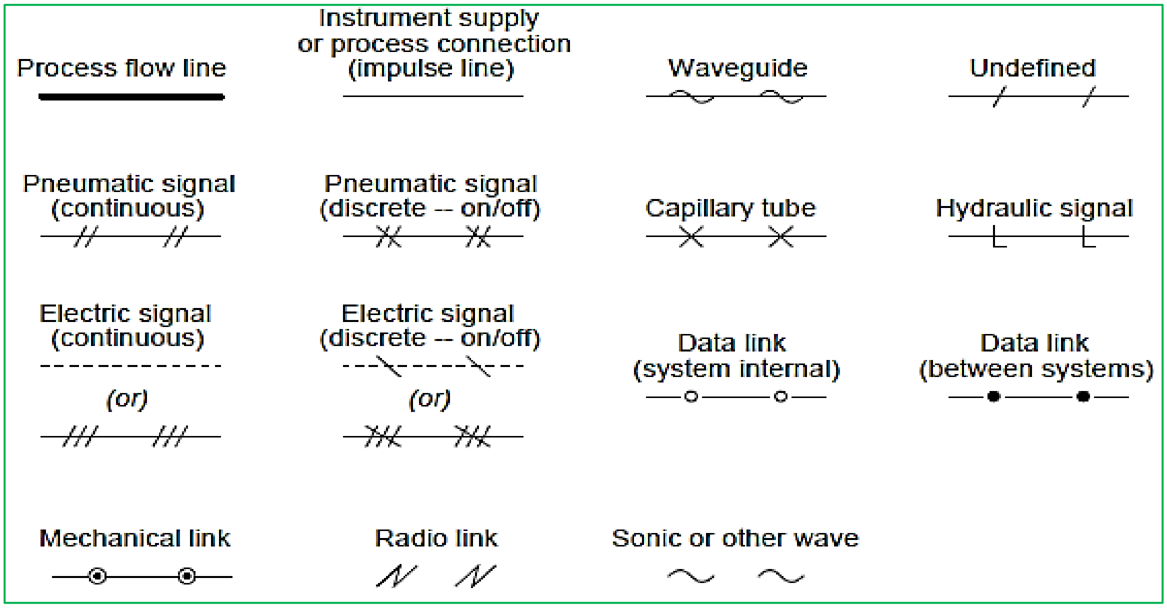
Piping & Instrumentation Diagram

Instrumentation and Process Equipment Symbols: P&ID symbols are used to define mechanical equipment, piping, piping components, valves, equipment drivers and instrumentation and controls. This section shows some of the many instrument symbols found in different types of technical diagrams used to document instrument systems.

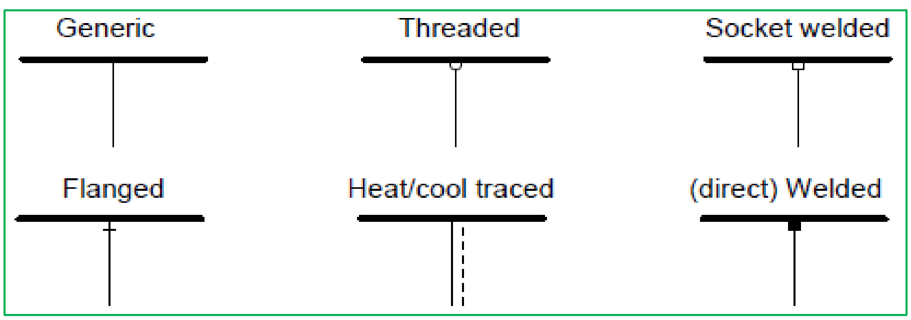




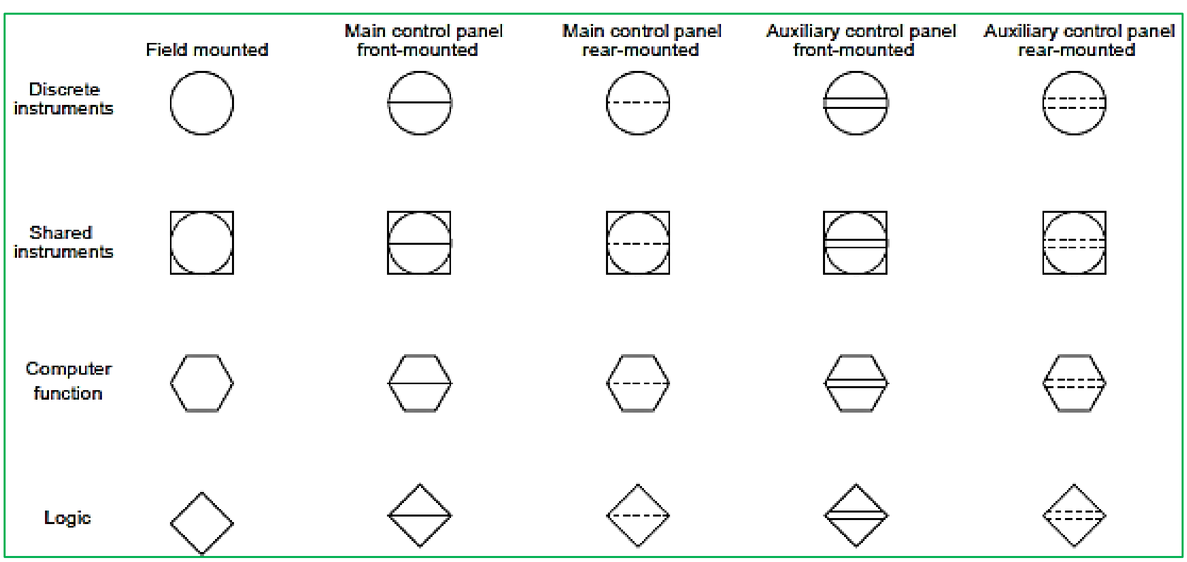
1. **Line types**:



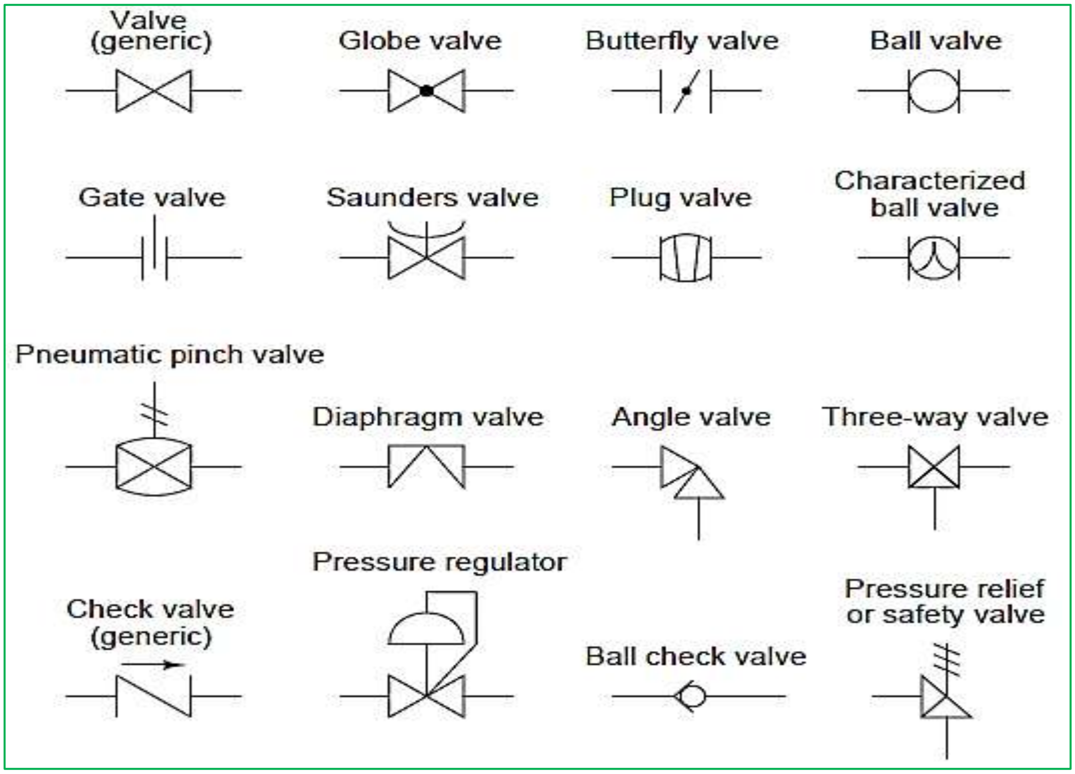
2. **Process/Instrument line connections:**



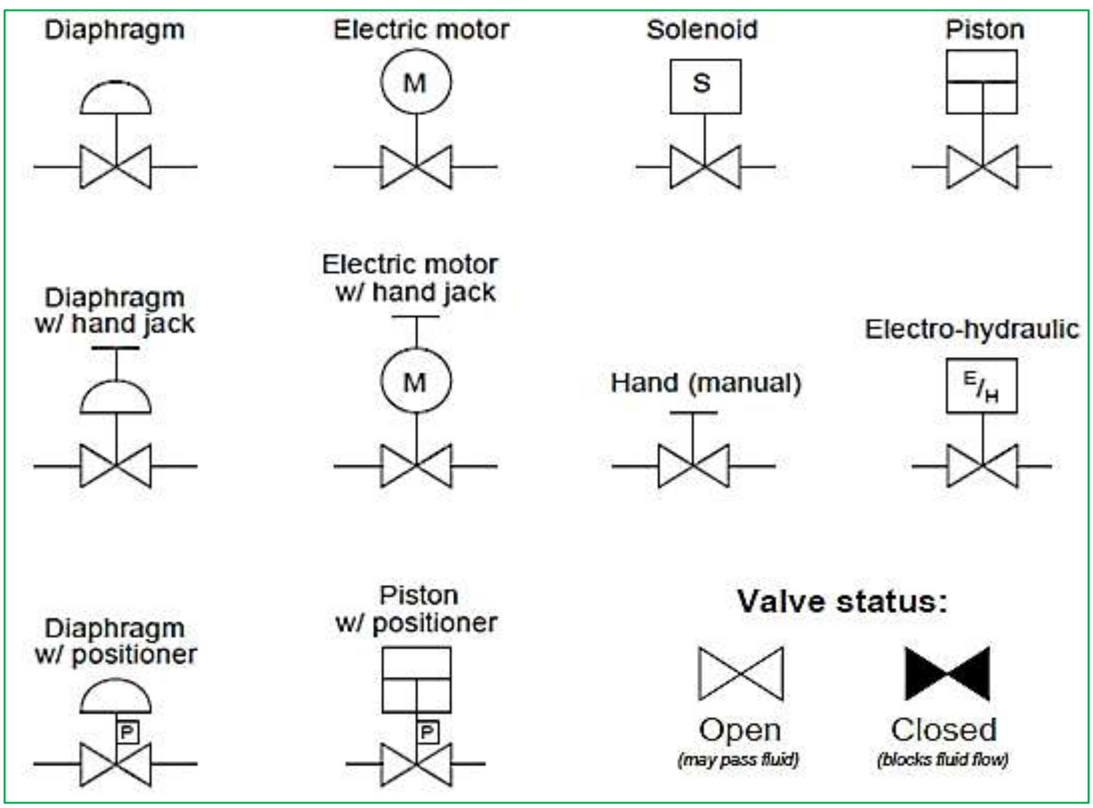
3. **Instrument bubbles:**



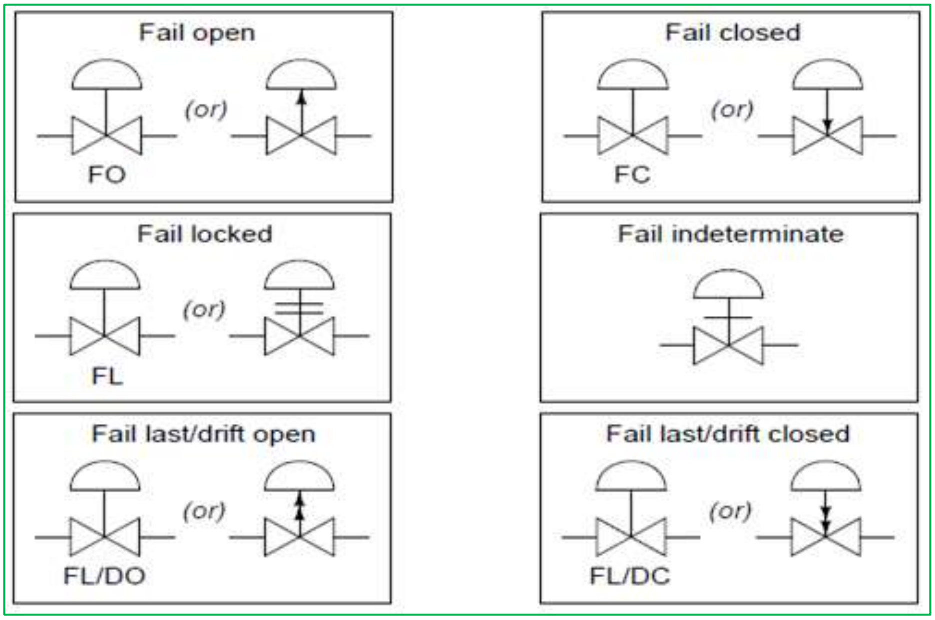
4. Process valve types:



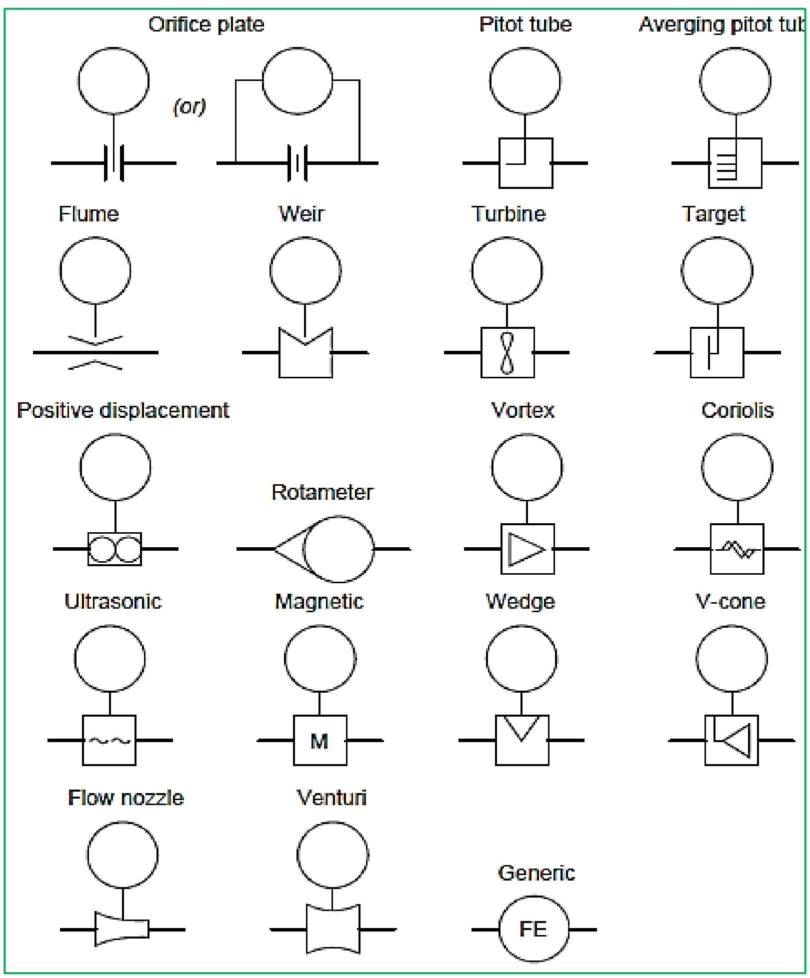
5. Valve actuator types:



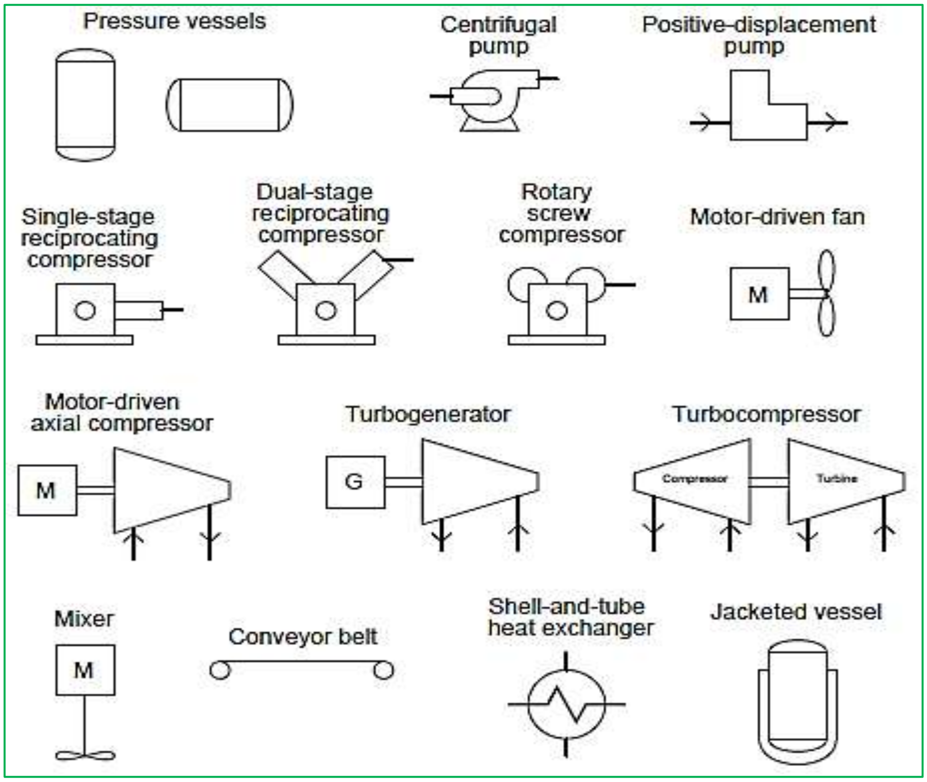
6. Valve failure mode:



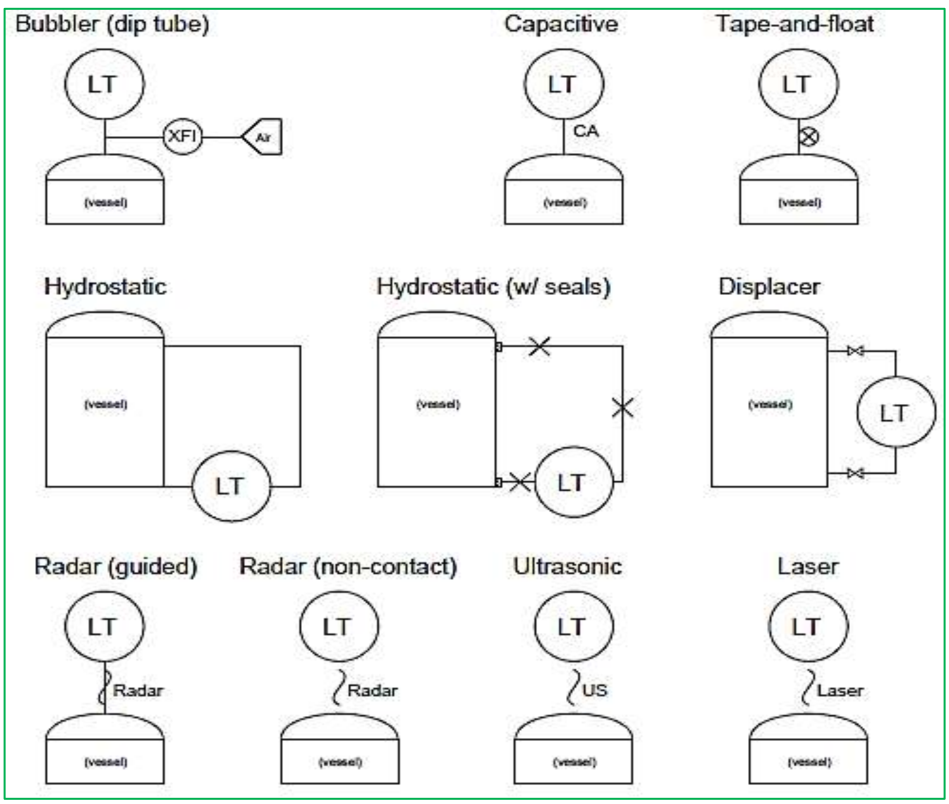
7. Flow measurement devices (flowing left-to-right):



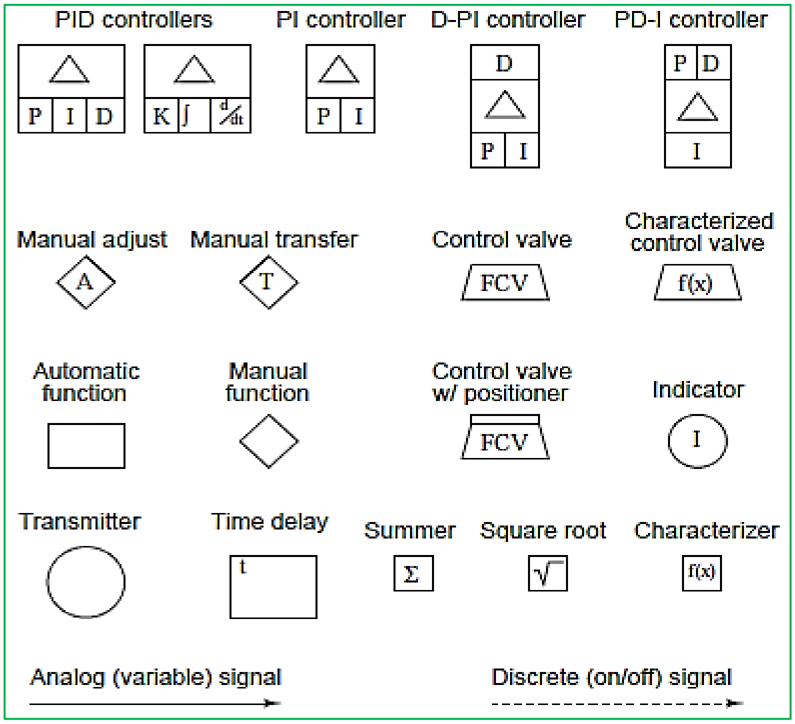
8. Process equipment:



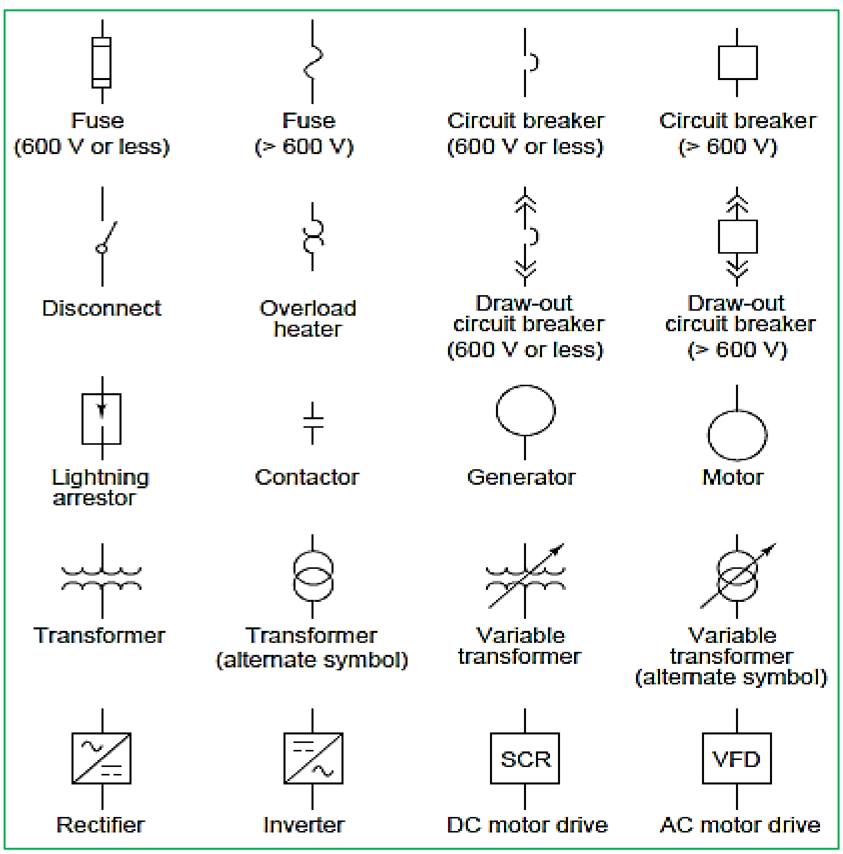
9. Liquid level measurement devices:



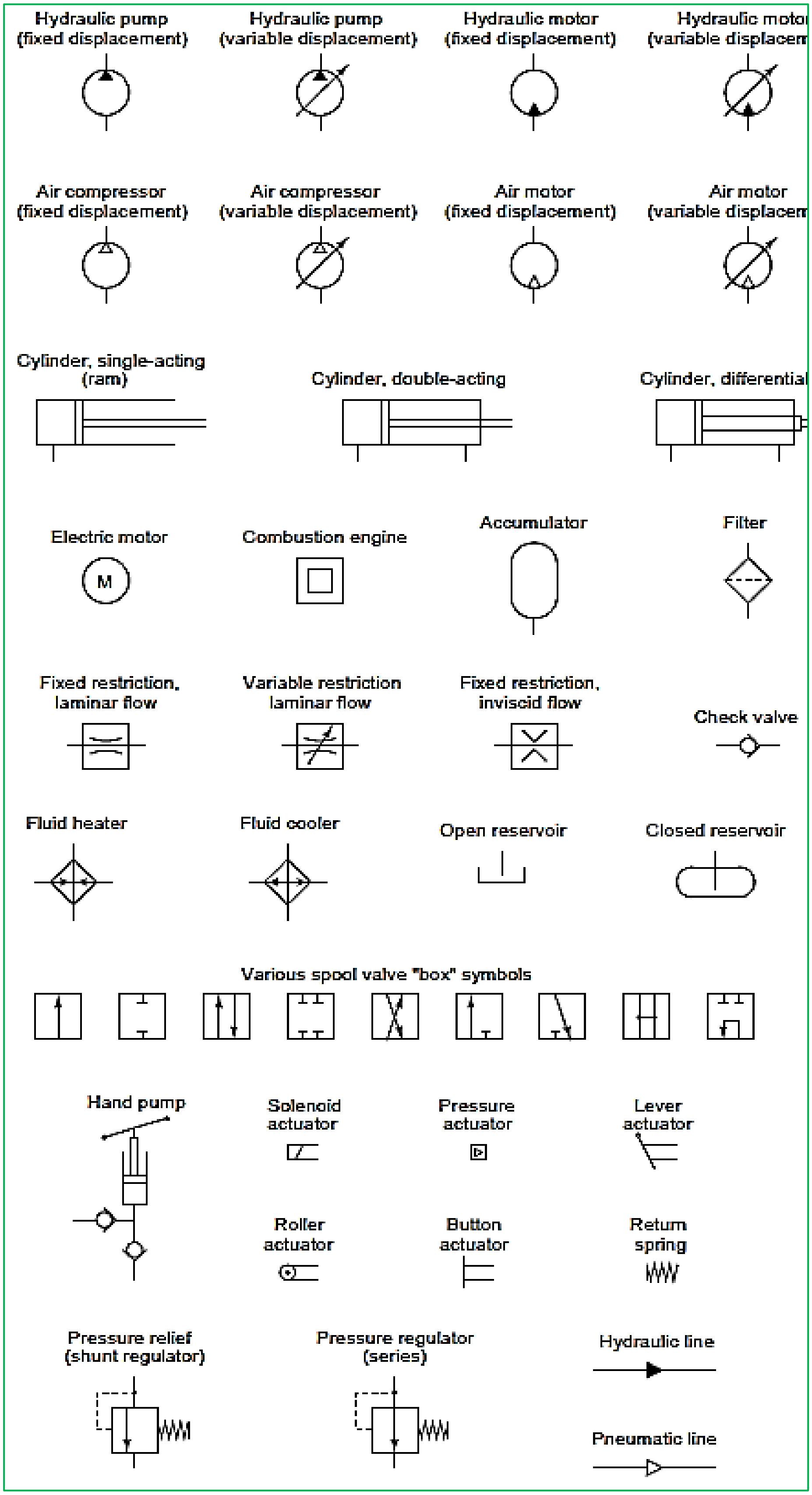
10. Functional diagram symbols:



11. Single-line electrical diagram symbols:



12. Fluid power diagram symbols:

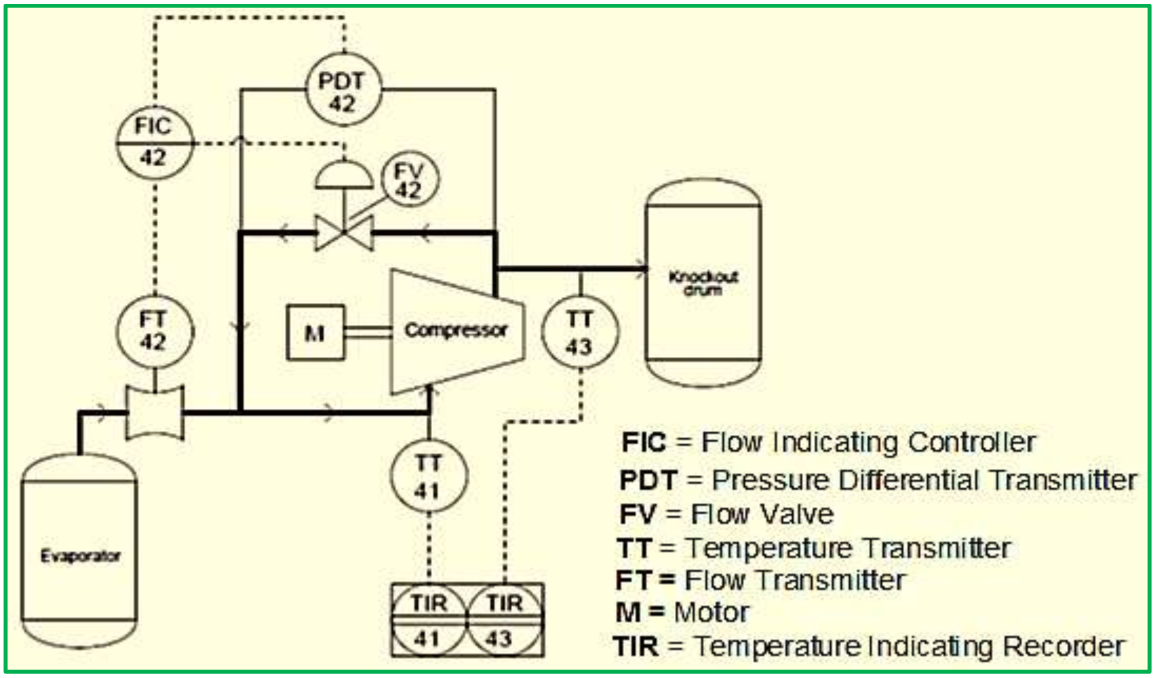


Instrumentation Identification Letters: A variety of other letter combinations are often used to identify details not standardized by the ISA. Some instrument tag letters are indicated in the page 12 list. The ISA-5.1 standard defines a standard tag number convention for valves, transmitters, other field devices, commonly applied as indicated below:

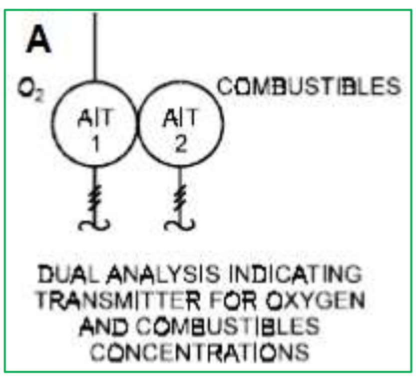
			Controllers				Switches and Alarm Devices*			Transmitters		
First-Letters	Initiating or Measured Vaiable	Final Element	Recording	Indicating	Blind	Self-Actuated Control Valves	High**	Low	Comb	Recording	Indicating	Blind
A	Analysis	AV	ARC	AIC	AC		ASH	ASL	ASHL	ART	AIT	AT
B	Burner/Combustion	BZ	BRC	BIC	BC		BSH	BSL	BSHL	BRT	BIT	BT
C	User's Choice											
D	User's Choice											
E	Voltage	EZ	ERC	EIC	EC		ESH	ESL	ESHL	ERT	EIT	ET
F	Flow Rate	FV	FRC	FIC	FC	FCV, FICV	FSH	FSL	FSHL	FRT	FIT	FT
FQ	Flow Quantity	FQV	FQRC	FQIC			FQSH	FQSL			FQIT	FQT
FF	Flow Ratio	FFV	FFRC	FFIC	FFC		FFSH	FFSL				
G	User's Choice											
H	Hand	HV		HIC	HC				HS			
I	Current	IZ	IRC	IIC			ISH	ISL	ISHL	IRT	IIT	IT
J	Power	JV	JRC	JIC			JSH	JSL	JSHL	JRT	JIT	JT
K	Time	KV	KRC	KIC	KC	KCV	KSH	KSL	KSHL	KRT	KIT	KT
L	Level	LV	LRC	LIC	LC	LCV	LSH	LSL	LSHL	LRT	LIT	LT
M	User's Choice											
N	User's Choice											
O	User's Choice											
P	Pressure/ Vacuum	PV	PRC	PIC	PC	PCV	PSH	PSL	PSHL	PRT	PIT	PT
PD	Pressure, Differential	PDV	PDRC	PDIC	PDC	PDCV	PDSH	PDSL		PDRT	PDIT	PDT
Q	Quantity	QZ	QRC	QIC			QSH	QSL	QSHL	QRT	QIT	QT
R	Radiation	RZ	RRC	RIC	RC		RSH	RSL	RSHL	RRT	RIT	RT
S	Speed/Frequency	SV	SRC	SIC	SC	SCV	SSH	SSL	SSHL	SRT	SIT	ST
T	Temperature	TV	TRC	TIC	TC	TCV	TSH	TSL	TSHL	TRT	TIT	TT
TD	Temperature, Differential	TDV	TDRC	TDIC	TDC	TDCV	TDSH	TDSL		TDRT	TDIT	TDT
U	Multivariable	UV										
V	Vibration/Machinery Analysis	VZ					VSH	VSL	VSHL	VRT	VIT	VT
W	Weight/Force	WZ	WRC	WIC	WC	WCV	WSH	WSL	WSHL	WRT	WIT	WT
WD	Weight/Force, Differential	WDZ	WDRC	WDIC	WDC	WDCV	WDSH	WDSL		WDRT	WDIT	WDT
X	Unclassified											
Y	Event/State/Presence	YZ		YIC	YC		YSH	YSL				YT
Z	Position/Dimension	ZV	ZRC	ZIC	ZC	ZCV	ZSH	ZSL	ZSHL	ZRT	ZIT	ZT
ZD	Gauging/Deviation	ZDV	ZDRC	ZDIC	ZDC	ZDCV	ZDSH	ZDSL		ZDRT	ZDIT	ZDT

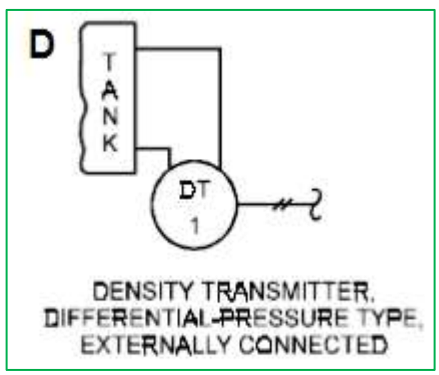
Note: It is common practice for engineering flow diagrams to omit the symbols of interlock-hardware components, actually necessary for a working system, particularly when symbolizing the electric interlock systems. For example, a *level switch* may be shown as tripping a pump, or separate flow and pressure switches may be shown as actuating a solenoid valve or other interlock devices. In both instances, *auxiliary electrical relays* and other components may be considered details to be shown elsewhere. By the same, a current transformer sometimes may be omitted, and its receiver is shown connected directly to the process, in this case the electric motor.

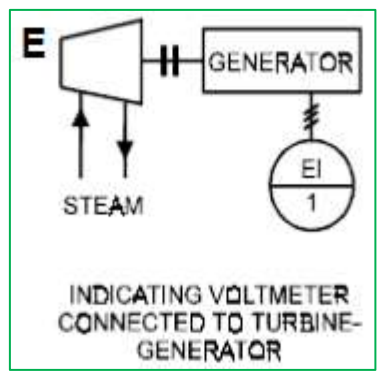
P&ID Examples: The next level shows some examples of P&ID, as the evaporator below:

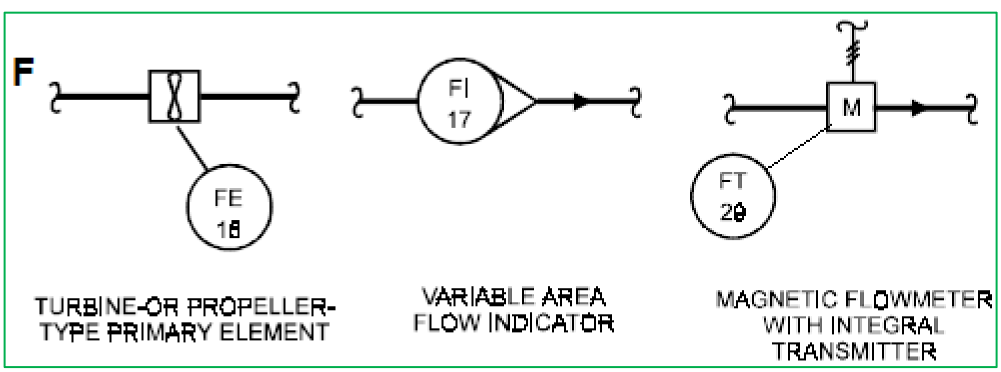


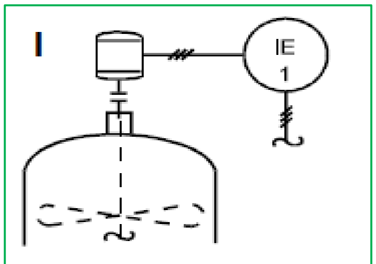
The *examples* below show how the instrumentations are used in control processes. All examples are indicated according to *ANSI/ISA-S5.1* and ***alphabetical order*** following the table above:



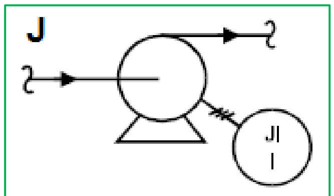




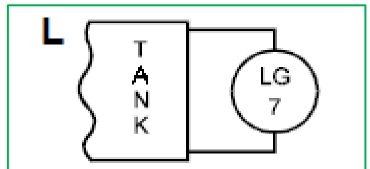




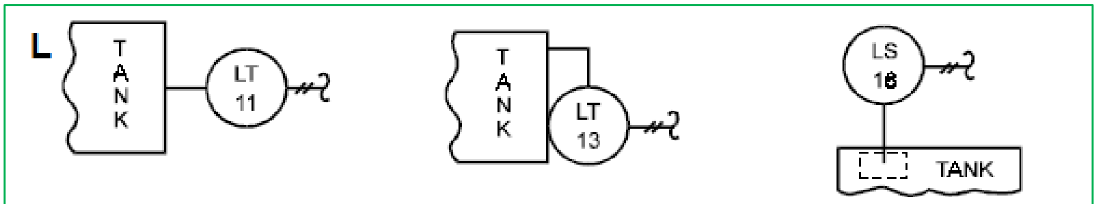
CURRENT TRANSFORMER MEASURING CURRENT OF ELECTRIC MOTOR



INDICATING WATTMETER CONNECTED TO PUMP MOTOR



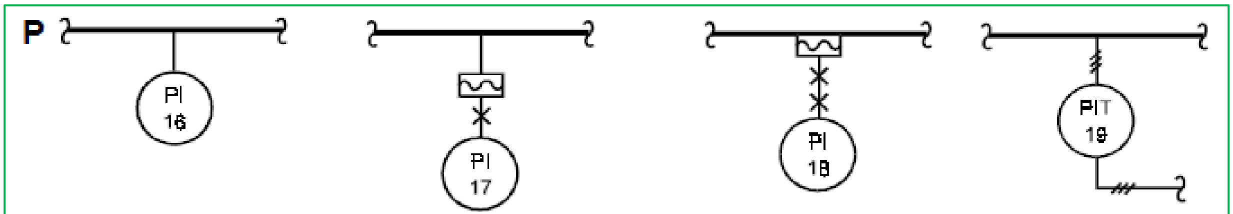
GAGE GLASS, EXTERNALLY CONNECTED



LEVEL TRANSMITTER, WITH ONE CONNECTION

LEVEL TRANSMITTER, DIFFERENTIAL-PRESSURE TYPE, MOUNTED ON TANK

LEVEL SWITCH, PADDLE WHEEL OR LEVER TYPE, TO MEASURE LEVEL OF SOLIDS



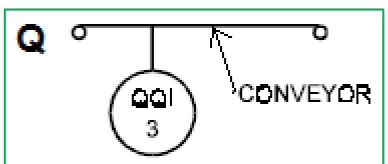
WITH PRESSURE LEAD LINE

LINE-MOUNTED

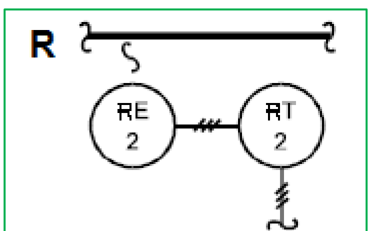
PRESSURE INDICATOR, DIRECT CONNECTED

PRESSURE INDICATOR CONNECTED TO DIAPHRAGM SEAL WITH FILLED SYSTEM

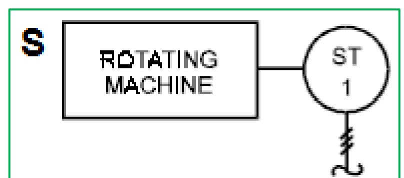
PRESSURE ELEMENT, STRAIN-GAGE TYPE, CONNECTED TO PRESSURE INDICATING TRANSMITTER



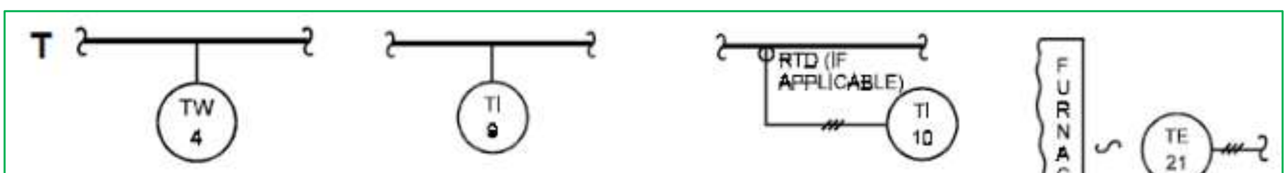
INDICATING COUNTER, MECHANICAL TYPE



RADIATION MEASURING ELEMENT AND TRANSMITTER



SPEED TRANSMITTER

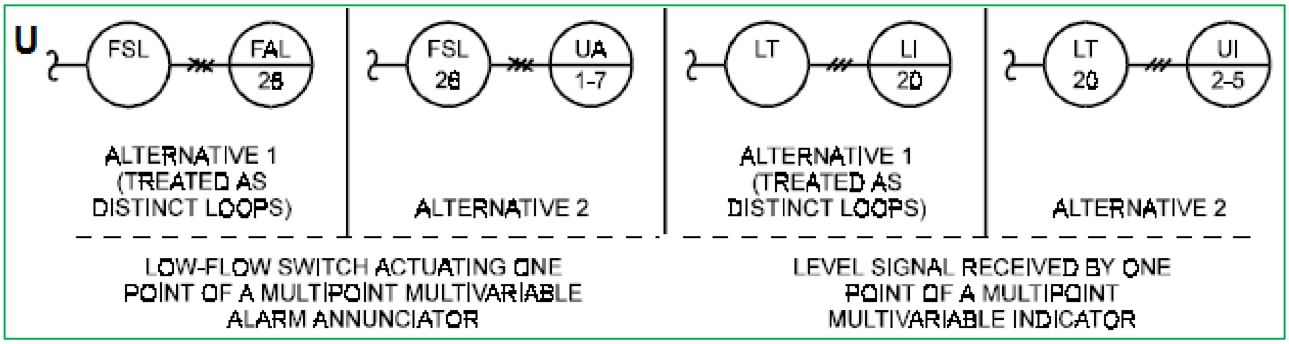


TEMPERATURE CONNECTION WITH WELL

BIMETALLIC-TYPE THERMOMETER, GLASS THERMOMETER, OR OTHER LOCAL UNCLASSIFIED TEMPERATURE INDICATOR

THERMOCOUPLE, RESISTANCE BULB (RTD) OR THERMISTOR (TH) CONNECTED TO TEMPERATURE INDICATOR

THERMAL-RADIATION-TYPE TEMPERATURE ELEMENT



ALTERNATIVE 1 (TREATED AS DISTINCT LOOPS)

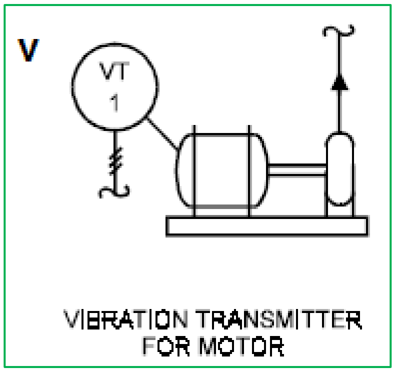
ALTERNATIVE 2

ALTERNATIVE 1 (TREATED AS DISTINCT LOOPS)

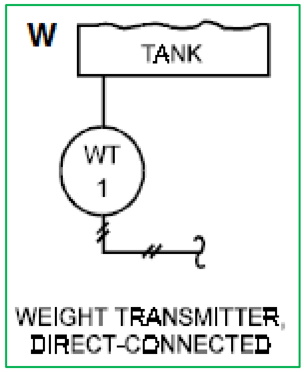
ALTERNATIVE 2

LOW-FLOW SWITCH ACTUATING ONE POINT OF A MULTIPOINT MULTIVARIABLE ALARM ANNUNCIATOR

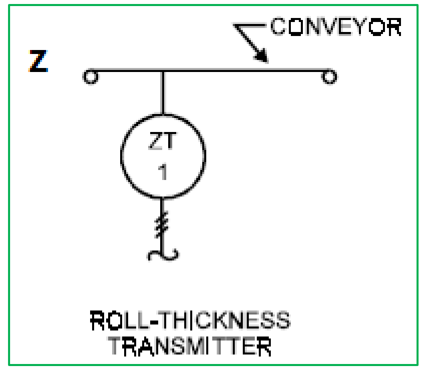
LEVEL SIGNAL RECEIVED BY ONE POINT OF A MULTIPOINT MULTIVARIABLE INDICATOR



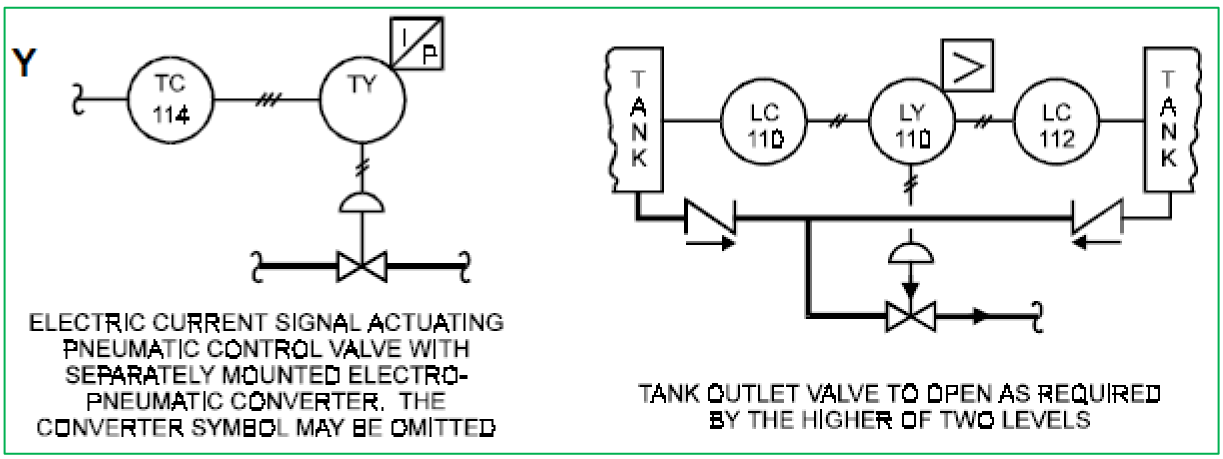
VIBRATION TRANSMITTER FOR MOTOR



WEIGHT TRANSMITTER, DIRECT-CONNECTED



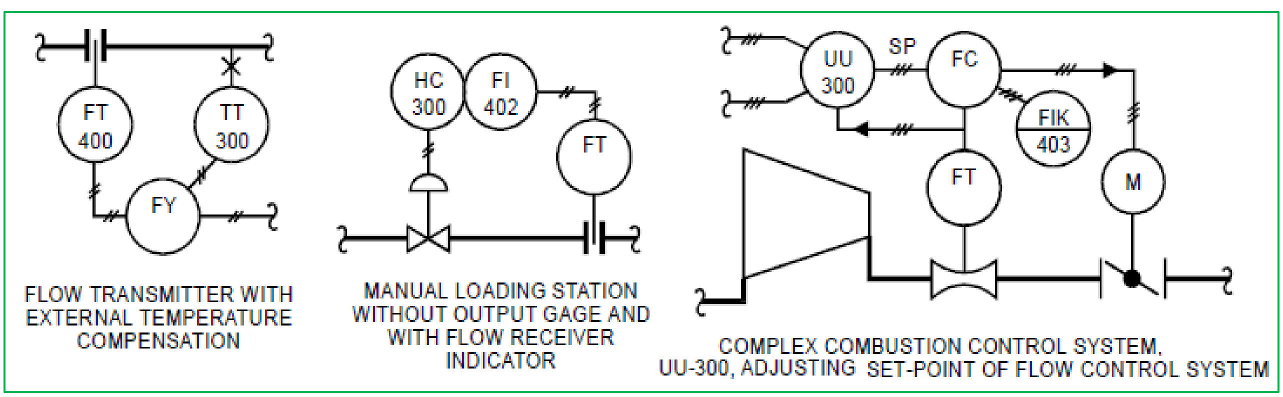
ROLL-THICKNESS TRANSMITTER



ELECTRIC CURRENT SIGNAL ACTUATING PNEUMATIC CONTROL VALVE WITH SEPARATELY MOUNTED ELECTRO-PNEUMATIC CONVERTER. THE CONVERTER SYMBOL MAY BE OMITTED

TANK OUTLET VALVE TO OPEN AS REQUIRED BY THE HIGHER OF TWO LEVELS

Examples: Miscellaneous Combinations:

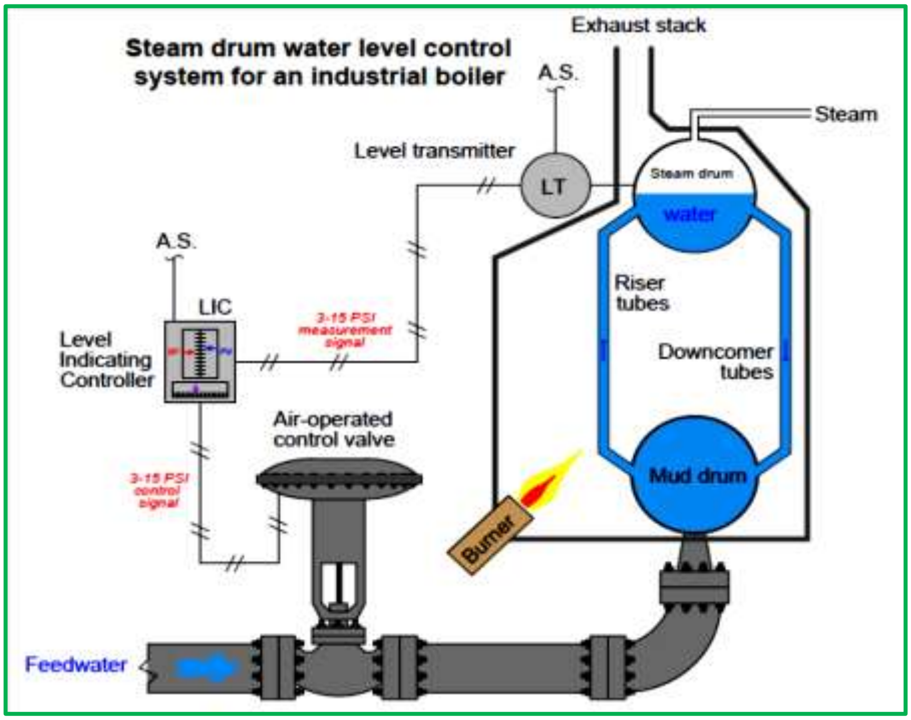


FLOW TRANSMITTER WITH EXTERNAL TEMPERATURE COMPENSATION

MANUAL LOADING STATION WITHOUT OUTPUT GAGE AND WITH FLOW RECEIVER INDICATOR

COMPLEX COMBUSTION CONTROL SYSTEM, UU-300, ADJUSTING SET-POINT OF FLOW CONTROL SYSTEM

Boiler Water Level Control System: In this illustrative example, below, is shown the essential elements of a water level control system, showing transmitter, controller, and a control valve:

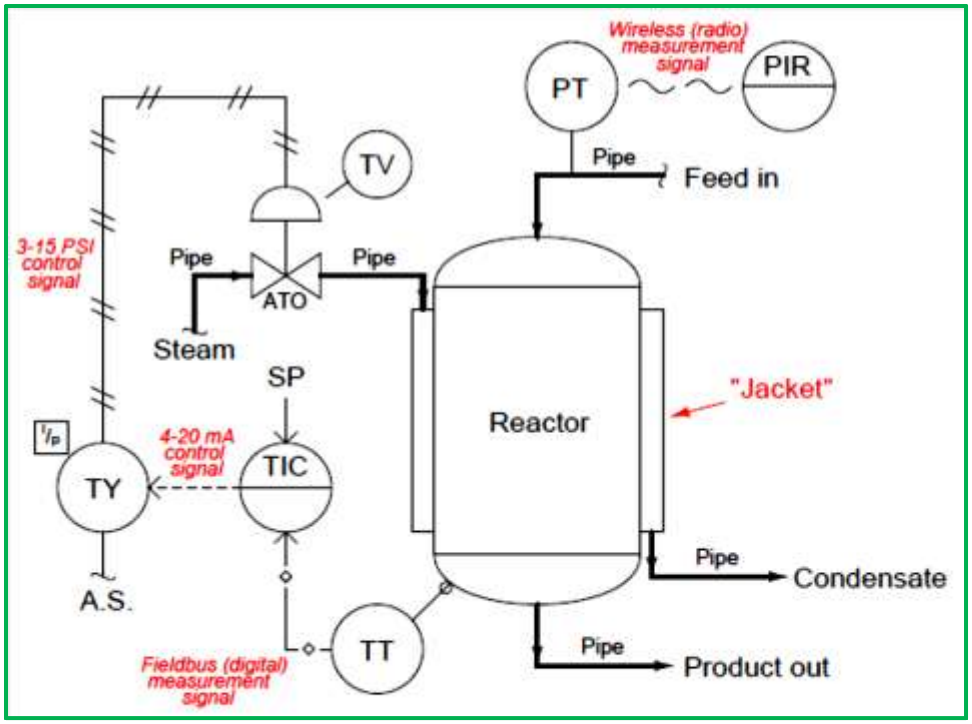


The first instrument in this control system is the *level transmitter, or "LT"*. The purpose of this device is *to sense the water level* in the steam drum and report that measurement to the controller in the form of an instrument signal. This pneumatic signal is sent to the next instrument in the control system, the *level indicating controller, or "LIC"*. The purpose of this instrument is to compare the level of transmitter's signal with a setpoint value entered by a human operator (the desired water level in the steam drum).

The controller, then, generates an output signal telling the control valve to either introduce *more or less water into the boiler,* to maintain the steam drum water level at setpoint. The boiler's steam drum level controller outputs a pneumatic output signal to the control valve, using the same 3 to 15 PSI standard to command different valve positions:

Controller output signal pressure	Control valve position
3 PSI	0% open (Fully shut)
6 PSI	25% open
9 PSI	50% open
12 PSI	75% open
15 PSI	100% (Fully open)

Chemical Reactor Temperature Control: In this example, *three different signal standards* are used to convey information between the instruments. Below, a P&ID (Process and Instrument Diagram) shows the inter-relationships of the process piping, vessels, and instruments. The purpose of this control system is to ensure the *chemical solution inside the reactor vessel to be maintained at a* *constant temperature,* by measuring the temperature of the reactor vessel, and throttling the steam inlet from a boiler to the steam jacket to *add more or less heat as needed.*



A *temperature transmitter (TT)* is used to connect with the *temperature indicating controller (TIC)*, through a *digital electronic instrument signal*, sometimes referred to as a *fieldbus*, rather than an analog type (such as 4 to 20 mA or 3 to 15 PSI). However, this electronic signal does not go directly to the control valve, it passes through a *transducer labeled "TY",* which is used to convert the 4 to 20 mA electronic signal into a 3 to 15 PSI pneumatic signal to actuate the valve.

At the *temperature control valve (TV)*, the 3 to 15 PSI signal applies a force on the diaphragm actuator to move the valve mechanism against the restraining force of a large spring, opening the valve, as more air signal pressure is applied to its actuator. The letters "ATO" immediately below the valve symbol mean "Air-To-Open," referring to the direction of this valve mechanism (wider open).

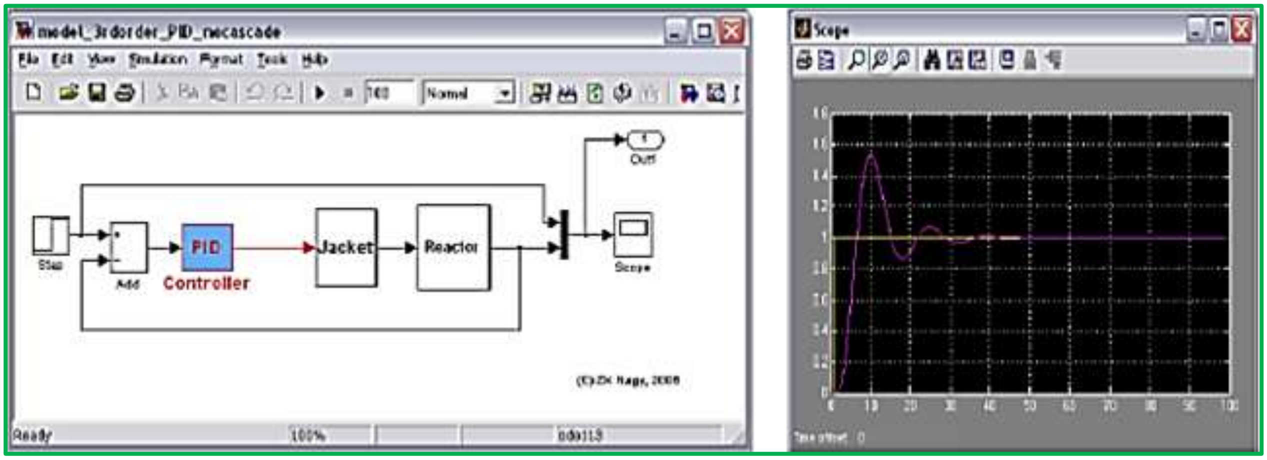
In essence, the signal transducer acts as an electrically-controlled air pressure regulator, taking the supply air pressure (usually 20 to 25 PSI), thus, regulating to a level commanded by the controller's electronic output signal. The *transmitter* in this system is, *then a computer*, and so is the controller. The *transmitter reports* the process variable (as example, the reactor temperature) to the controller using digital bits of information. Here there is no analog scale of 4 to 20 milliamps, but rather *electric voltage/current pulses representing the 0 and 1 binary data*.

Thus, if an increasing process variable signal requires a decreasing controller output signal, the controller in this case needs to be configured *for reverse action*. Alternatively, if the steam valve were *air-to-close (ATC)* and not *air-to-open (ATO)*, for controlling the reactor temperature would be necessary that the controller outputs an increased signal to the valve, requiring less steam should be sent to the reactor.

13. PROCESS CONTROL & SOFTWARE SIMULATIONS:

SIMULINK: Is a part of MATLAB (MATrix LABoratory) that can be used for modeling, and analyzing dynamic systems, including controls, signal processing, communications, and other complex systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Systems can also be multirate, that is, they can have different parts that are sampled or updated at different rates.

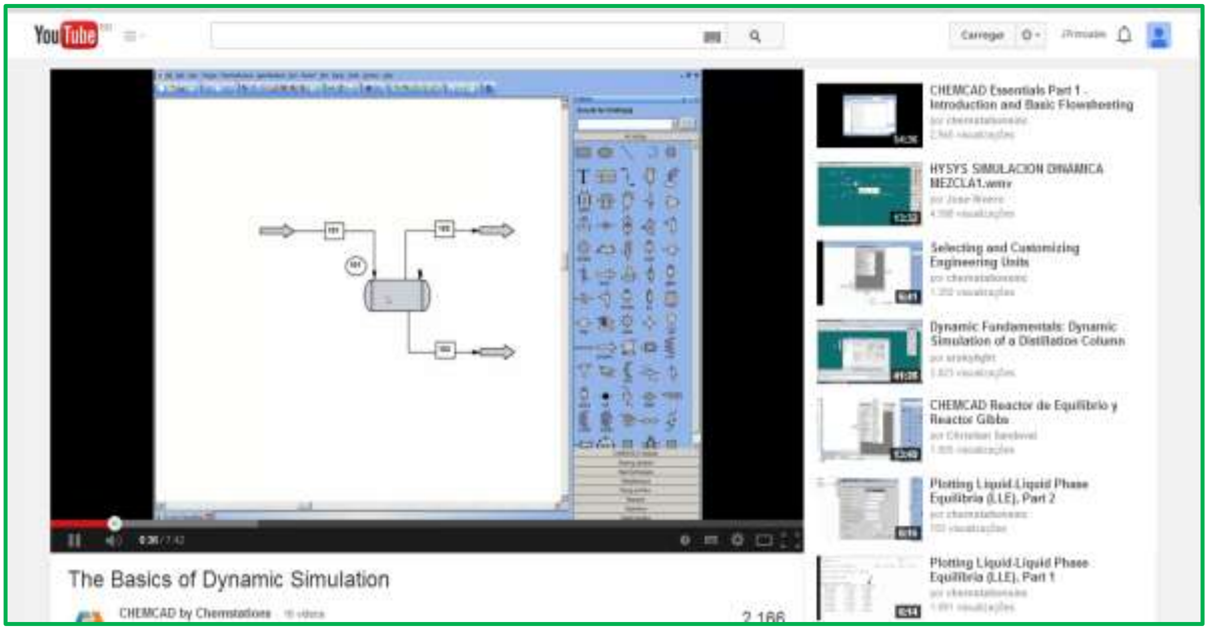
SIMULINK adds a new class, called block diagram windows, where models are created and edited primarily by mouse-driven commands. You can construct your block diagram by drag-and-dropping the appropriate blocks from the main Simulink window. (Visit http://www.mathworks.com/).

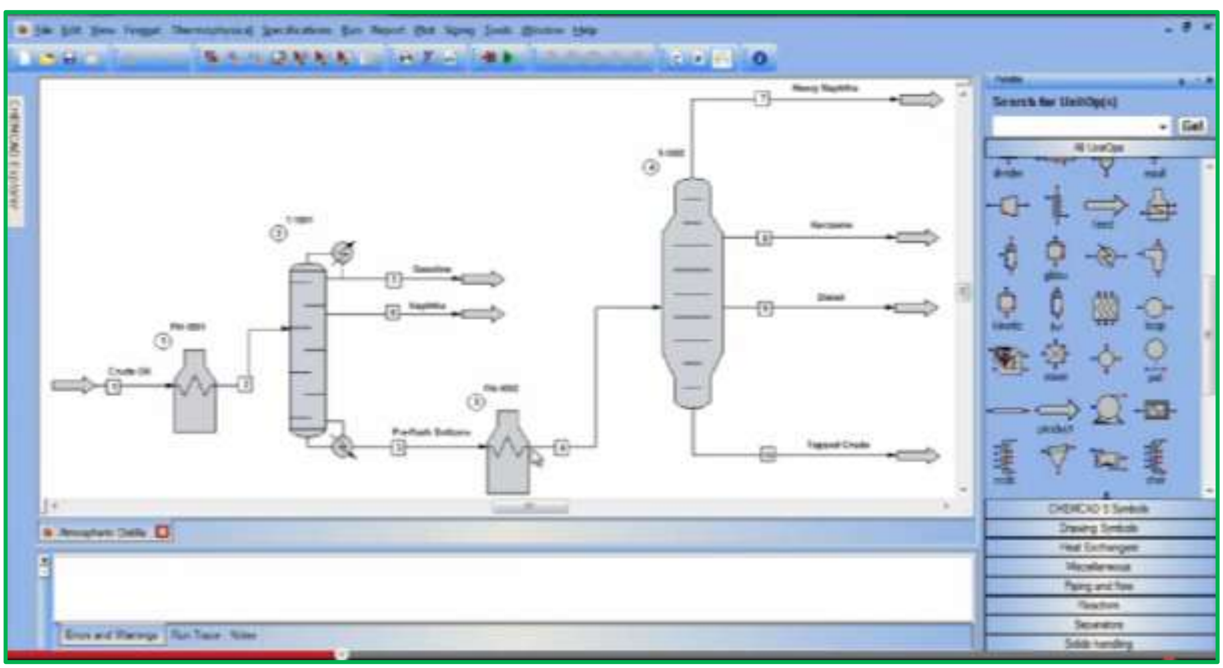


The Simulink Introduction videos give a brief introduction how it can be used to simulate a transfer function and build a PID controller. (See https://www.youtube.com/watch?v=ThA7zhLX98A).

CHEMCAD: Is from Chemstations, an intuitive suite of chemical process simulation softwares that broadens an engineer's capabilities, commonly used for process design, simulation, implementation, and plant operations. CHEMCAD is scalable and allows the users to purchase only the features they need for a specific industry and process, enabling them to create their own customized version. Each module in the suite can be purchased separately and all modules work together within the same interface. (Visit http://www.chemstations.com/).

The CHEMCAD 5 Process Simulation Software can be used in various process industry areas, as different as oil refining and cosmetics manufacture. Exceptional ease of this program running in all platforms of Microsoft Windows, have won a wide acceptance, from engineering companies, to process plants, to universities. (See https://www.youtube.com/watch?v=IgowkvM6gPo).





14. REFERENCES AND LINKS:

REFERENCES:

Kuphaldt, Tony R., Lessons in Industrial Instrumentation.

Liptak, Bela G., Instrument Engineers' Handbook – Process Control Volume II, Third Edition, 1999.

Mollenkamp, Robert A., Introduction to Automatic Process Control, ISA, 1984.

ANSI/ISA-84.00.01-2004 Part 1 (IEC 61151-1 Mod), "Functional Safety: Safety Instrumented Systems for the Process Industry Sector – Part 1: 2004.

ANSI/ISA-84.00.01-2004 Part 2 (IEC 61151-2 Mod), "Functional Safety: Safety Instrumented Systems for the Process Industry Sector – Part 2: 2004.

LINKS:

http://www.pacontrol.com/ - Online Training and Tutorial

http://www.instrumentation.co.za/

http://www.atctrain.com/ - Training

http://www.spiraxsarco.com/

http://www.appliedcontrolequipment.com/

http://www.omega.com/

http://www.emerson.com/en-US/Pages/Default.aspx

http://www.altera.com/

http://www.modbus.org/

VIDEOS:

https://www.youtube.com/watch?v=ThA7zhLX98A

https://www.youtube.com/watch?v=IgowkvM6gPo