Introduction to Instrumentation and Measurement of Process Variables-I

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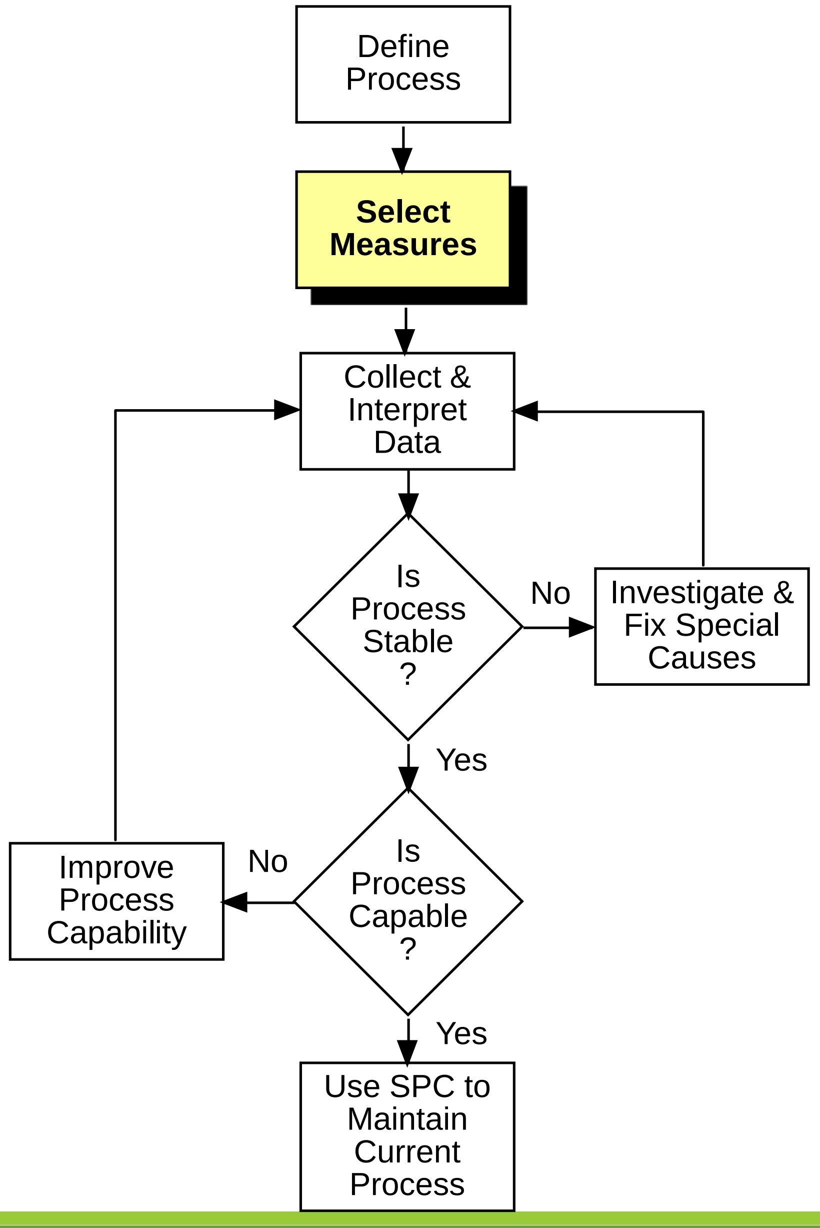
Instrumentation

Instrumentation is the variety of measuring instruments to monitor and control a process. It is the art and science of measurement of process variables within a production, laboratory, or manufacturing area.

Process Variables

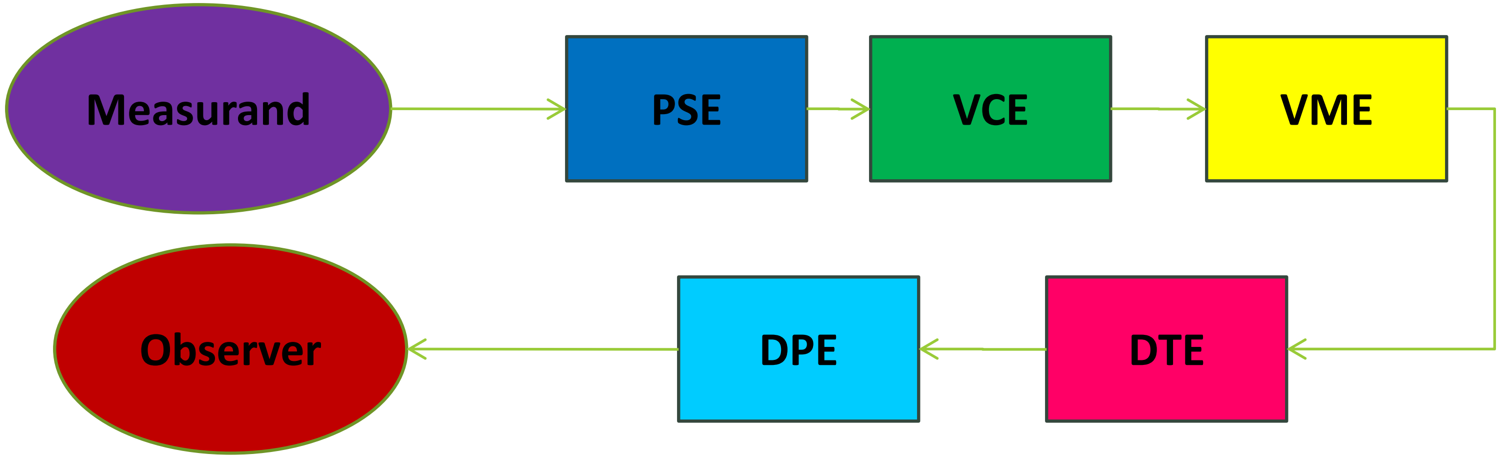
Why Measurement is so important????



Or

Analysis to make the process more effective.

General Block Diagram for Measurement System

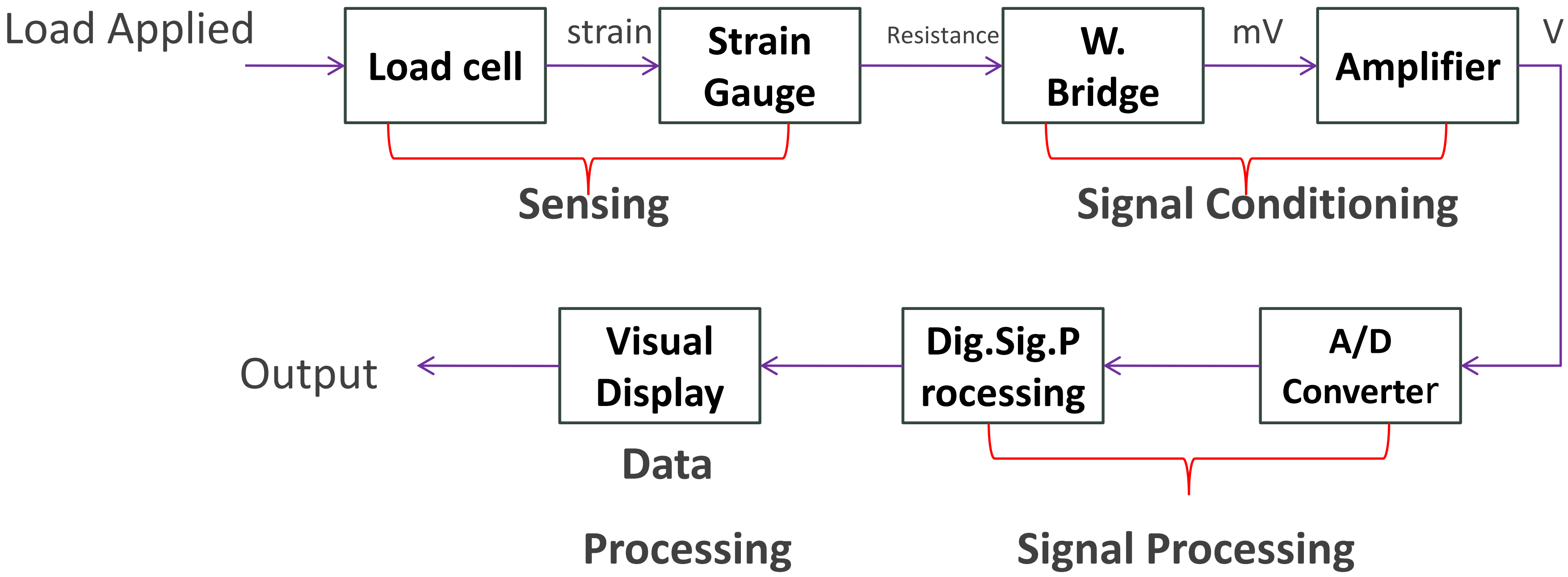


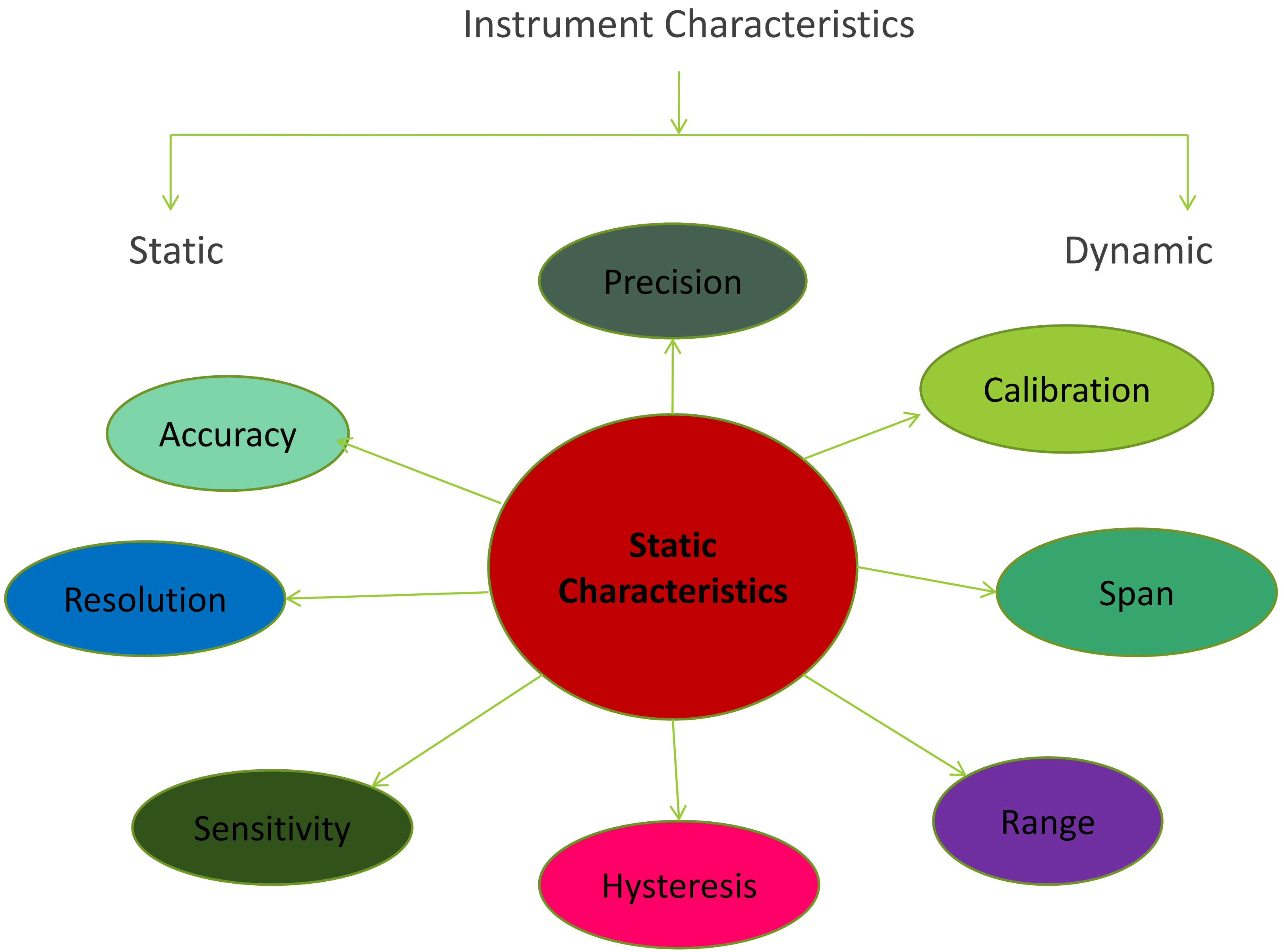
PSE	:	Primary Sensing Element
VCE	:	Variable conversion Element
VME	:	Variable Manipulation Element
DTE	:	Data Transmission Element
DPE	:	Data Presentation Element

Elements of Measurement System

1. **PSE** : Primary sensing element of an instrument is that which first receives energy from the measure medium and produces an output depending in some way on the value of the measured quantity.
2. **VCE** : This element converts the output signal of PSE into a more suitable variable which is compatible with the next stage.
3. **VME** : In this process physical nature of the variable is preserved.
4. **DTE** : It transmits the data from one element to the other element through various techniques like telemetry etc.
5. **DPE** : It performs the translation function, such as the simple indication of a pointer moving over a scale.

Example – Weight measurement system




Instrument Characteristics
Static
Dynamic
Precision
Calibration
Accuracy
Static Characteristics
Resolution
Span
Sensitivity
Range
Hysteresis

Static Characteristics

Accuracy: It is the closeness with which an instrument reading approaches the true value of the quantity being measured.

Accuracy may be defined as

1. % of full scale
2. % of Span
3. % of the reading

Precision : It is a measure of the reproducibility of the measurements. i.e. Given a fixed value of the quantity , precision is a measure of the degree of agreement within a group of measurements.

For ex. Consider a measurement of known voltage of 100 V with a meter , five readings are taken and the indicated values are 104,103,105,103 and 105 V. From these values it is seen that the instrument is not accurate but a precision of ±1% is indicated since the max deviation from the mean reading of 104 is only 1 V.

Resolution : The smallest increment in input which can be detected by an instrument is called the resolution of an instrument.

Static Characteristics Contd:-

Sensitivity : Sensitivity is defined as the change in output divided by change in input.

Hysteresis : It is the non – coincidence of loading and unloading curves. This arises because of the fact that all the energy put into the stressed parts when loading is not recoverable upon unloading.

Range and span: A thermometer is calibrated between 200 to 500 degC.

Hence

Range	=	500 degC
Span	=	300 degC

Calibration : It is the process of comparing a particular instrument to the primary standard or secondary standard or a standard of higher accuracy than that of the instrument.

Select Measures

Select Measures:-

Generally in the process industry there are various parameters which are being measured and controlled simultaneously and they are as follows:-

- Temperature
- Pressure
- Flow
- Level
- pH
- Brix
- Moisture
- Gas Analysers

In Situ/ Off Situ Measurements

- Measurement of the any parameters are done by electrical arrangement, mechanical arrangement and the combination of both.
- The output of the electrical arrangement can be programmed and used to control in various manner
- In the case of mechanical arrangements the output can be seen at the situ without further any signal conditionings.

Transducer

Transducer is a Device which converts one form of energy to another like Mechanical Energy into Electrical Energy or vice versa.

For eg:- Very Basic:- Fan where the electrical energy gets converted into mechanical energy.

There are several types of transducer which are currently being used in the process industry and some of them are being as follows:-

I. RTD
II. LVDT
III. Capacitive
IV. Piezoelectric for e.g quartz crystal, Rochelle salt, barium titanate
V. Strain gauge

Temperature

Temperature Measurement has been classified widely into two types:-

I. **Contact Type**
   I. **Liquid Filled Thermometer**
   II. **Gas Filled Thermometer**
   III. **Bimetallic Thermometer**
   IV. **Resistance Temperature Detector (RTD)**
   V. **Thermistor**
   VI. **Thermocouple (T/C)**

II. **Non-contact Type.**
   I. **Pyrometers**
   II. **Infrared**

Liquid Filled Thermometers

A Liquid is contained in a glass bulb which is connected to a capillary of the same glass and the end is sealed with an expansion bulb. The space above the liquid is a mixture of nitrogen and the vapor of the liquid. For the working temperature range, the meniscus or interface between the liquid is within the capillary. With increasing temperature, the volume of liquid expands and the meniscus moves up the capillary. The position of the meniscus shows the temperature against an inscribed scale.

Depending upon the range to be measured the liquid in the thermometer is chosen such as Mercury for range:- -37 deg C to 357 deg C

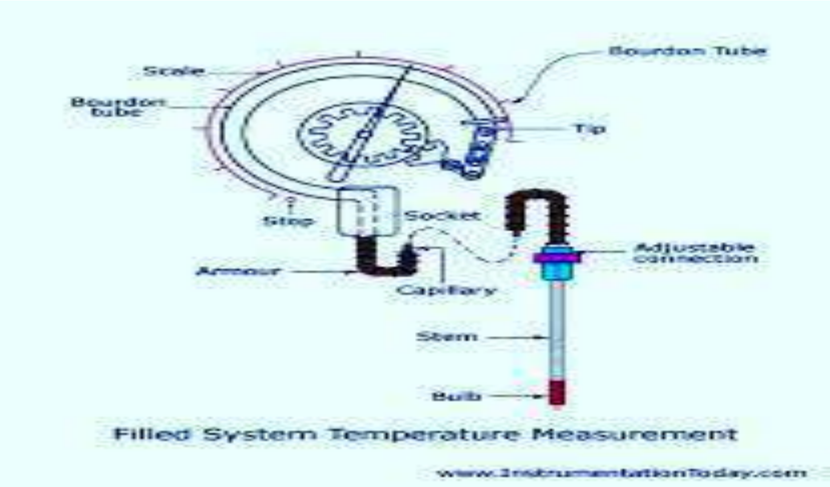
Range for Alcohol filled thermometer:- $-112^{o}C$ to $78^{o}C$
Other liquid used can be used **are pure ethanol toluene, kerosene or Isoamyl acetate.**

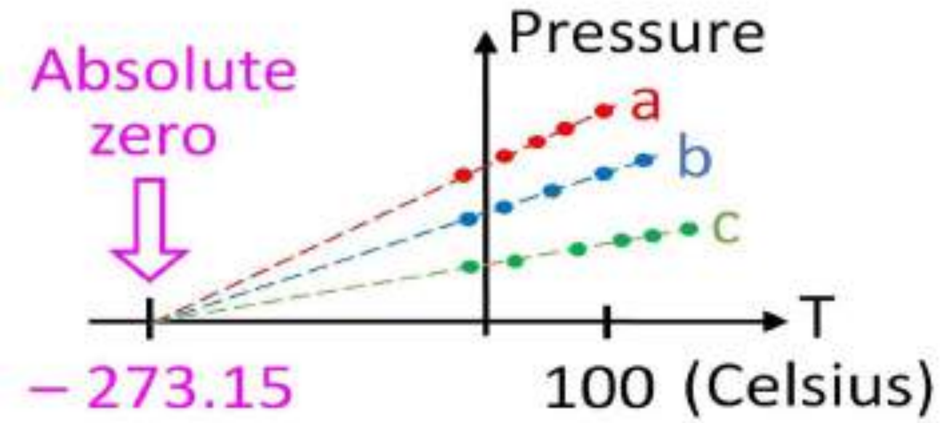
Gas Filled Thermometer

- Gas Filled Thermometer is designed for accurate temperature measurement by a flexible capillary tube made of stainless steel and filled with nitrogen gas under pressure.

- The capillary tube is wound to form a spiral spring. As the temperature rises, the pressure of the gas inside the tube increases proportionally, causing the spring to unwind. This rotary movement amplified by a mechanism, action the pointer of the thermometer.

- To the extent that the gas is ideal, the pressure depends linearly on temperature, and the extrapolation to zero pressure occurs at absolute zero





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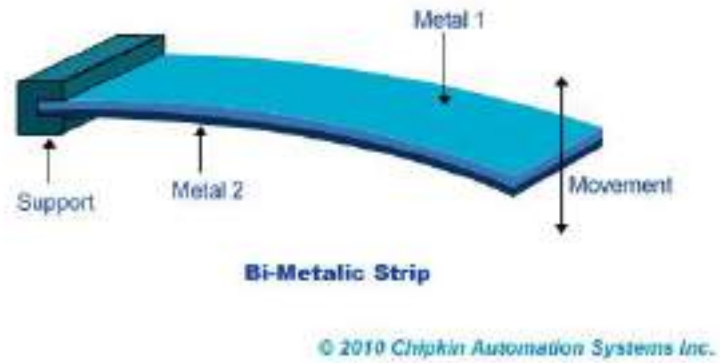
Bimetallic Thermometer

- **A bimetallic strip is used to convert a temperature change into mechanical displacement.**

- **The strip consists of two strips of different metals which expand at different rates as they are heated, usually steel and copper, or in some cases steel and brass.**

- **The strips are joined together throughout their length by riveting, brazing or welding. The different expansions force the flat strip to bend one way if heated, and in the opposite direction if cooled below its initial temperature.**

- **The metal with the higher coefficient of thermal expansion is on the outer side of the curve when the strip is heated and on the inner side when cooled**



Resistance Temperature Detector(RTD)

- **The electrical conductivity of a metal depends on the mobility of the conduction electrons. If a voltage is applied to the ends of a metal wire the electrons move to the positive pole.**

- **Faults in the crystal lattice interfere with this movement. They include foreign or missing lattice atoms, grain boundaries, and atoms on inter-lattice positions. Since these fault positions are independent of temperature they produce a constant resistance.**

- **With rising temperature the atoms of the metal lattice exhibit increasing oscillations about their rest positions and thereby impede the movement of the conduction electrons. Since this oscillation increases linearly with temperature, the resistance increase caused by it depends as a first approximation directly on the temperature.**

RTD Contd:-

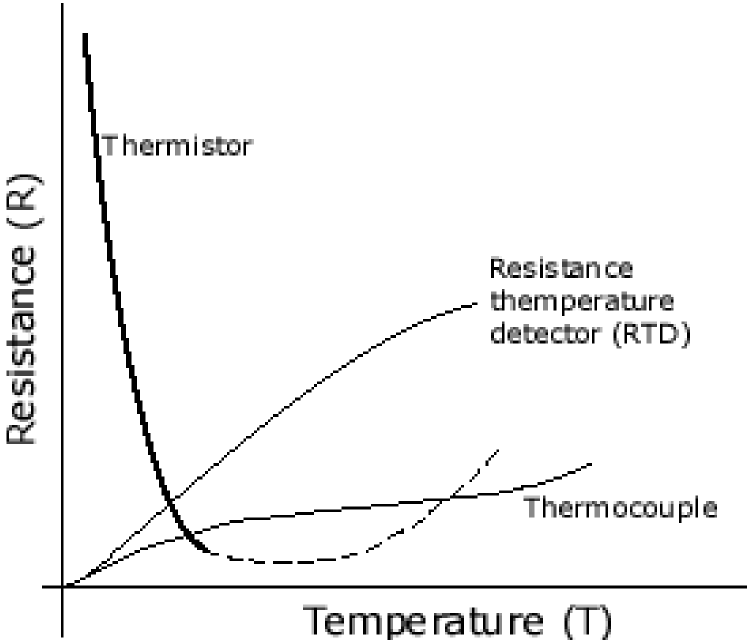
Accordingly , with the increase in the temperature the resistance of the metal increases and hence they are also known as Positive Temperature Coefficient (PTC) Sensors. The relation between the temperature and the resistance of the metal is as under:-

$$Rt = R_0(1+\alpha t)$$

Rt = Resistance at temperature t degC

R_0 = resistance at 0 degC

α = Temperature coefficient of resistance



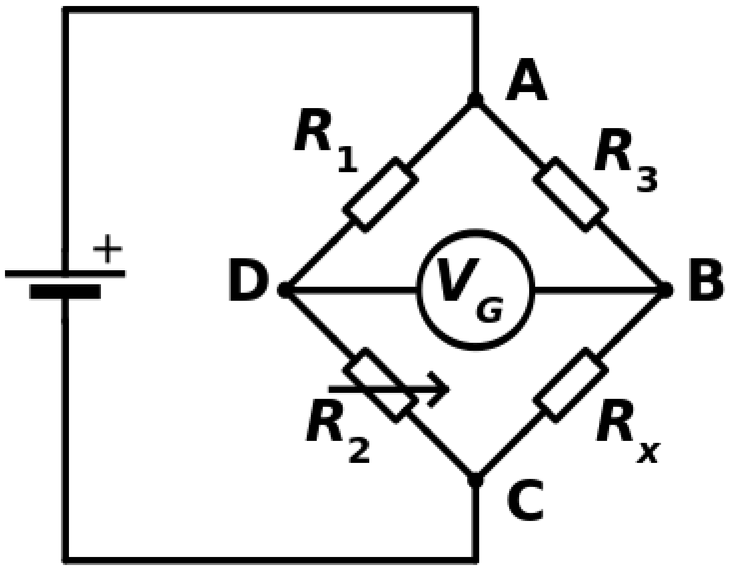
RTD Contd:-

- In RTD the main metals in use are platinum and nickel. The most widely used sensor is the 100 ohm or 1000 ohm RTD or platinum resistance thermometer.

- Commonly they are known as Pt100 and Pt 1000 which means that when the temperature is 0degC the resistance of Pt 100 will be 100 Ohms and Pt1000 will be 1000 Ohms.

- RTD's are the most accurate sensors for industrial applications and also offer the best long-term stability. A representative value for the accuracy of a platinum resistance is +0.5 percent of the measured temperature. After one year there may be a shift of +0.05°C through aging. Platinum resistance thermometers can cover temperature ranges from -200 to 800°C.
- Temperature coefficient i.e α of Platinum RTD is 0.00385 Ohms/Ohm/ºC and linear range is 0-200deg C

RTD Contd:-



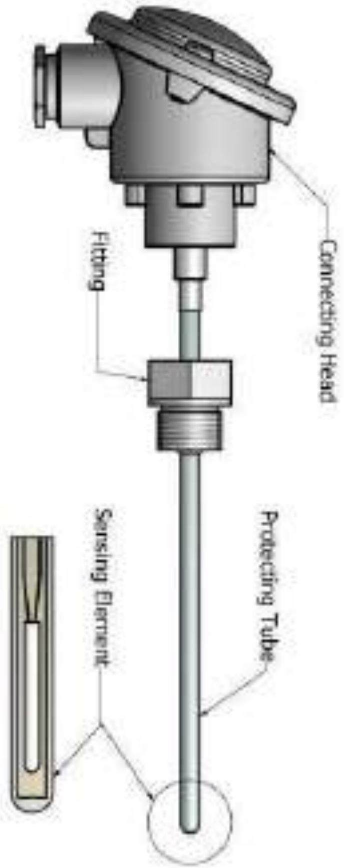
At the point of balance, the ratio of:-

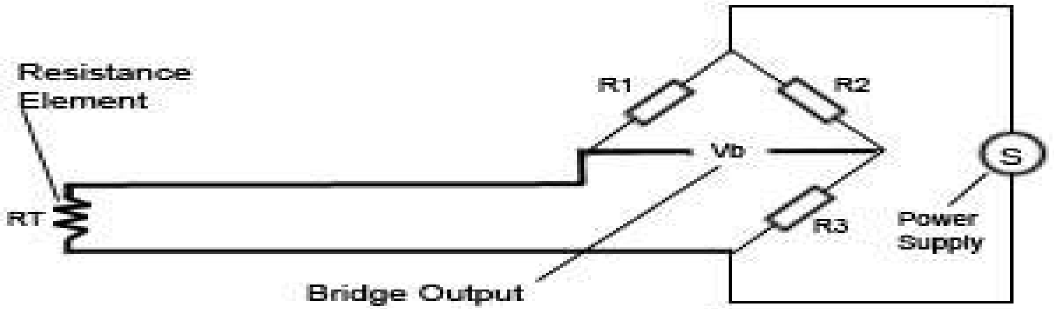
$$\frac{R_2}{R_1} = \frac{R_x}{R_3}$$

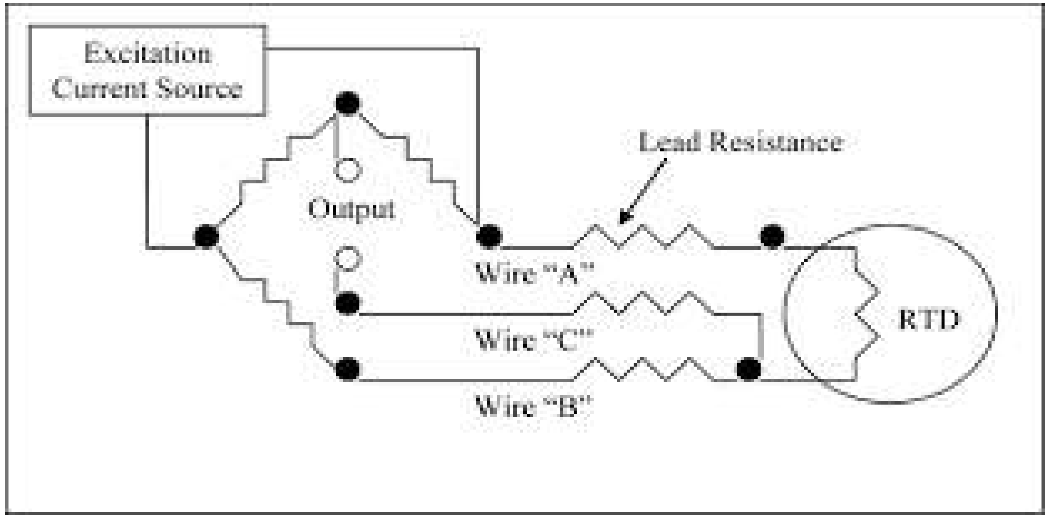
$$\Rightarrow R_x = \frac{R_2}{R_1} \cdot R_3$$

Wheat Stone Bridge

RTD Contd:-

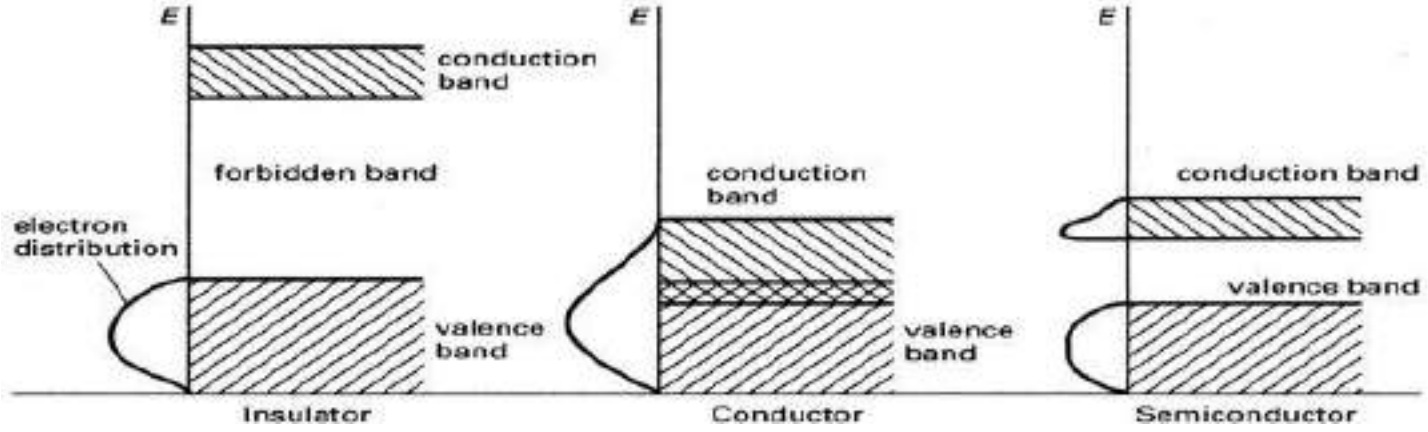

Connecting Head
Fitting
Protecting Tube
Sensing Element


Resistance
Element
RT
R1
R2
Vb
R3
S
Power
Supply
Bridge Output


Excitation
Current Source
Output
Lead Resistance
Wire "A"
Wire "C"
Wire "B"
RTD

Thermistor

Thermistors are made from certain metal oxides whose resistance decreases with increasing temperature. Because the resistance characteristic falls off with increasing temperature they are called negative temperature coefficient (NTC) sensors.



Thermistor Contd:-

- Due to the nature of the basic process the number of conducting electrons increases exponentially with temperature; the characteristic therefore exhibits a strongly rising form. This pronounced non-linearity is a disadvantage of NTC resistors and limits their useful temperature span to about 100°C.

- Their field of use is limited to monitoring and indicating applications where the temperatures do not exceed 200°C. In such simple applications they are actually preferable to more expensive thermocouples and RTD's in view of their low cost and the comparatively simple electronic circuitry required. In addition they can be produced in very small designs with a fast response and low thermal mass.

- As compared to the RTD they have very high temperature coefficient and hence they are more sensitive than RTD

Thermocouple

Thermocouple is based on Seebeck effect, *“in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances. When heat is applied to one of the two conductors or semiconductors, heated electrons flow toward the cooler one.”*

Thermocouple Contd:-

Mathematically, we can represent the Seeback effect as follows:-

$$E = \int (Q_a - Q_b)\, dT$$

Qa and Qb – Thermal Transport Constant of the material respectively

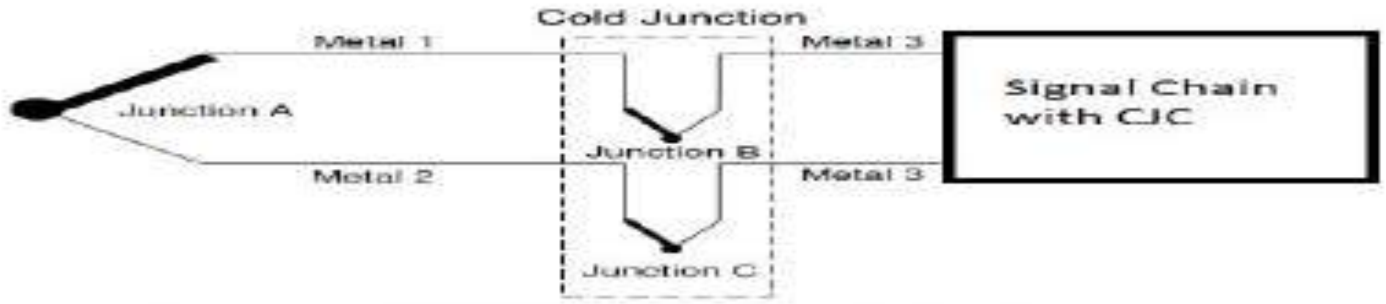
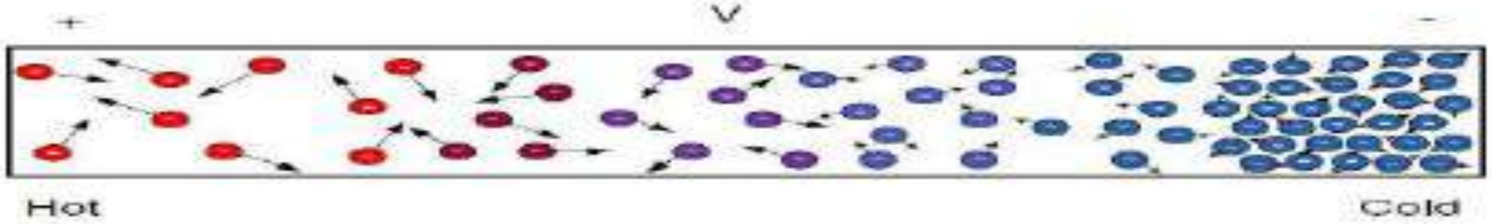


Figure 1. Thermocouple Junction Diagram



Cold Junction Compensation T/C

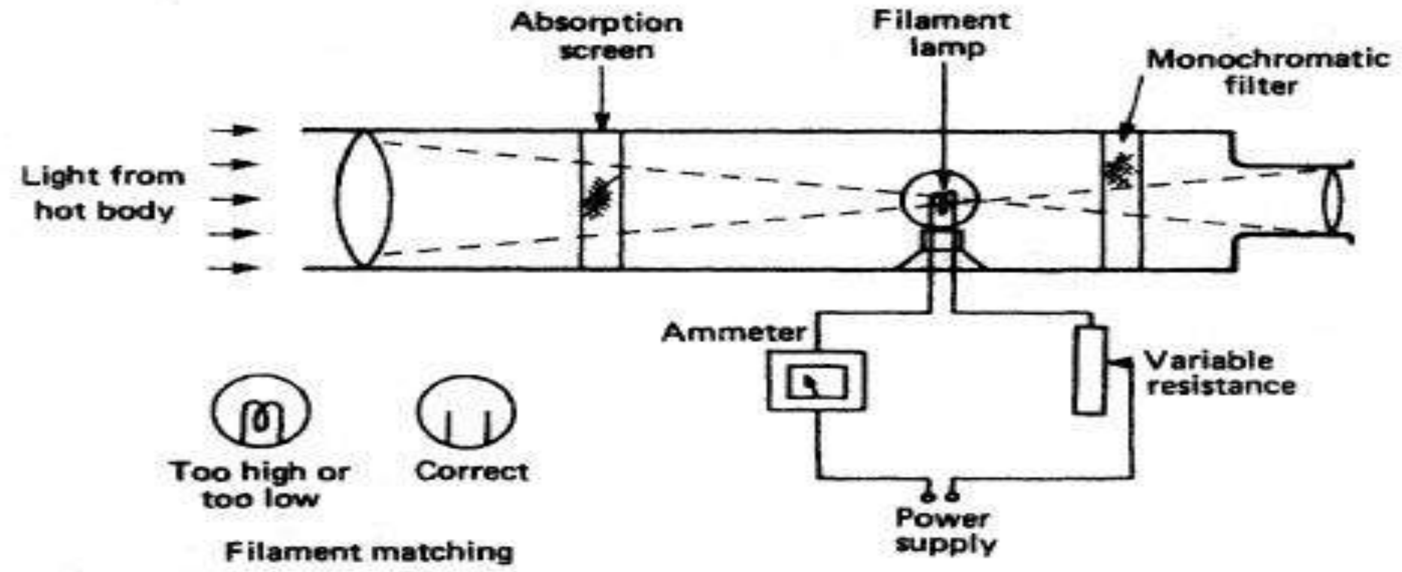
In a classical design, one end of a thermocouple is kept in an ice bath (junctions B and C in Figure 1) in order to establish a known temperature. In reality, for most applications, providing a true ice point reference is not practical. Instead, the temperature of junctions B and C of the thermocouple are continuously monitored and used as a point of reference to calculate the temperature at junction A at the other end of the thermocouple. These junctions are known as the cold junctions or ice point for historical reasons, although they do not need to be kept cold or near freezing. These endpoints are referred to as junctions because they connect to some form of terminal block that transitions from the thermocouple alloys into the traces used on the printed circuit board (PCB), which is usually copper. This transition back to copper is what creates the cold junctions B and C. Because of the law of intermediate metals, junctions B and C can be treated as a single reference junction, provided that they are held at the same temperature or isothermal. When the temperature of the reference junction is known, the absolute temperature at junction A can be calculated. Measuring the temperature at junctions B and C and then using that temperature to calculate a second temperature at junction A is known as cold-junction compensation.

Types of thermocouple

Type	Material	Normal Range, °C
J	Iron-constantan	–190 to 760°C
T	Copper-constantan	–200 to 37°C
K	Chromel-alumel	–190 to 1260°C
E	Chromel-constantan	–100 to 1260°C
S	90% platinum + 10% rhodium-platinum	0 to 1482°C
R	87% platinum + 13% rhodium-platinum	0 to 1482°C

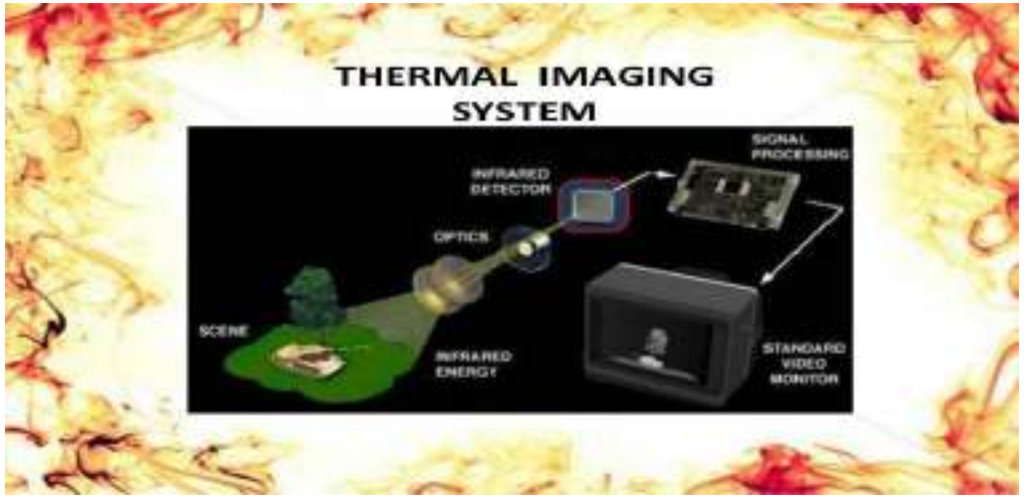
Optical Pyrometer

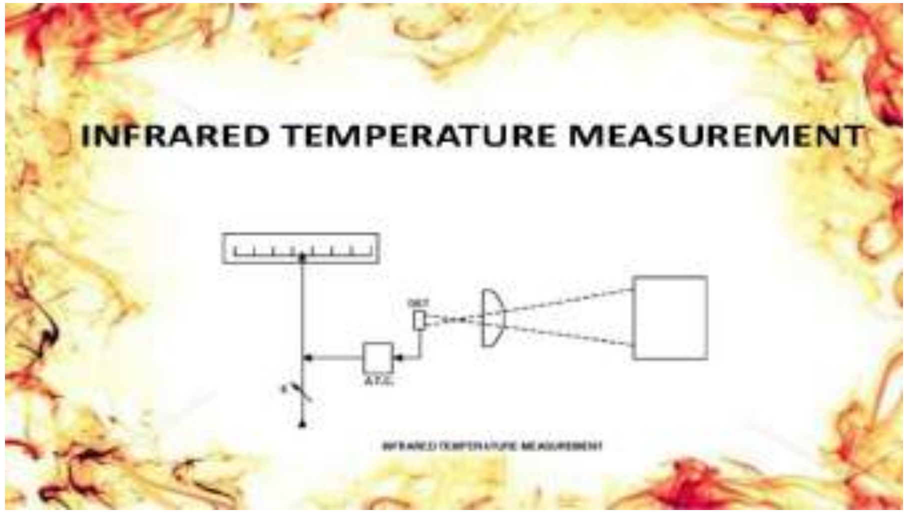
A **pyrometer** is a type of remote sensing thermometer used to measure temperature. Various forms of pyrometers have historically existed. In the modern usage, it is a non-contacting device that intercepts and measures thermal radiation, a process known as pyrometry. The thermal radiation can be used to determine the temperature of an object's surface



Infrared Thermal Imaging

An **infrared thermometer** is a thermometer which infers temperature from a portion of the thermal radiation sometimes called blackbody radiation emitted by the object being measured. They are sometimes called **laser thermometers** if a laser is used to help aim the thermometer, or **non-contact thermometers** or **temperature guns**, to describe the device's ability to measure temperature from a distance. By knowing the amount of infrared energy emitted by the object and its emissivity, the object's temperature can often be determined. Infrared thermometers are a subset of devices known as "thermal radiation thermometers".





Measurement of Process variable -II

Transmission Of Data

Standard Signal for transmissions of data are as follows:-

i. **0-10V**
ii. **4-20 mA**
iii. **Others such Modbus, Ethernet, Fieldbus and etc.**

Pressure

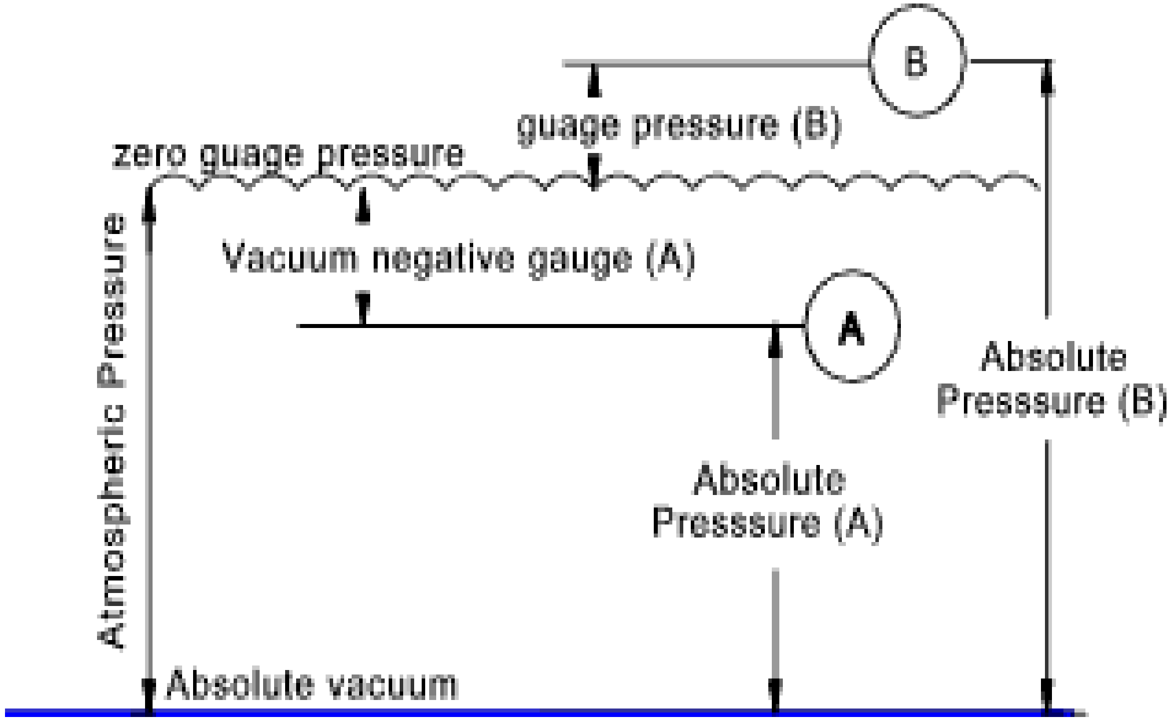
Pressure (symbol: *p* or *P*) is the force applied perpendicular to the surface of an object per unit area over which that force is distributed.

Gauge pressure = Absolute pr. – Atmospheric Pr.

Vacuum = Atmospheric Pr. – Absolute Pr.

Pressure units

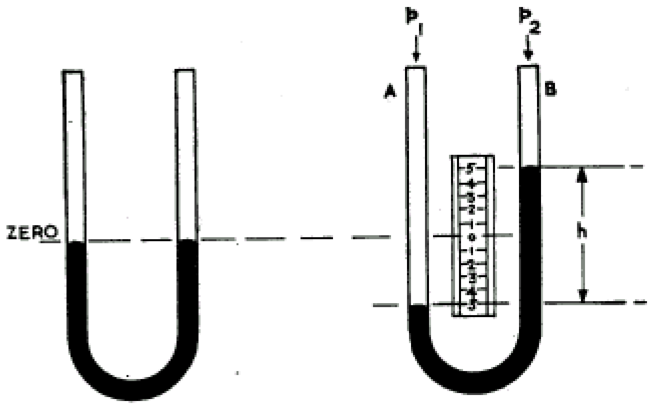
	Pascal (Pa)	Bar (bar)	Technical atmosphere (at)	Standard atmosphere (atm)	Torr (Torr)	Pounds per square inch (psi)
1 Pa	$= 1\ N/m^2$	10^{-5}	1.0197×10^{-5}	9.8692×10^{-6}	7.5006×10^{-3}	$1.450\,377 \times 10^{-4}$
1 bar	10^5	$= 100$ kPa $= 10^6\ dyn/cm^2$	1.0197	0.986 92	750.06	14.503 77
1 at	$9.806\,65 \times 10^4$	0.980 665	$= 1\ kp/cm^2$	0.967 8411	735.5592	14.223 34
1 atm	$1.013\,25 \times 10^5$	1.013 25	1.0332	1	= 760	14.695 95
1 Torr	133.3224	$1.333\,224 \times 10^{-3}$	$1.359\,551 \times 10^{-3}$	$1.315\,789 \times 10^{-3}$	$= {}^1/_{760}$ atm $\approx 1\ mm_{Hg}$	$1.933\,678 \times 10^{-2}$
1 psi	6.8948×10^3	6.8948×10^{-2}	$7.030\,69 \times 10^{-2}$	6.8046×10^{-2}	51.714 93	$= 1\ lb_F/in^2$



Pressure Measurement

U – Tube manometer

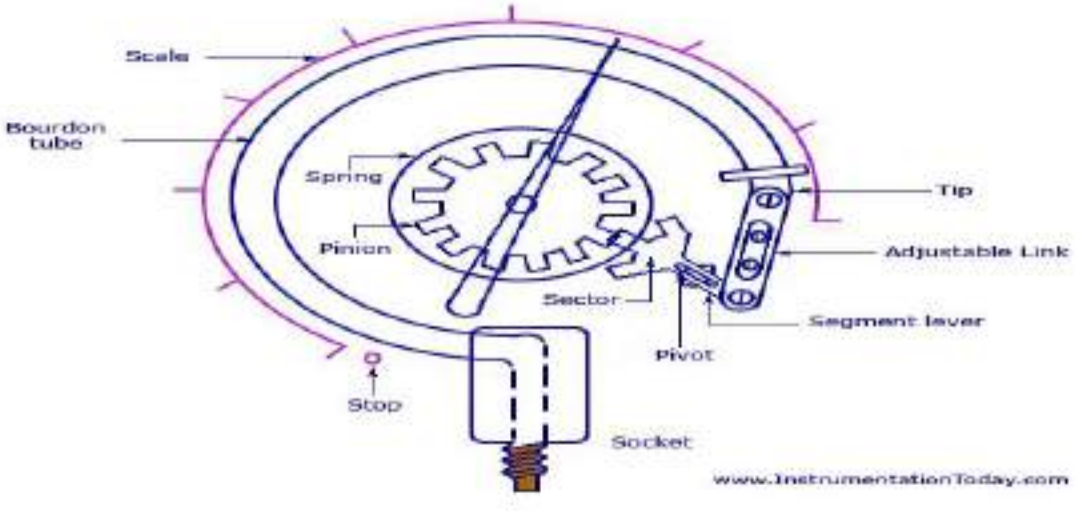
Manometer is the simplest measuring instrument used for gauge pressure measurements, by balancing the pressure against the weight of a column of liquid.



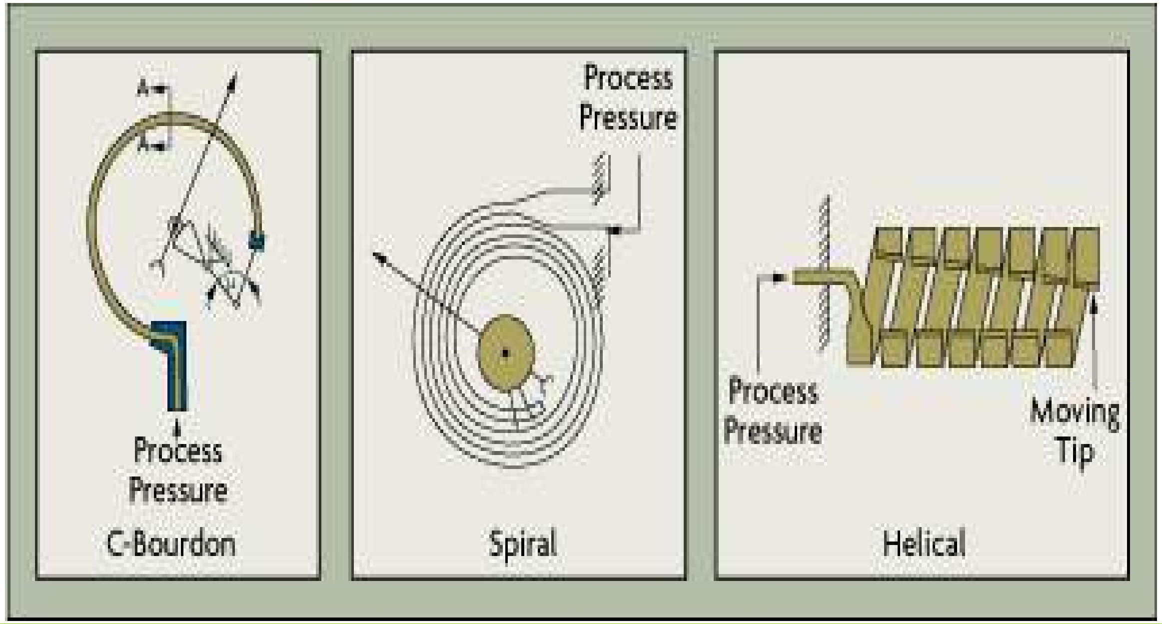
Pressure Measurement Contd:-

Bourdon Tube Pressure gauge:

A C-Type Bourdon tube consists of a long thin walled cylinder of non circular cross section, sealed at on end ,made from materials such as phosphor bronze, steel etc and attached by a light line work to the mechanism which operates the pointer.

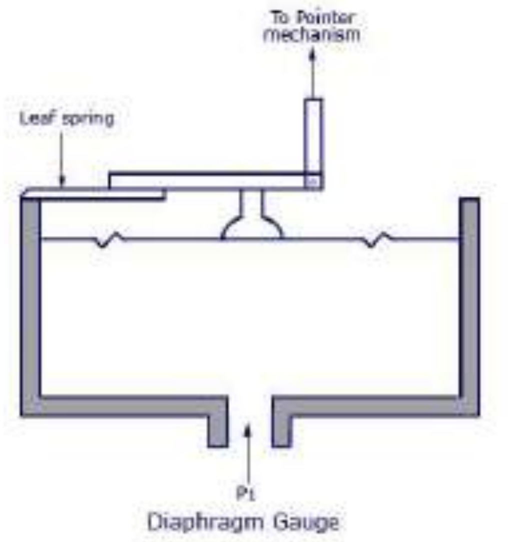


Bourdon Tube Pressure Gauge

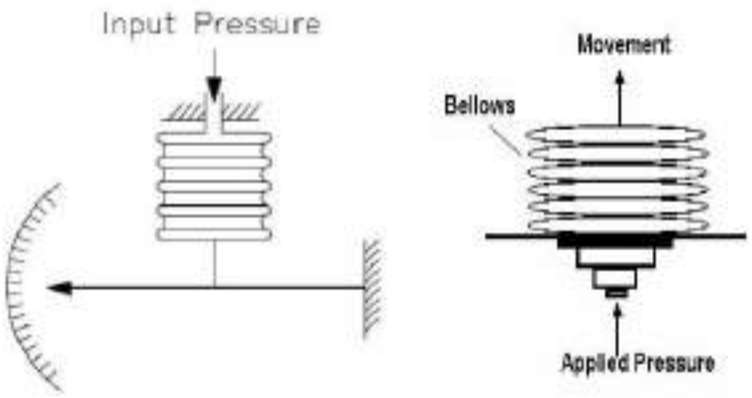


Pressure Measurement Contd:-

DIAPHRAGM



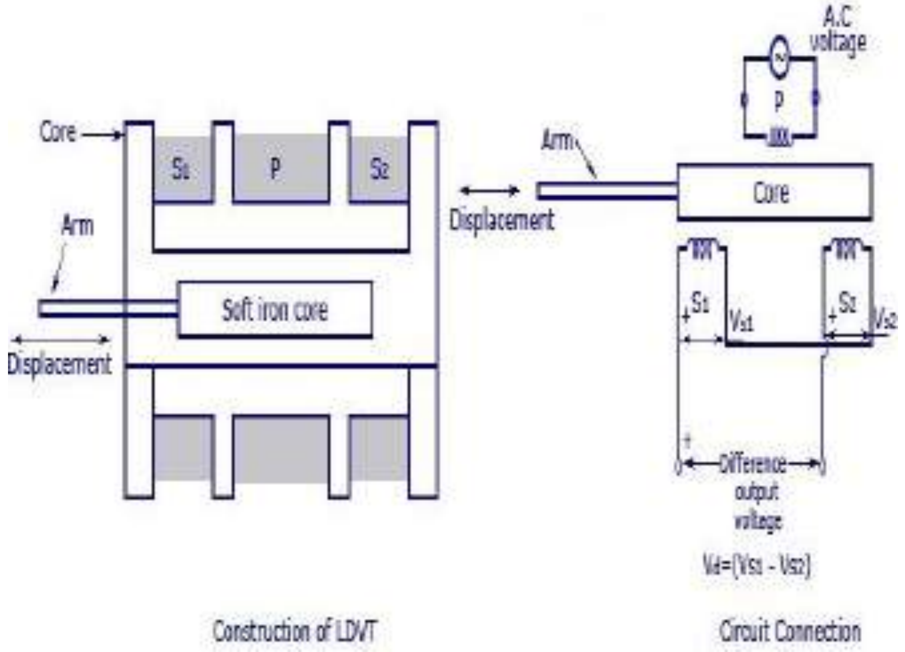
BELLOWS



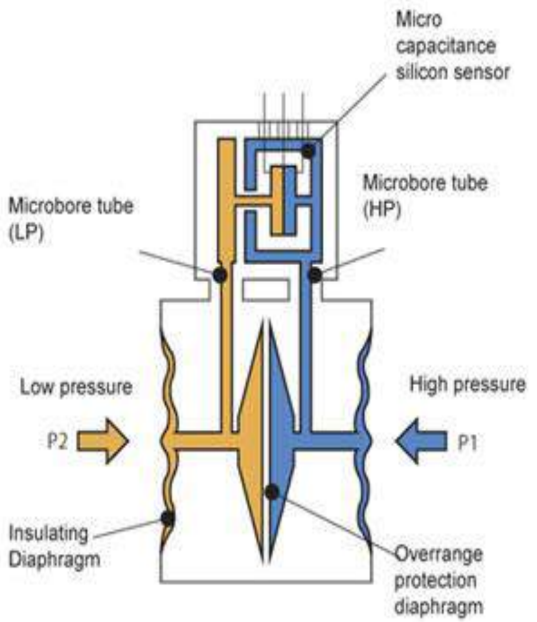
Pressure Measurement Contd:-

Pressure Transmitter:- It is device which converts the measurement of any pressure from mechanical energy to electrical form which is further used to read the process variable and take any action as per process requirement.

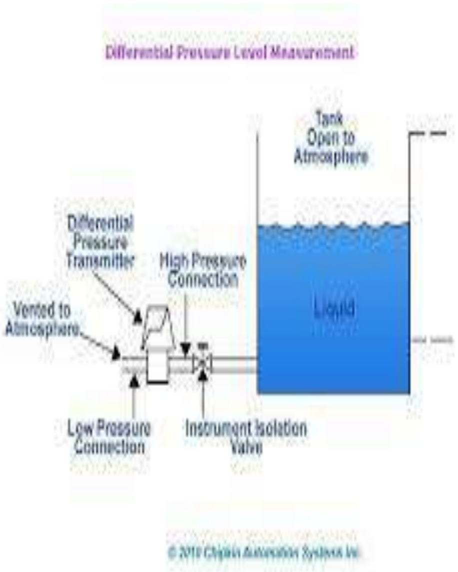
LVDT



Capacitive

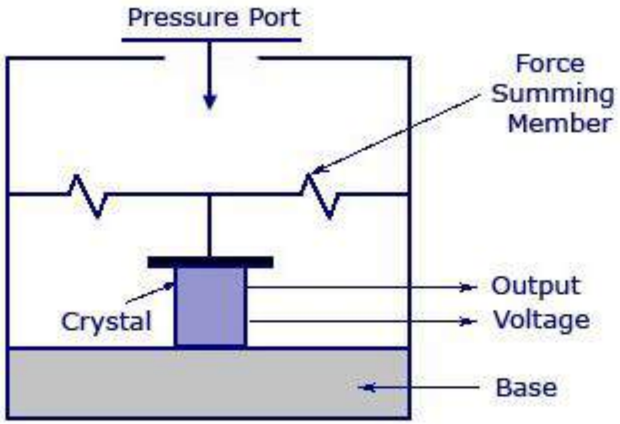


Process Connection

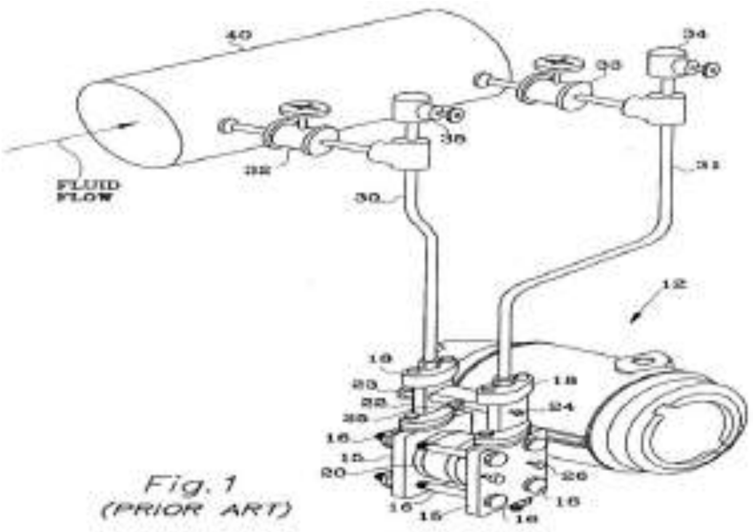


Pressure Measurement Contd:-

The figure below shows the Piezo Electric type Pressure Transmitter fitted with Piezo-Electric transducer and the other figure shows how the process connection needs to be done

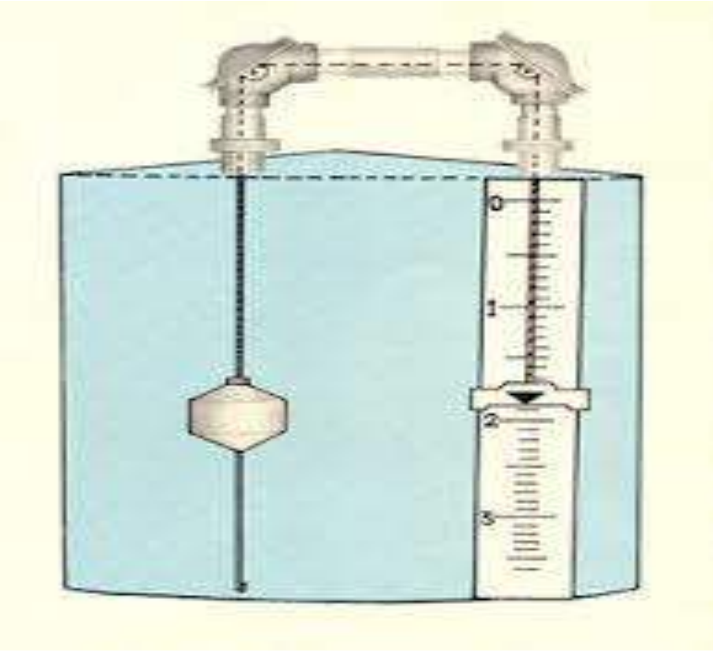


Piezo-Electric Transducer

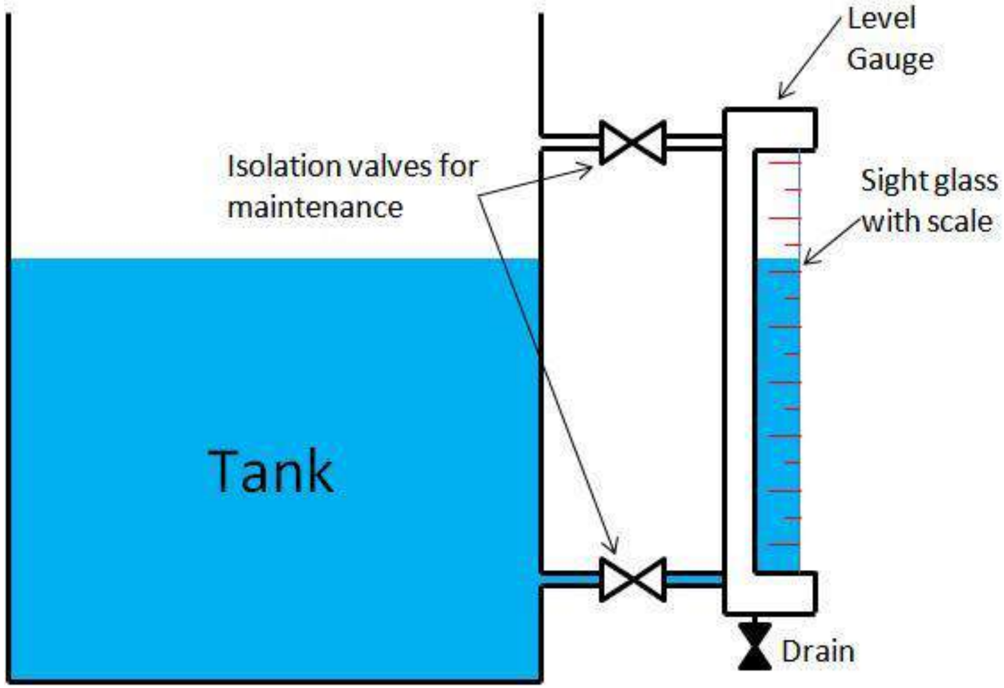


Level

FLOAT TYPE LEVEL MEASUREMENT:-



SIGHT GAUGE GLASS:-



Level- Ultrasonic

- Short ultrasonic impulses emitted from transducer
- Bursts are created from electrical energy applied to piezeo electric crystal inside the transducer
- The transducer creates sound waves (mechanical energy)
- With longer measuring ranges a lower frequency and higher amplitude are needed to produce sound waves that can travel farther
- The longer the measuring range the larger the transducer must be

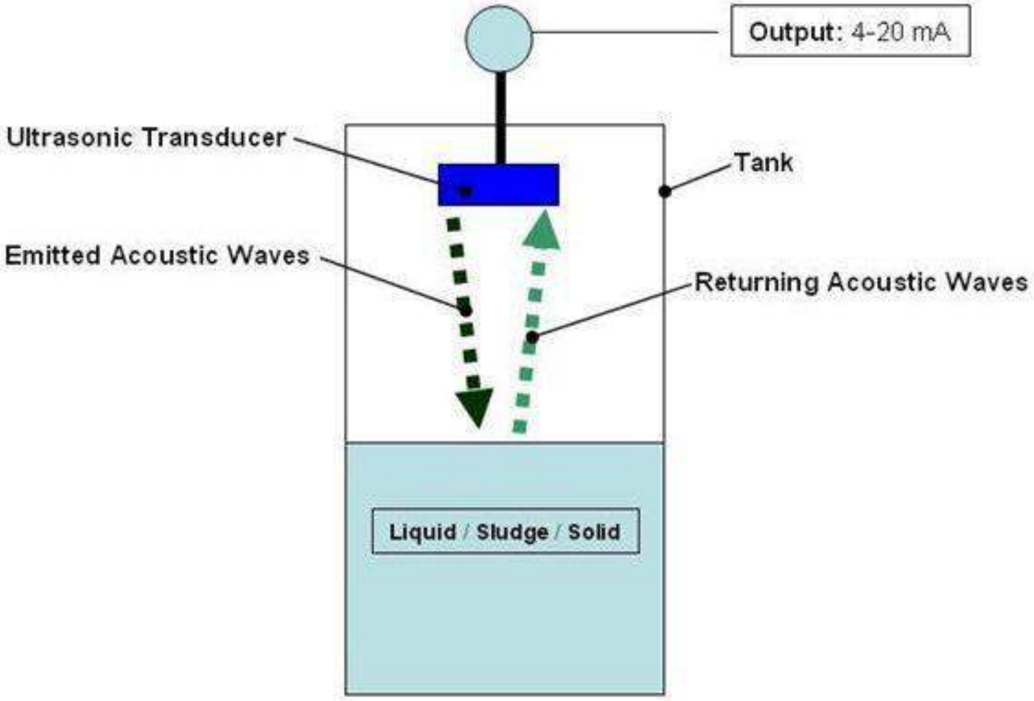


Fig.1.1 – Working of Ultrasonic Level Sensor

Level -Radar

Radar level measurement is based on the principle of measuring the time required for the microwave pulse and its reflected echo to make a complete return trip between the non-contacting transducer and the sensed material level.

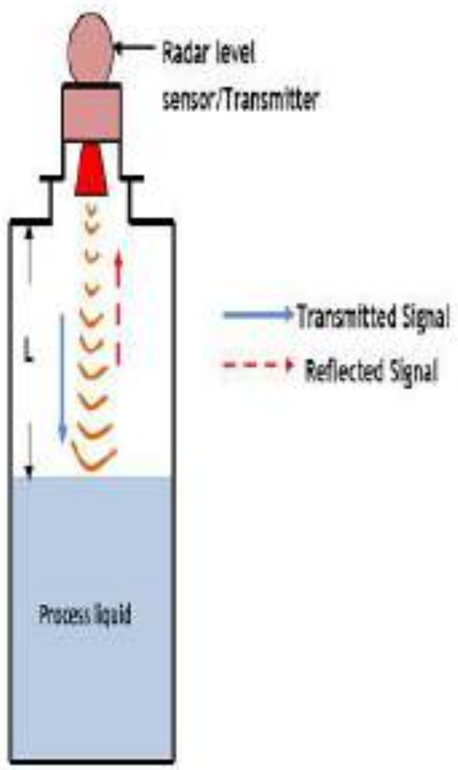
Then, the transceiver converts this signal electrically into distance/level and presents it as an analogue and/or digital signal.

The benefits of radar as a level measurement technique are clear and as under:-

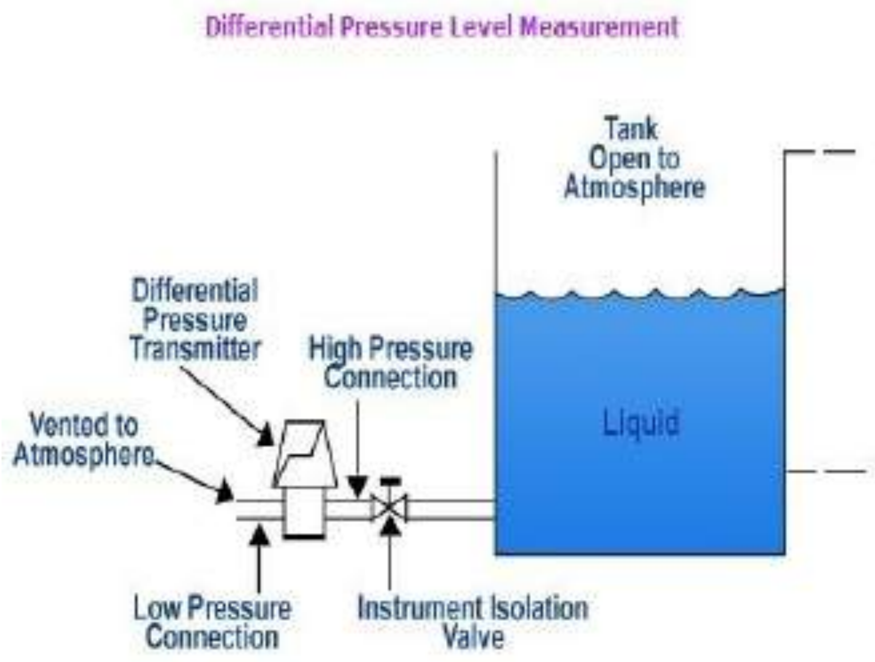
Radar provides a non-contact sensor that is virtually unaffected by changes in process temperature, pressure or the gas and vapor composition within a vessel.

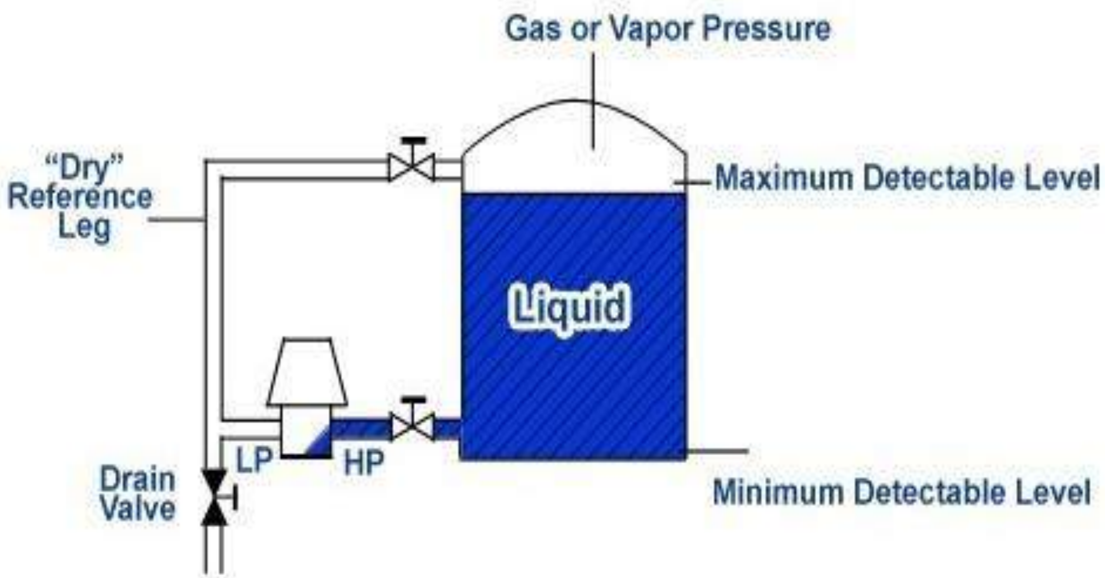
The measurement accuracy is unaffected by changes in density, conductivity and dielectric constant of the product being measured or by air movement above the product.

The echoes derived from pulse radar are discrete and separated in time. This means that pulse radar is better equipped to handle multiple echoes and false echoes that are common in process vessels and solids silos.



Level Measurement DP Type:-

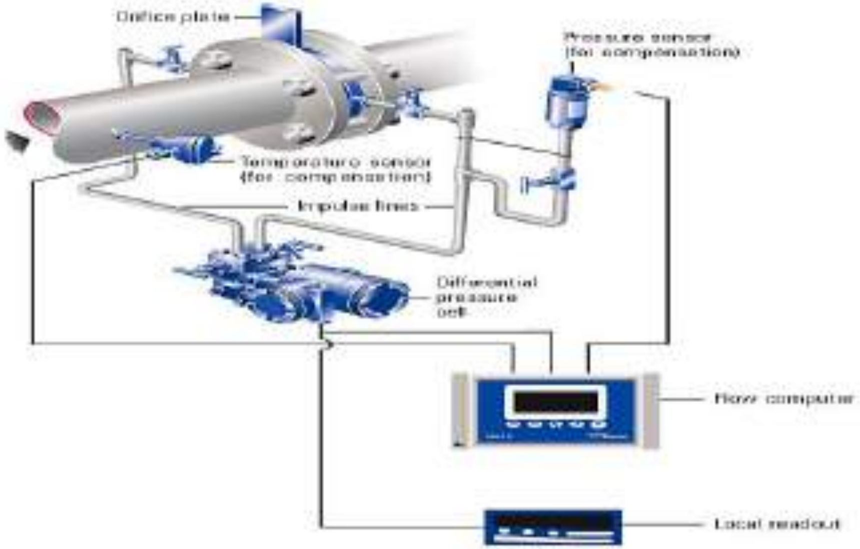


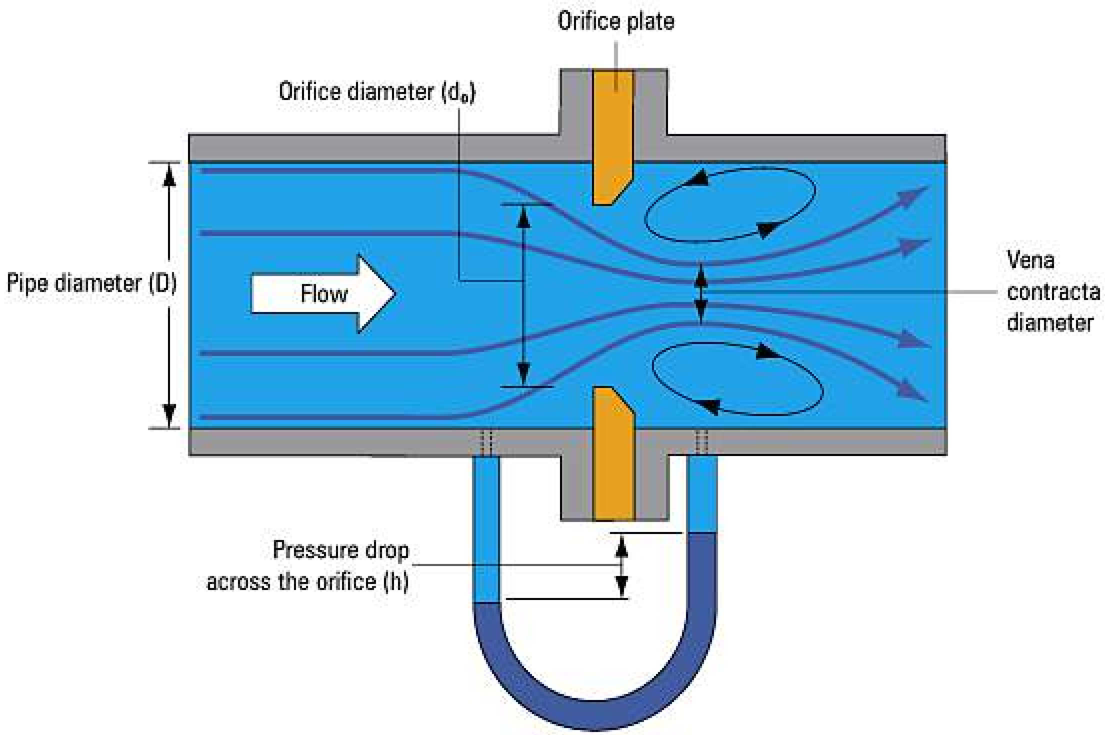


Flow Measurement :- Orifice Based

Variable Head Flow Meters: it operates on the principle that a restriction in the line of flowing fluid, introduced by the orifice plate or ventury or flow nozzle, produces differential pressure across the restriction element which is proportional to the flow rate. This relation can be derived with the help of Bernouli's theorem.

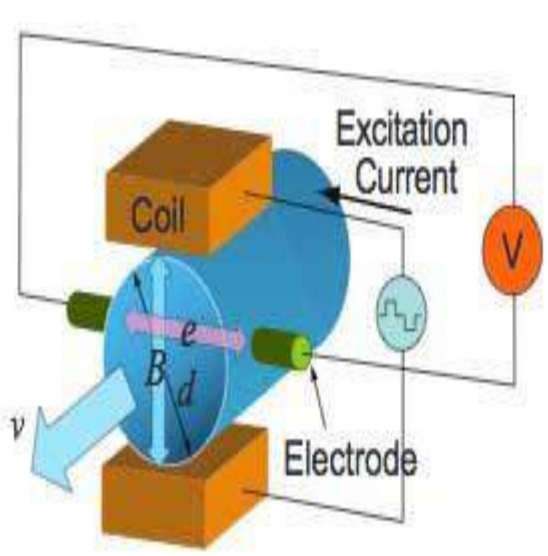
Flow Rate = K * √ΔP





Flow Meter: Magnetic Flow meter

Electromagnetic Flow Meter: It utilizes the principle of Faraday's Law of Electromagnetic Induction for making flow measurement. It states that whenever a conductor moves through a magnetic field of given strength, a voltage is induced in the conductor which is proportional to the relative velocity between the conductor and the magnetic field.



$B \propto N \cdot Iex$

B: Magnetic Flux Density
N: Number of Coil Turns
Iex: Excitation Current

$e = k \cdot B \cdot v \cdot d$

e: Electromotive Force
k: Constant
v: Mean Flow Velocity
d: Internal Diameter

Flow Measurement: Mass Flow

- Coriolis based mass flow meters measure the force resulting from the acceleration caused by mass moving toward (or away from) a center of rotation.
- This effect can be experienced when riding a merry-go-round, where moving toward the center will cause a person to have to “lean into” the rotation so as to maintain balance
- In a Coriolis mass flow-meter, the “swinging” is generated by vibrating the tube(s) in which the fluid flows. The amount of twist is proportional to the mass flow rate of fluid passing through the tube(s). Sensors and a Coriolis mass flow-meter transmitter are used to measure the twist and generate a linear flow signal.