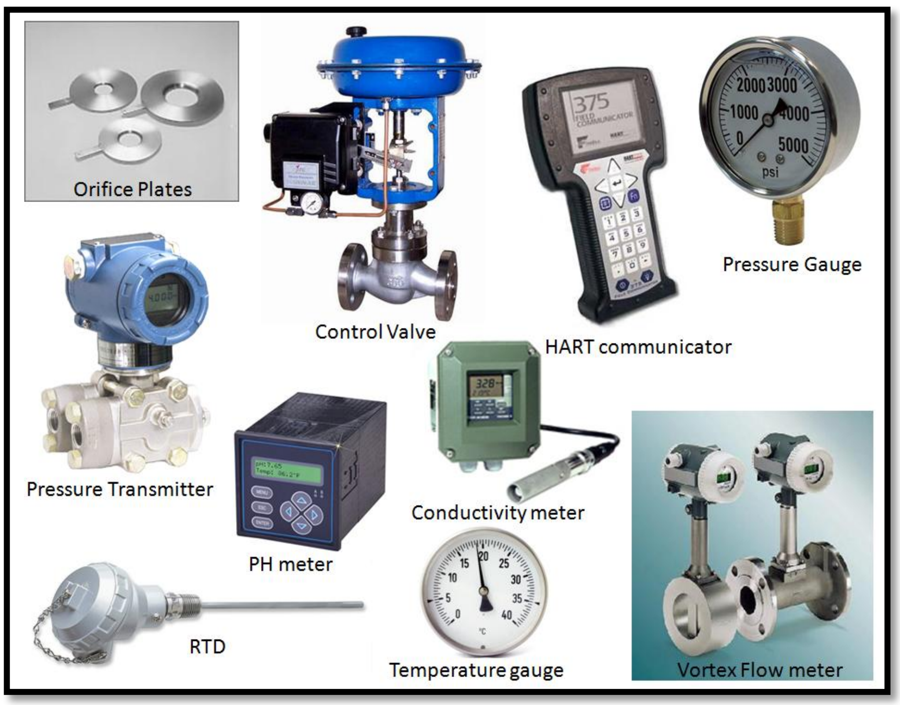
Field Instrumentation

Instrument Unit



PAKARAB FERTILIZERS LIMITED MULTAN

GEN-02 (Rev 0)

Prepared by : Muhammad Akmal
Reviewed by : Muhammad Aqeel
Approved by: Pervaiz Iqbal

Contents

1. TEMPERATURE

OBJECTIVES:

Upon Completion of this training one should be able to understand:

- Basic terms related to temperature
- Different scales conversion
- Basic temperature measuring techniques
- RTD's and its application
- Thermocouple and its applications
- Comparison between RTD's and Thermocouples
- State the effect on the indicated temperature for failures, open circuit and short circuit;

1.1 Temperature

Can be defined as

a) The condition of a body which determines the transfer of heat to or from other bodies.
Or
b) The degree of hotness or coldness as referenced to a specific scale of temperature measurement.

HEAT:

Energy that flows through a body and causes it, to increase its temperature, melt, boil, expand, or undergo other changes is called heat.

Unit of heat is BTU (British thermal unit). The amount of thermal energy required to raise the temperature of 1 lb of water 1 degree F at atmospheric pressure.
1 BTU = 1055 joules.

Calorie:

The amount of heat needed to raise the temperature of one gram of water 1 deg C (starting at 15 deg C) at atmospheric pressure. 1 Cal = 4.184 joule.

Specific heat:

It is defined as the ratio of heat required to raise the temperature of a certain weight of a substance 1°F to that required to raise the temperature of the same weight of water 1°F (measured under constant pressure)

Vaporization:

The change of physical state from liquid to gas is called vaporization.

Condensation:

The change of physical state from gas to liquid is called condensation.

Latent heat of vaporization:

The amount of heat necessary to change a substance at the boiling point from liquid to gas is called latent heat of vaporization.

Fusion:

The change of physical state from liquid to solid is called fusion (or freezing).

Melting:

The change of physical state from solid to liquid is called melting.

Latent heat of fusion:

The amount of heat that must be removed as a substance changes from a liquid to a solid, or added as the solid becomes liquid is referred to as the latent heat of fusion.

1.2 Temperature scales:

Celsius: Melting point of ice is 0 and boiling point is 100.

$^oC = (^oF – 32) / 1.8$.

Fahrenheit: Melting point of ice is 32 and boiling point is 212.

$^oF = (1.8 * {}^oC) + 32$.

Kelvin: It is absolute scale.

$K = {}^oC +273.15$.

Rankine:

$^oR = {}^oF +459.67$

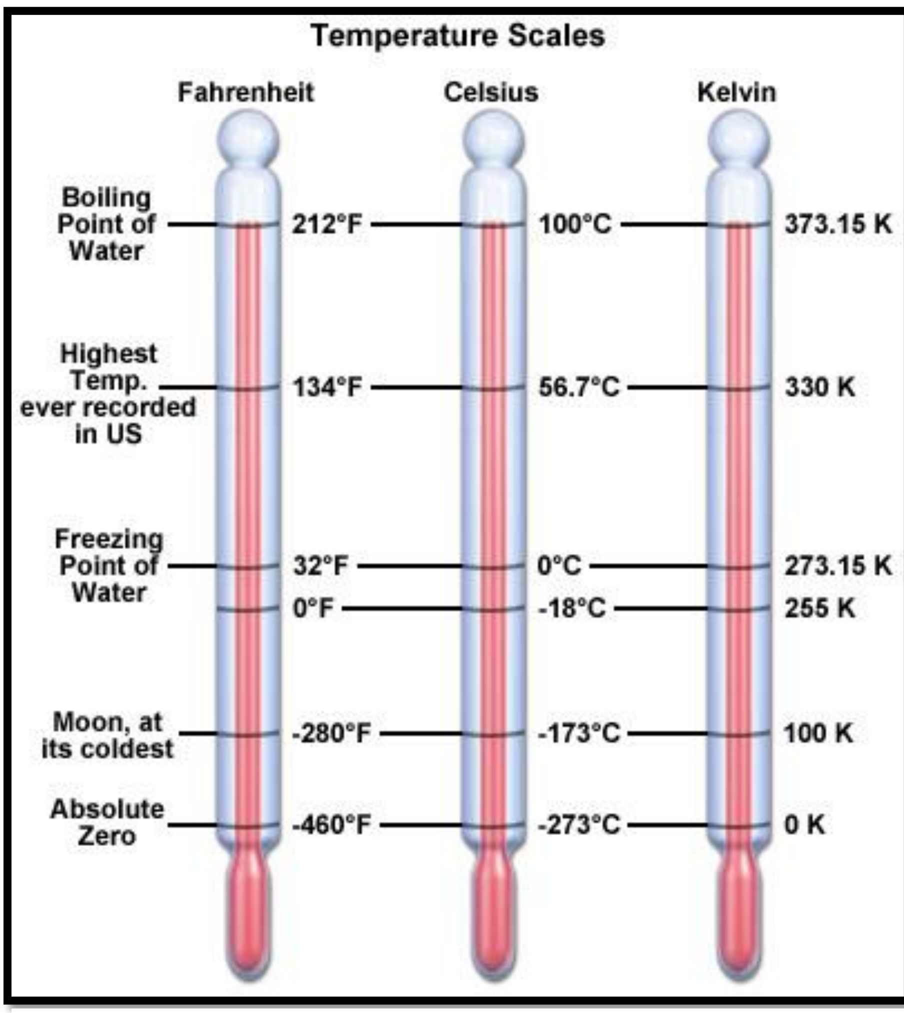
Absolute zero:

A hypothetical temperature at which a substance would have no thermal energy. T (abs.) = -273.15 ^{o}C

Triple point:

The temperature at which gaseous, liquid, and solid states of a substance exist simultaneously.

For example, the triple point of mercury occurs at a temperature of −38.8344 °C and a pressure of 0.2 mPa.



THREE DIFFERENT SCALES AND THEIR COMPARISONS

1.3 Types of Temperature measurement:

All temperature measurements in industry are of two basic groups.

i. **Non Electric Type**

Bimetallic, Liquid in glass, Filled thermal system.

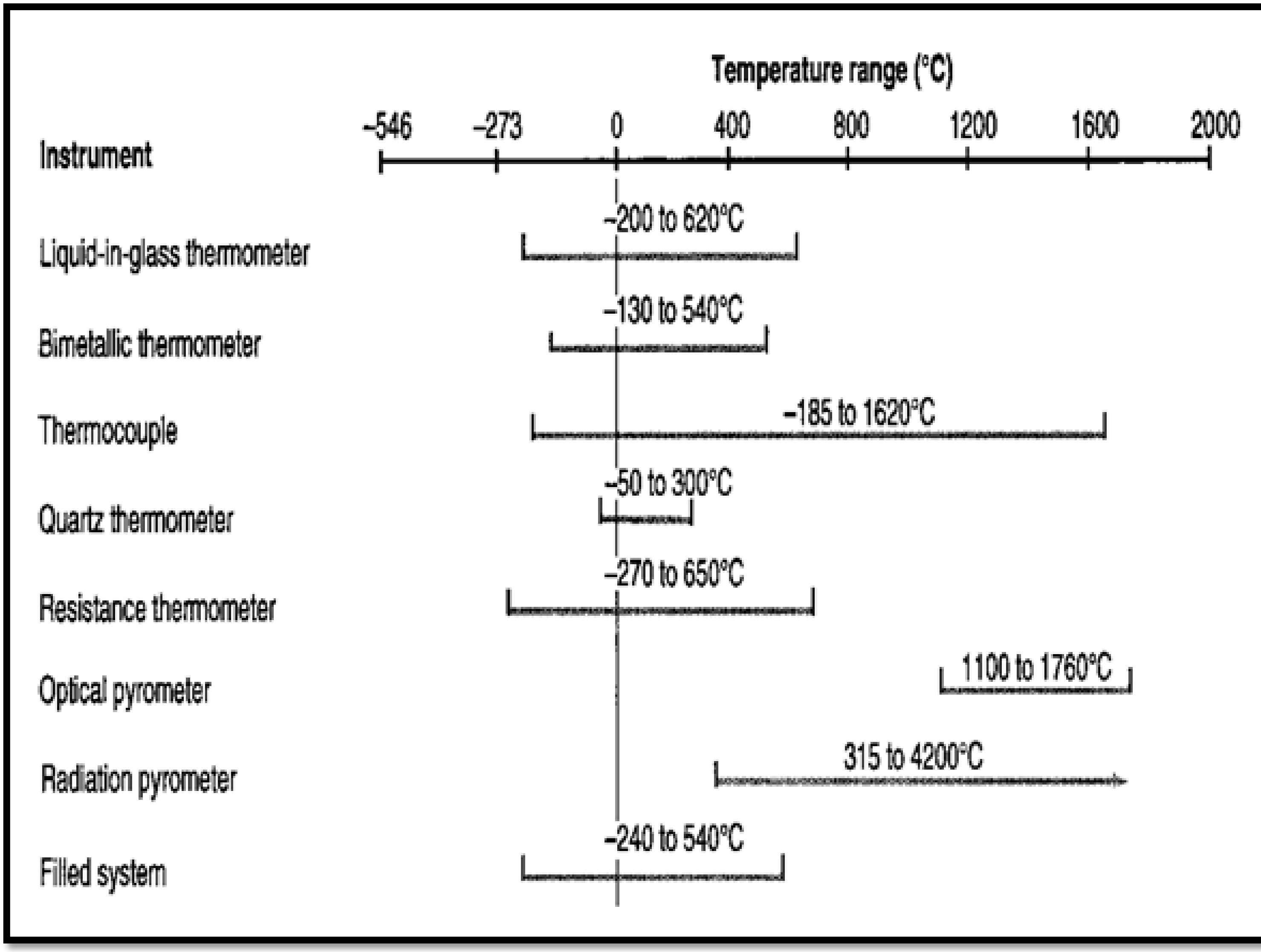
ii. **Electric Type**

Thermocouple, RTD, Thermistors, Pyrometer (Radiation & Optical)

Temperature Indication:

Temperature is indicated by the changes it causes in certain instruments.

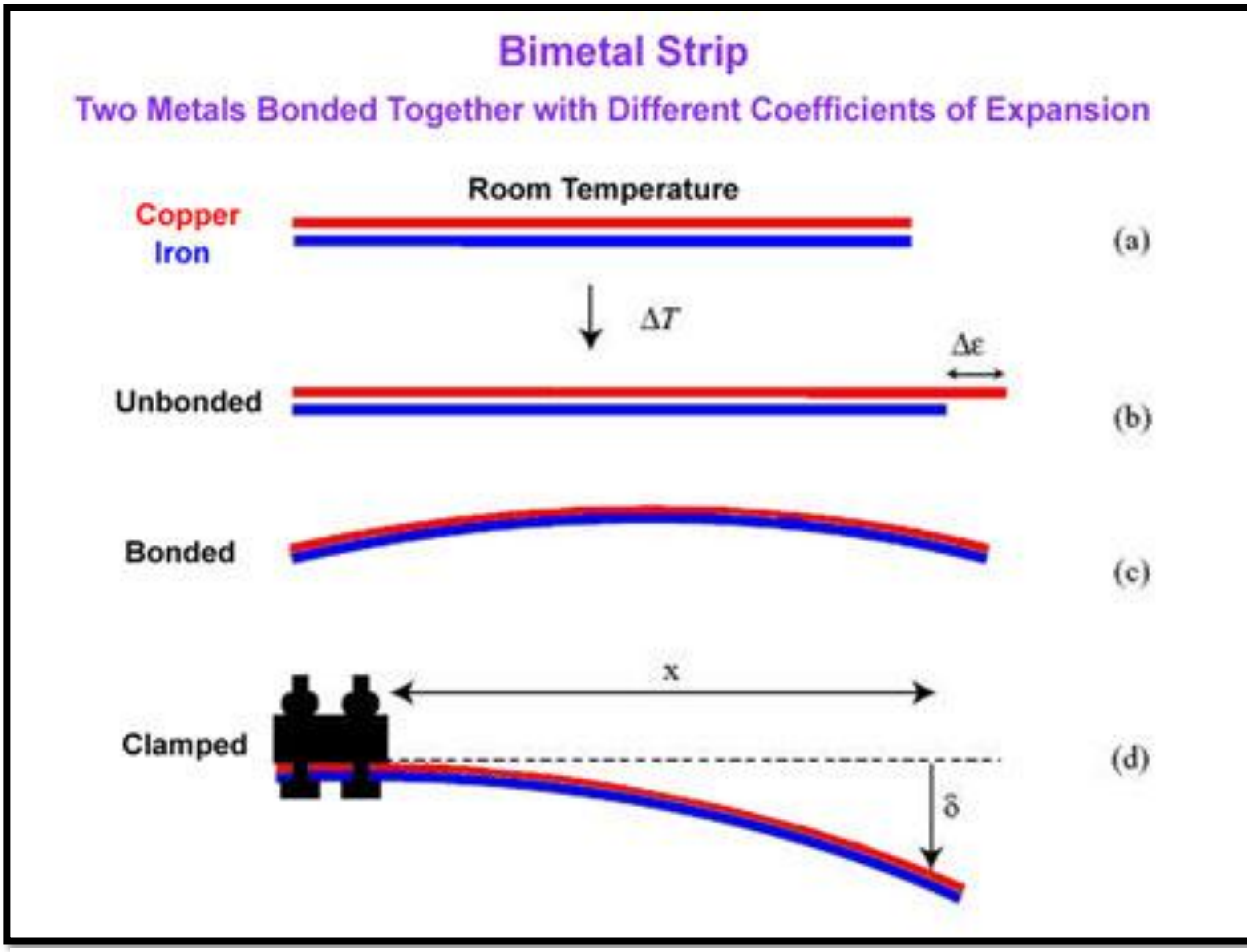
- Changes in density (liquid in glass thermometers)
- Changes in length or volume (bimetallic or filled system)
- Voltage generated at junction of dissimilar metals (thermocouple)
- Resonant frequency of crystals (quartz thermometers)
- Changes in electrical resistance (Resistance thermometers)



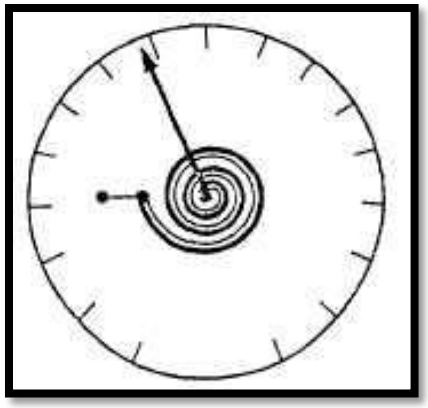
TEMPERATURE RANGES FOR DIFFERENT TEMPERATURE MEASURING DEVICES

BIMETALLIC THERMOMETERS

Coefficient of thermal expansion:
It is the change in length or volume of a substance per degree of temperature change.

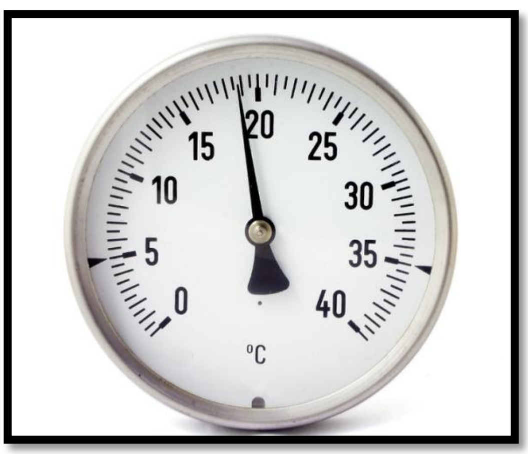


DIFFERENT CONDITIONS OF A BIMETAL STRIP

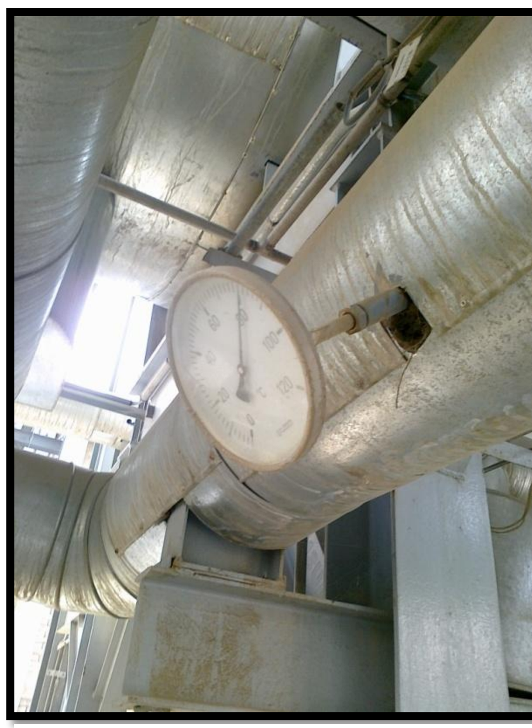


APPLICATION OF A BIMETAL STRIP IN A TEMPERATURE GAUGE

If one end of strip is fixed , the distance the other end bends is directly proportional to the square of the length of the metal strip, as well as to the total change in temperature, while inversely proportional to the thickness of the metal. Invar (alloy of iron and nickel) is used as low expansion material while brass (alloy of copper and zinc) is used as high expansion material.



AN INDUSTRIAL TEMPERATURE GAUGE



A TEMPERATURE GAUGE AT CO-GEN PLANT

LIQUID IN GLASS THERMOMETERS:

Its operation is based on the principle that liquids expand as temperature increases. It consists of a small bore glass tube with a thin wall glass tube at its lower end. Liquid filled is usually mercury or an organic compound.

FILLED THERMAL SYSTEMS:

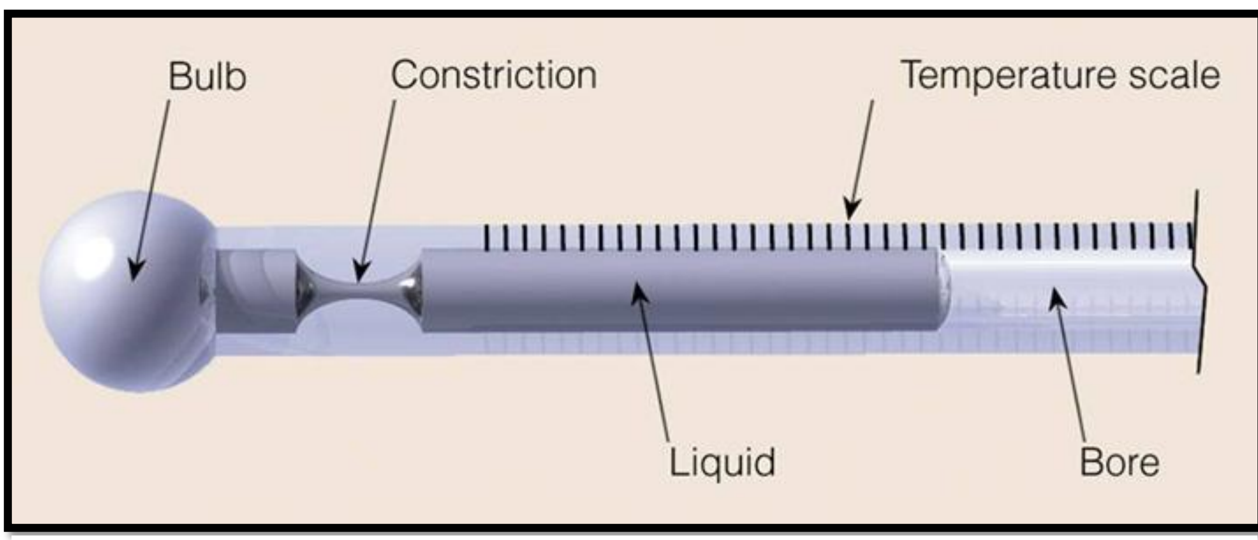
The basic components of a filled system thermometer are

- Thermometer bulb
- Capillary tube
- Bourdon tube

The entire system is filled with filling fluid. A change in temperature causes the fluid to expand or contract, in turn causing the bourdon tube to move.

Liquid filled system:

A bulb is inserted into the substance to be measured. Filling liquid inside the bulb (commonly toluene or xylene) is heated or cooled until the temperature of the filling liquid matches the temperature of the measured substance. Mercury is also used as filling fluid due to rapid response to temperature changes.



A LIQUID FILLED THERMOMETER AND ITS DIFFERENT PARTS

Gas filled systems:

It operates on the principle that the pressure of a confined gas varies directly with its absolute temperature.

P=kT, where k=constant, and T=absolute temperature.

Nitrogen gas is normally used as filled gas.

A GAS FILLED TEMPERATURE GAUGE

Vapor pressure systems:

Liquid in vapor pressure system vaporizes during operation. Bulb is partially filled with liquid while capillary and bourdon are filled with vapor. Liquids used are methyl chloride, sulfur dioxide, ether alcohol, and toluene.

A gas remains gaseous under pressure at normal room temperature, but a vapor under pressure at normal room temperature returns to its liquid or solid state.

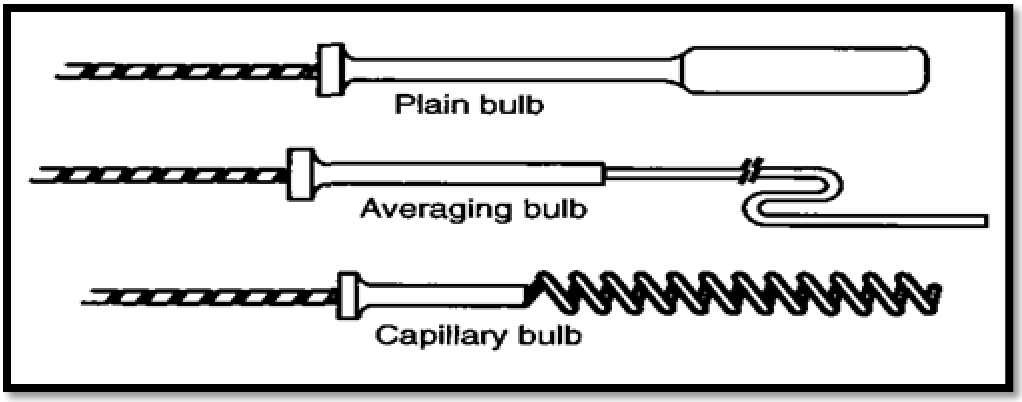
Thermometer bulbs:

It is usually made of stainless steel due to good heat transfer properties.

Plain bulb: Not used where rapid response is important.

Averaging bulb: provides rapid response to temperature changes.

Capillary bulb: It is wound in helix, increasing surface area and improving response time.



THREE DIFFERENT TYPES OF BULBS

Capillary tube:

A capillary should contain the smallest possible volume of filling fluid. Change of temperature in liquid in capillary can cause movement of bourdon tube.

Bourdon tubes:

Helical bourdon tube is commonly used. Bourdon tube uncoils due to temperature rise in system. An attached linkage is used to indicate system temperature.

Advantages

Filled system thermometers are used with accuracy of ±0.5%.
Their advantages are:

- Lesser maintenance
- No electric power requirement
- Satisfactory time response and accuracy.

Disadvantage

The disadvantage is that the entire system usually must be replaced in case of failure.

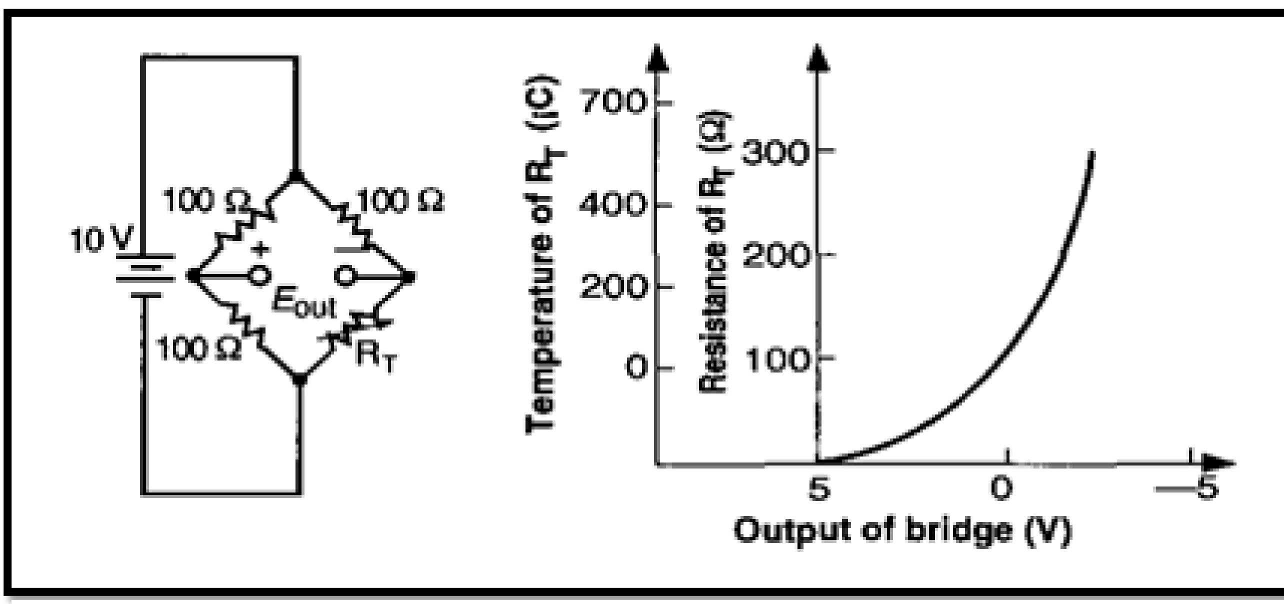
1.4 RESISTANCE TEMPERATURE DETECTOR:

It works on the principle that electrical resistance of any material increases with temperature increase and vice versa. A piece of nickel or platinum wire can be used to measure resistance for different temperatures.
RTD resistance elements are constructed of platinum, copper or nickel. The metal should have a high coefficient of resistance (change in resistance that occurs with a change in temperature).

A platinum RTD is normally used to measure precise temperature from -259 to 631 ^{o}C.
Pt 100 means: its platinum and temperature is 0 ^{o}C at 100 ohms resistance.

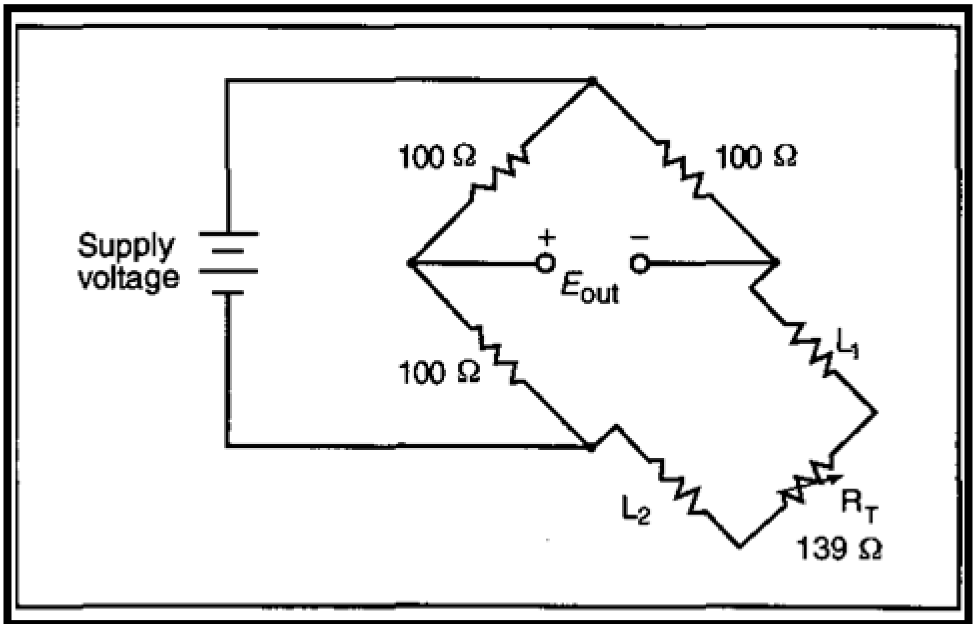
Measurement of unknown resistance:

The electrical circuit used for temperature measurement is a Wheatstone bridge. The bridge converts the RTD's change in resistance to a voltage output. This circuit uses four separate electrical resistors, one of which is the RTD.
The bridge is initially balanced, with voltage output equal to zero, because all four resistors are equal. If the resistance of the RTD changes, due to a temperature changes, the bridge becomes unbalanced, resulting in a voltage output other than zero.



A.RTD BRIDGE CIRCUIT B. RTD RESISTANCE VS VOLTAGE GRAPH

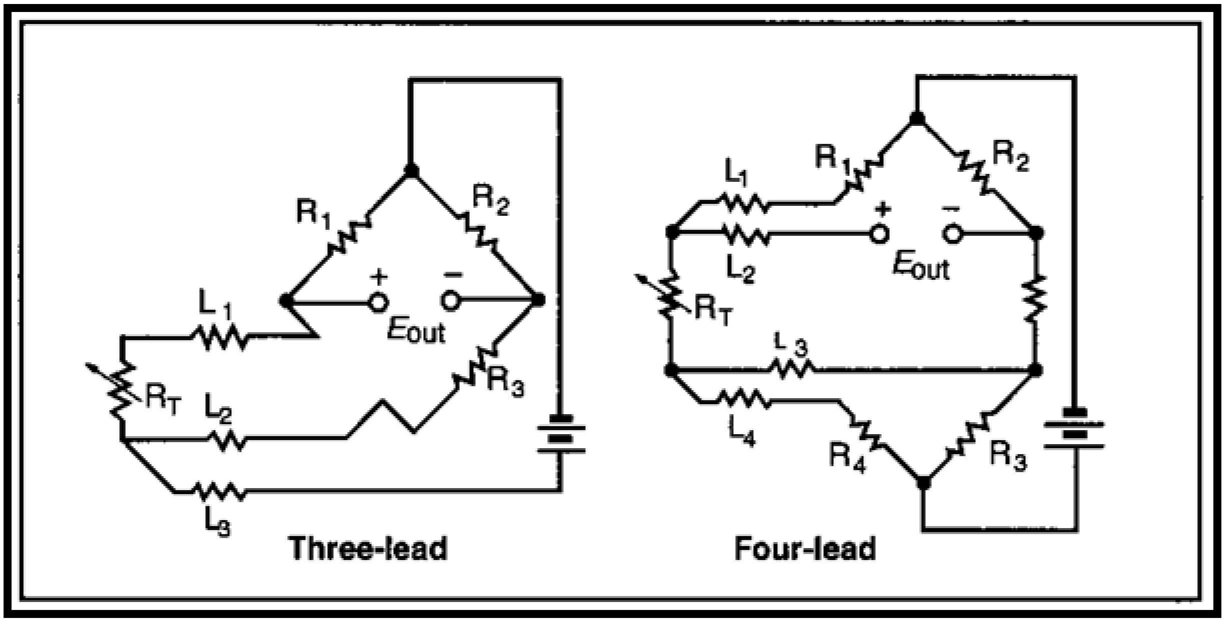
In two conductors RTD, these conductors become part of resistance being measured, so ambient temperature variation will result in error of net temperature.



A TWO WIRE RTD CIRCUIT

Three conductor RTD cable is mostly used to minimize the effect of ambient temperature variations on cable.
In three lead circuit, L1 and L2 are in opposite arms of the bridge. The change in L1 is equal to L2. Because L3 is in series with the input voltage, the bridge output voltage is unaffected.

Four conductor RTD is used to reduce temperature effects on cable. This circuit is used in a system with long lead wires whose temperature varies greatly during measurement.



A THREE WIRE AND A FOUR WIRE RTD CIRCUIT

Resistance elements are usually long spring like wires enclosed in a metal sheath. The platinum element is surrounded by a porcelain insulating material that prevents a short circuit from developing between the wire and the sheath. The sheath is made of Inconel, an alloy of nickel, iron, and chromium. This material has excellent corrosion resistance and can be used in extremely harsh environments for long periods of time without deteriorating.

The thermo well protects the RTD from any contamination or corrosion caused by the gases or liquids being measured.

A heavy metal head, made of cast iron or aluminum, covers the terminal block containing the electrical connections between the RTD and Wheatstone bridge.
The main advantage of RTD is stability, linearity and accuracy.

RTD Advantages and Disadvantages

Advantages:

• The response time compared to thermocouples is very fast. In the order of fractions of a second.

• An RTD will not experience drift problems because it is not self powered.

• Within its range it is more accurate and has higher sensitivity than a thermocouple.

• In an installation where long leads are required, the RTD does not require special extension cable.

• Unlike thermocouples, radioactive radiation (beta, gamma and neutrons) has minimal effect on RTDs since the parameter measured is resistance, not voltage.

Disadvantages:

• Because the metal used for a RTD must be in its purest form, they are much more expensive than thermocouples.

• In general, an RTD is not capable of measuring as wide a temperature range as a thermocouple.

• A power supply failure can cause erroneous readings Small changes in resistance are being measured, thus all connections must be tight and free of corrosion, which will create errors.

• Among the many uses in a nuclear station, RTDs can be found in the reactor area temperature measurement and fuel channel coolant temperature.

Failure Modes:

• An open circuit in the RTD or in the wiring between the RTD an19d the bridge will cause a high temperature reading.

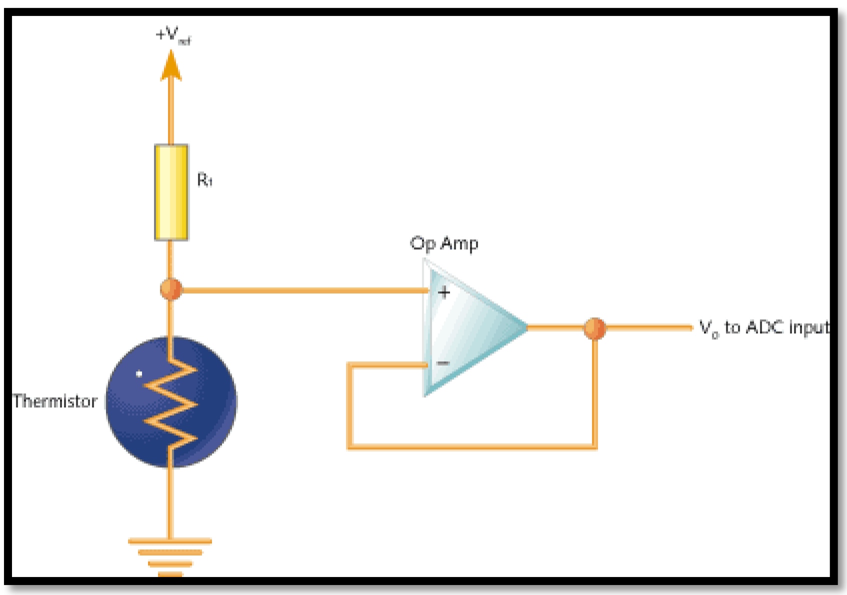
• Loss of power or a short within the RTD will cause a low temperature reading.

1.5 THERMISTOR

Its name is derived from thermally sensitive resistor. Resistance of a thermistor varies as a function of temperature. Thermistor is an electrical device made of solid semiconductor with high temperature coefficient of resistivity.

It is usually made of complex metal oxides (manganese-nickel, manganese – nickel – iron).

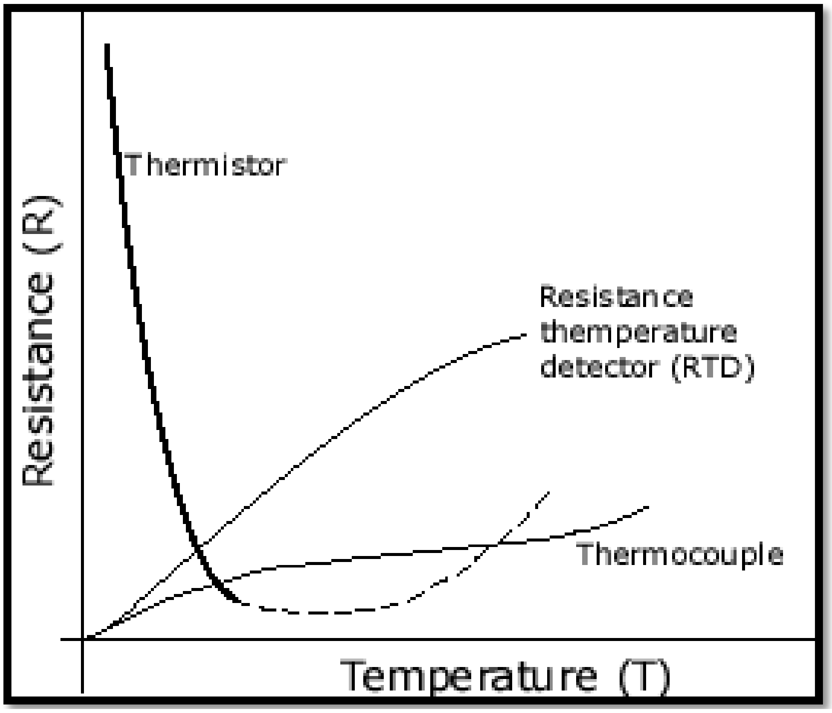
In negative coefficient thermistor resistance decreases as temperature increases.



A positive coefficient thermistor (resistance increases as temp. increases) is connected in series with a control relay to react to temperature limits or overload conditions. As temperature increases the resistance of thermistor increases. This causes current in the relay coil to decrease, and relay trips out. It is used to protect industrial motors.

Thermistor is very sensitive so it often does not require wheat stone bridge.

They are used in range of -260 to 315 °C.

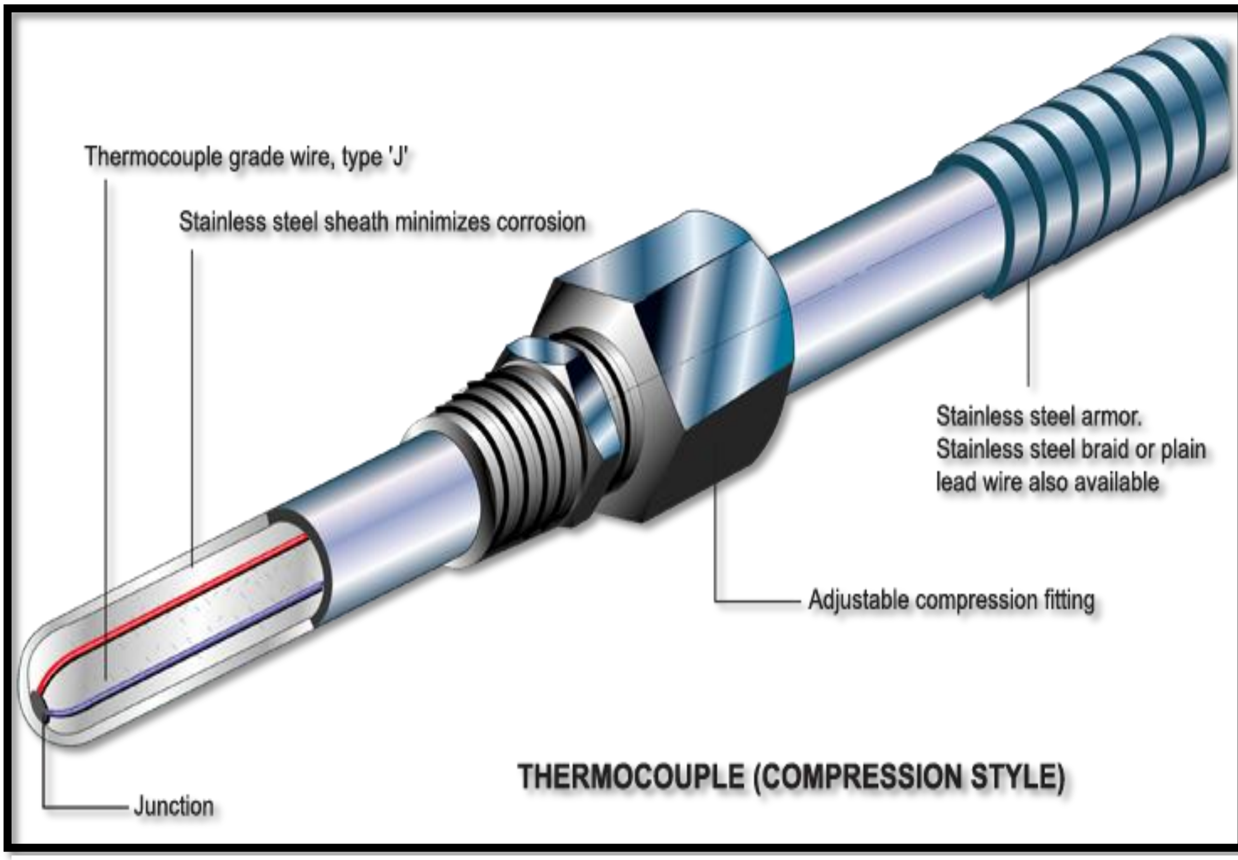


TEMPERATURE CURVES OF RTD, THERMOCOUPLES AND THERMISTORS

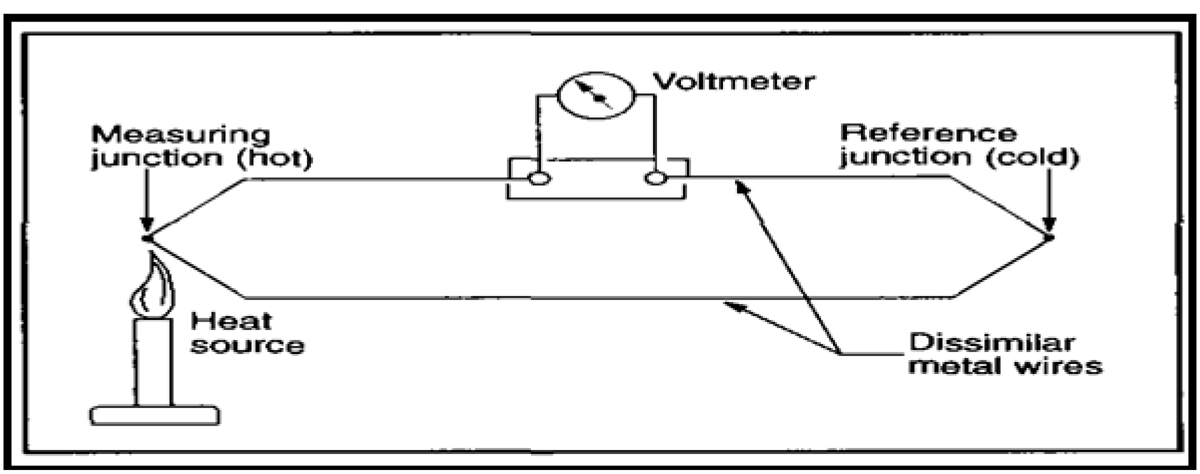
1.6 THERMOCOUPLE:

It works on the principle that if two wires made of different metals are joined at one end and joined ends are at different temperatures than the open ends, a small voltage is produced across the open ends. Joined ends are called hot junction while open ends are called cold junction.
To keep the wires apart, porcelain insulator is used for higher temperature.

For accurate temperature measurement, reference junction temperature must remain constant. Indicating or recording instruments use internal and automatic cold junction compensation. Either a thermistor directly measures mV in junction box and is compensated for net temperature output or a thermocouple added to actual thermocouple can give net temperature.



INTERNAL CONSTRUCTION OF A THERMOCOUPLE



WORKING PRINCIPLE OF A THERMOCOUPLE

Two main classes of thermocouples are

Noble metal thermocouples: platinum or gold is used as one wire. Highly resistant to corrosion, low electric resistivity, good repeatability. Type S,R and B are all noble metal thermocouples.

Base metal thermocouples: type J, T, E, and K are all base metal thermocouples.
Thermal emf developed is dependant on metals of thermocouple. Common types of thermocouples are as follows.

A).COPPER-CONSTANTAN (T TYPE)

Copper element used as positive conductor and constantan element for negative conductor. Constantan contains 55% copper and 45% Nickel. This thermocouple is used in Oxidizing or reducing atmosphere.
Range: -300 ^{o}F to +600 ^{o}F

B).IRON – CONSTANTAN (J TYPE)

Iron element is used as positive conductor and constantan element for negative conductor. This thermocouple is used in Oxidizing or reducing atmosphere.
Range: -100 ^{o}F to +1500 ^{o}F

C).CHROMEL- ALUMEL (K TYPE)

Chromium alloy is used as positive conductor and Alumel element for negative conductor.This thermocouple is used in Oxidizing atmosphere.
Range: -300 ^{o}F to +1600 ^{o}F

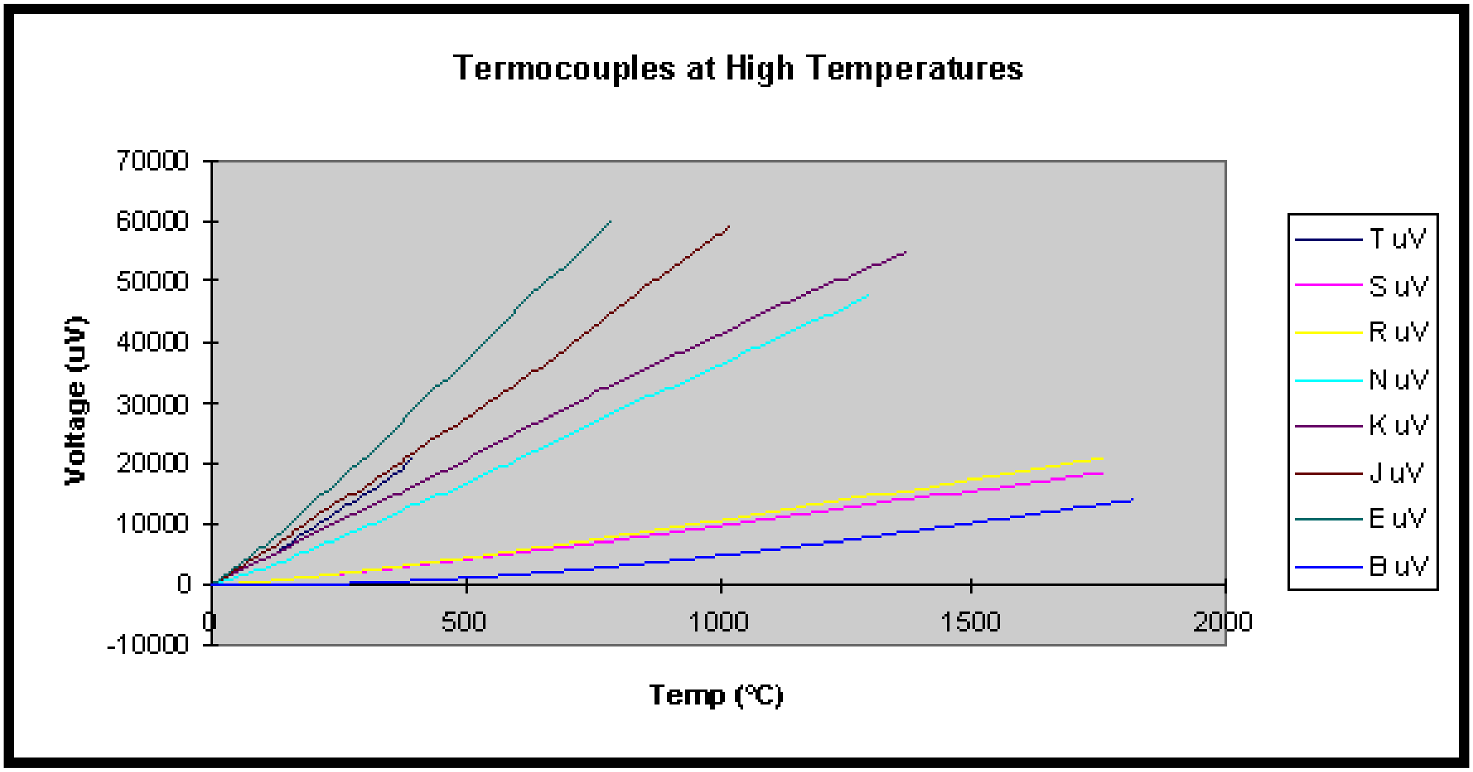
D).CHROMEL-CONSTANTAN (E TYPE)

- This thermocouple is used in Oxidizing atmosphere.
- Chromel = 90% Nickel & Chromium = 9%
- Constantan = 44% Nickel & Cupper = 55%
- Range: +32 ^{o}F to +1600 ^{o}F

E). PLATINUM RHODIUM/PLATINUM (R ,B, S TYPE)

-
- This thermocouple is used in Oxidizing atmosphere.

- In R type thermo couple, pt = 87% & Rh = 13%
- Range: Up to +2700 °F
- In S type thermo couple, pt = 90% & Rh = 10%
- Range: 0 °F to +2100 °F
- In B type thermo couple, pt = 70% & Rh = 30%
- Range: 1472 °F to +3092 °F

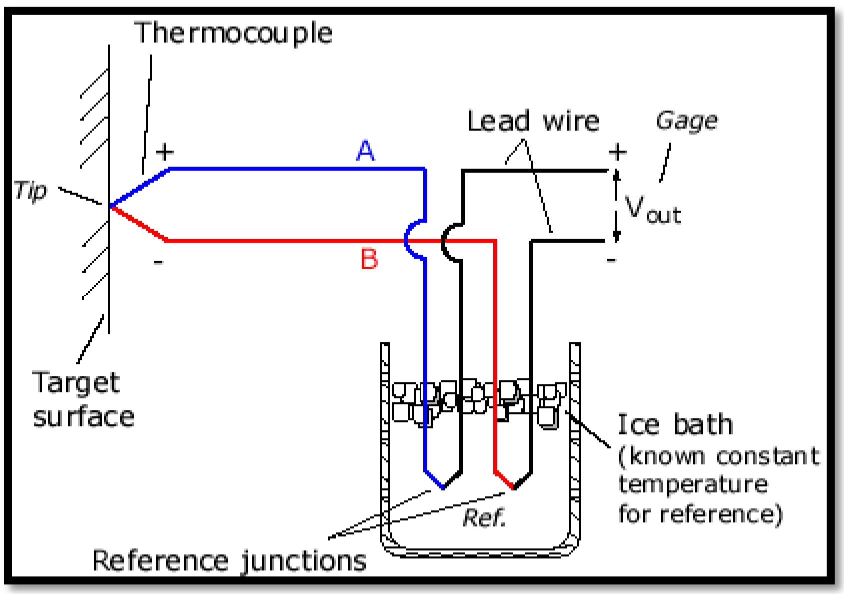


TEMPERATURE RANGES OF DIFFERENT THERMOCOUPLES

Thermocouple Standard Type	Metal Content in Positive Leg	Metal Content in Negative Leg	Temperature Range
B	70.4% Platinum (Pt). 29.6% Rhodium (Rh)	93.9% Pt, 6.1% Rh	1600 - 3100° F (870 - 1700°C)
E	90% Nickel. (Ni). 10% Chromium (Cr)	55% Copper (Cu). 45% Ni	32 - 1650°F (0-900°C)
J	99.5% Iron (Fe)	55% Cu, 45% Ni	32 - 1380°F (0 - 750° C)
K	90% Ni. 10% Cr	95% Ni 5% Various Elements	32 - 2280°F (0 - 1250° C)
N	84.4% Ni. 14.2% Cr 1.4% Silicon	95.5% Ni, 4.4% Si	32 - 2280°F (0 - 1250° C)
R	87% Pt, 13% Rh	100% Pt	32 - 2640°F (0 - 1450°C)
S	90% Pt, 10% Rh	100% Pt	32 - 2640°F (0 - 1450°C)
T	100% Copper (Cu)	55 % Cu, 45% Ni	-330 - 660° F (-200 - 350°C)
C*	95 % Tungsten (W). 5% Rhenium (Re)	74% Tungsten (W). 26% Rhenium (Re)	32 - 4200°F (0 - 2315°C)
D*	97% W, 3% Re	75% W, 25% Re	32 - 4200°F (0 - 2315°C)
G*	100% W	74% W, 26% Re	32 - 4200°F (0 - 2315°C)

* Not Official ANSI (American National Standards Institute) designations.

An extension wire made of the same material as the thermocouple is referred to as thermocouple wire, but a wire made of different material (with characteristics similar to the thermocouple's) is referred to as compensating lead wire. thermocouple wire can be used for type T and J because material is not expensive. Compensating lead wire is normally made of copper or copper/nickel alloy.



A PICTURES EXPLAINING THE REFERENCE JUNCTION OF A THERMOCOUPLE

SPECIAL PURPOSE THERMOCOUPLES

HOT BLAST:

It has fast response. It is used to measure temperature of preheated air to furnace.

GASKET THERMOCOUPLE:

It is mounted on studs or bolts to measure skin temperature of process lines, shell vessels or other process machinery.

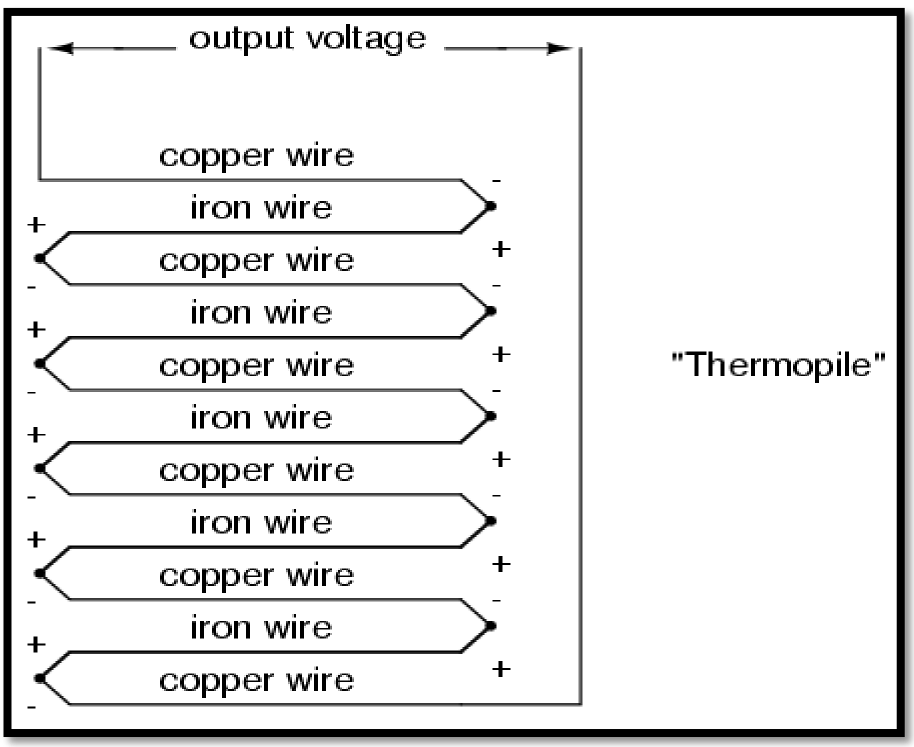
TUBE WALL THERMOCOUPLE:

It is used to measure furnace tube temperature. It is installed by welding pad to tube or other surface.

SPECIAL FEATURES OF THERMOCOUPLES

THERMOPILE:

Thermocouples connected in series to measure net voltage of thermocouples.



THERMOPILE

DIFFERENTIAL TEMPERATURE:

Two thermocouples can be used for measuring differential temperature between two points. Connections are made in such a way that emf's developed oppose each other. If temperature of both thermocouples is equal , net emf is zero. It can be used to measure differential temperature of top and bottom of steam line.

AVERAGE TEMPERATURE:

To measure average temperature across a vessel or duct, thermocouples may be used in parallel connection. Net voltage produced at instrument is average voltage developed by thermocouples.

For accurate measurement, resistance of all thermocouples and extension wires should be same. Due to variation in temperature of thermocouple and length of extension wire, a swamping resistor is used (1.5 Kilo ohm normally)

Thermocouple Advantages and Disadvantages Advantages:

• Thermocouples are used on most transformers. The hot junction is inside the transformer oil and the cold junction at the meter mounted on the outside. With this simple and rugged installation, the meter directly reads the temperature rise of oil above the ambient temperature of the location.

• In general, thermocouples are used exclusively around the turbine hall because of their rugged construction and low cost.

• A thermocouple is capable of measuring a wider temperature range
than an RTD

Disadvantages:

• If the thermocouple is located some distance away from themeasuring device, expensive extension grade thermocouple wires or compensating cables have to be used.

• Thermocouples are not used in areas where high radiation fields are present (for example, in the reactor vault). Radioactive radiation (e.g., Beta radiation from neutron activation), will induce a voltage in the thermocouple wires. Since the signal from thermocouple is also a voltage, the induced voltage will cause an error in the temperature transmitter output.

• Thermocouples are slower in response than RTDs

• If the control logic is remotely located and temperature transmitters (milli-volt to milli- amp transducers) are used, a power supply failure will of course cause faulty readings.

Failure Modes:

An open circuit in the thermocouple detector means that there is no path for current flow, thus it will cause a low (off-scale) temperature reading.

A short circuit in the thermocouple detector will also cause a low temperature reading because it creates a leakage current path to the ground and a smaller measured voltage.

2. PRESSURE

Learning Objectives:

Upon Completion of this topic one should be able to understand:

1. Pressure and its different units
2. Definitions Of pressure related terms and head pressure calculation
3. Types of pressure instruments and their detail
4. Types of pressure sensors and transducers
5. Pressure transmitter installation

6. State the effect of the following failures or abnormalities:

   a) Over-pressuring a differential pressure cell or bourdon tube;
   b) Diaphragm failure in a differential pressure cell;
   c) Blocked or leaking sensing lines; and
   d) Loss of loop electrical power.

2.1 Definition of Pressure:

Pressure is defined as force divided by the area over which it is applied. Pressure is often defined in terms of "Head". Pressure is a basic process variable in that it is utilized for measurement of flow (difference of two pressures), level (liquid pressure of back pressure from a bubble tube), and temperature (fluid pressure in a filled thermal system).

Pressure is measured as force per unit area. In English system force is measured in pounds and a common unit of pressure is pounds per square inch (psi). The pressure of atmosphere at sea level under standard conditions is 14.696 psi absolute.

UNITS OF PRESSURE

Gravity dependent units:

Units such as Psi, Kg/cm2, inches of water, and inches of mercury are all gravity dependent. The force at the bottom of each column is proportional to the height, density, and gravitational acceleration.

Gravity independent units:

Units such as pounds-force per square inch and Kilogram-force per centimeter square are independent of gravity because a specific value of gravitational acceleration was selected in defining these units. Pascal is exactly the same at every point, even on moon, despite changes in gravitational acceleration.

Pascal:

The English or SI (systems international) unit of pressure is defined as the pressure or stress that arises when a force of one Newton (N) is applied uniformly over an area of one square meter (m2). This pressure has been designated one Pascal (pa).

Pa=N/m2 (100Kpa=1 Kg/cm2)

Definitions

Absolute pressure: Pressure above perfect vacuum or zero absolute.

Atmospheric pressure: Pressure exerted by earth's atmosphere. It is also called **barometric pressure**. Atmospheric pressure at sea level is 14.7psia or 29.9 inches of mercury absolute.

Gauge pressure: Pressure above atmospheric pressure.

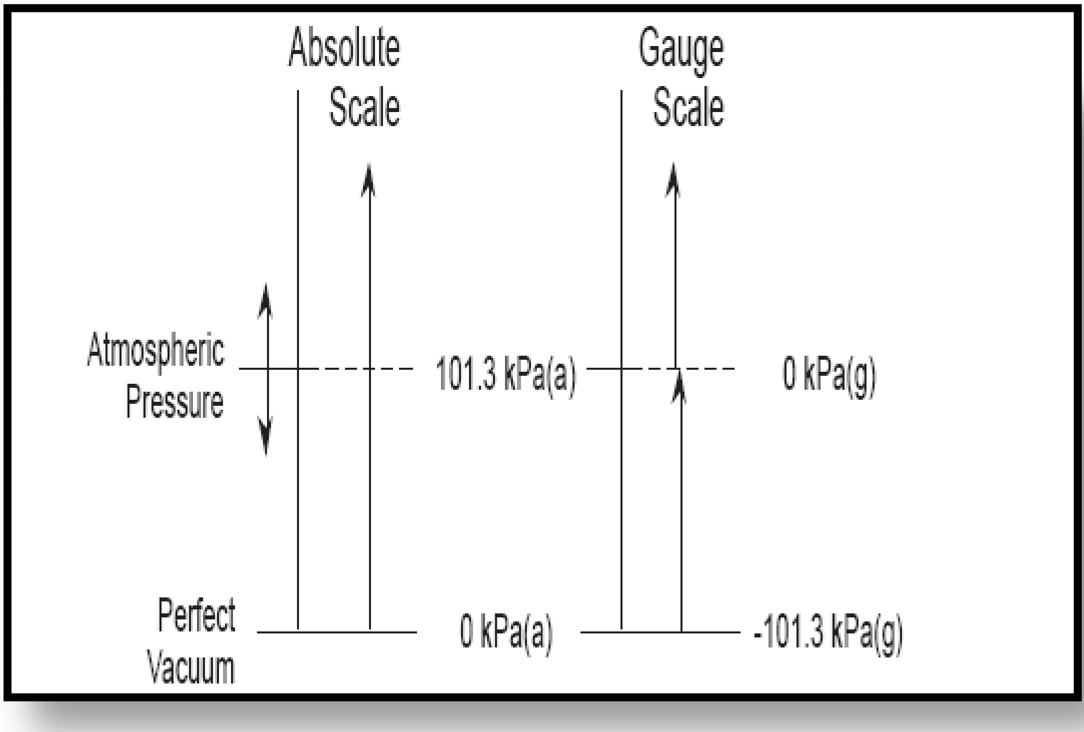


Figure 2.1 pressure scales

Differential pressure: It is difference between two pressures. The rate of flow through a restriction in a pipe is proportional to the square root of the differential pressure. The loss in pressure increases as the flow rate increases.

Vacuum: Pressure below atmospheric pressure.

Static pressure: Force per unit area exerted on a wall by a fluid at rest or flowing parallel to a pipe wall. It is also called **line pressure**.

Total pressure: All pressures, including static, acting in all directions.

Velocity pressure: Pressure exerted by the speed of flow. It is also called **velocity head or impact pressure.**

Hydrostatic pressure: Pressure below a liquid surface exerted by the liquid above.

Conditions affecting liquid pressure

Surface pressure: any pressure acting on the surface is transmitted throughout the liquid and contributes to the pressure at any location beneath the surface.

Depth: pressure is proportional to depth below the surface.

Density: pressure is proportional to the density (or relative density) of the liquid.

Relative density (specific gravity):
Water is used as reference in comparing the density of liquids or solids, while air is used for gases. The ratio of density of a liquid or a solid to the density of water is called relative density or specific gravity. Relative density is also used to compare pressure in a liquid to the pressure at the same depth in water.

Calculation of Head Pressure:

P (Head) = 0.433 * Height (ft) * specific gravity.

Where P = Pressure, H = Height of liquid.
0.433 = PCF (pressure conversion factor).
PCF = Head (ft) * Density (weight) of water.
PCF = 1 ft * 62.4 lb/ft3 = 62.4 lb/ft2 = 62.4 lb/144 in2 = 0.433 psi

Boyle's law: the pressure of a gas varies inversely with its volume when the gas is held at a constant temperature.

Charles' law: volume of a gas varies directly with its absolute temperature at a constant pressure.

Absolute zero: the temperature at which molecules would stop moving (-273 oC).

Gas law: relationship between pressure, volume, and temperature is, PV = nRT, n = no. of molecules of gas, R = a constant, T = absolute temperature.

2.2 Parts of pressure instruments

Pressure instruments are functionally divided into two parts

1. **Sensors**
2. **Transducers**

2.3 There are two basic kinds of sensors

1. **Wet sensors:** contain liquid that responds to the pressure.
2. **Dry sensors:** use an elastic element that responds to pressure.

Pressure instruments can be divided in to two major categories.

1). Those that employ mechanical means to detect and communicate pressure information from the process and secondary device

2). Those that rely on electrical phenomenon or relationship to carry out this function

Mechanical pressure measurement systems:

In mechanical systems pressure is determined by balancing a sensor against the unknown force. This can be done by another pressure or force.

Pressure balance sensors

The two most common pressure balance sensors are:

I. Manometers
II. Dead weight tester.

1. Force balance sensors

The most common force balance sensors are:

I. Bellows
II. Diaphragm

III. Bourdon metallic devices

Pressure balance systems

I. Dead weight tester:

It works on the basis of Pascal's law; any pressure communicated to the surface of a confined liquid is transmitted unchanged to every part of the liquid.

II. Manometer:

In this method the pressure created by a column of liquid is used to balance the pressure to be measured.

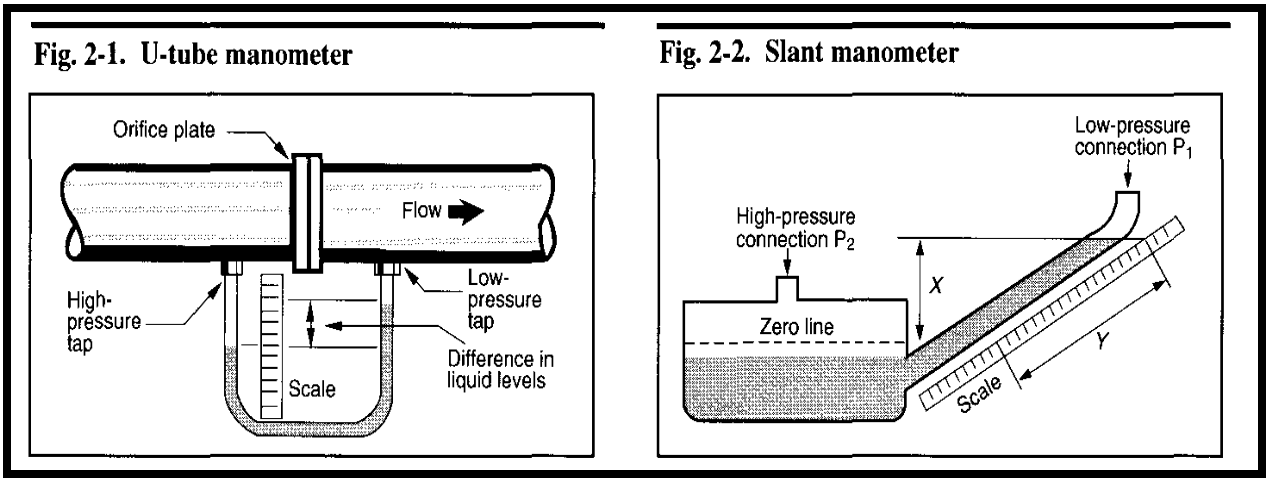
Pressure reading is the difference in height from the top of the pressure column to the top of the vented column. Mercury is normally used in manometers

Types of manometers:

Single leg manometer: It is used to measure barometric pressure. It is a closed tube manometer with a vacuum on sealed side. Pressure applied to open end forces liquid up into the sealed end. A barometer when moved vertically indicates changes in elevation, becoming an altimeter.

U- Tube manometer: It is used to measure differential pressure.

Inclined tube manometer (slant manometer): It is used to provide greater reading accuracy through the use of a longer tube.



U-Tube manometer and slant manometer

Force balance systems

I. **Bourdon tube**

One end of the tube is sealed; the other is connected to the process. As the pressure in the process increases, tube tends to straighten out. The resultant motion is transferred through a linkage or rack-and-pinion mechanism to an indicating pointer.

A bourdon tube is basically a spring that stretches as pressure is applied. Bourdon tube metals must not be subject to hysteresis i.e. the metal must not stretch a different amount for increasing or decreasing pressure, causing the gauge two different reading for one pressure. The choice of metals depends on corrosion resistance, flexibility, hysteresis characteristics, pressure range, and cost.

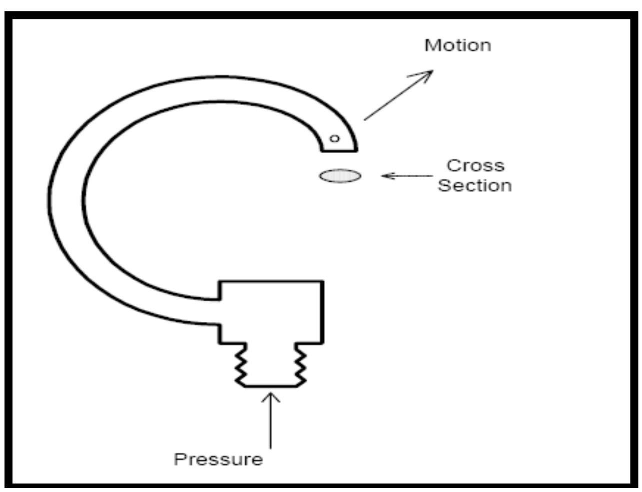


Figure 2.3 Bourdon tube

It exists normally in any of the three shapes.

a). 'C' shape bourdon tube.

It is used up to ranges from 0 to 10,000 psig. The range depends on material used, flatness of tube and cross sectional area of tube.

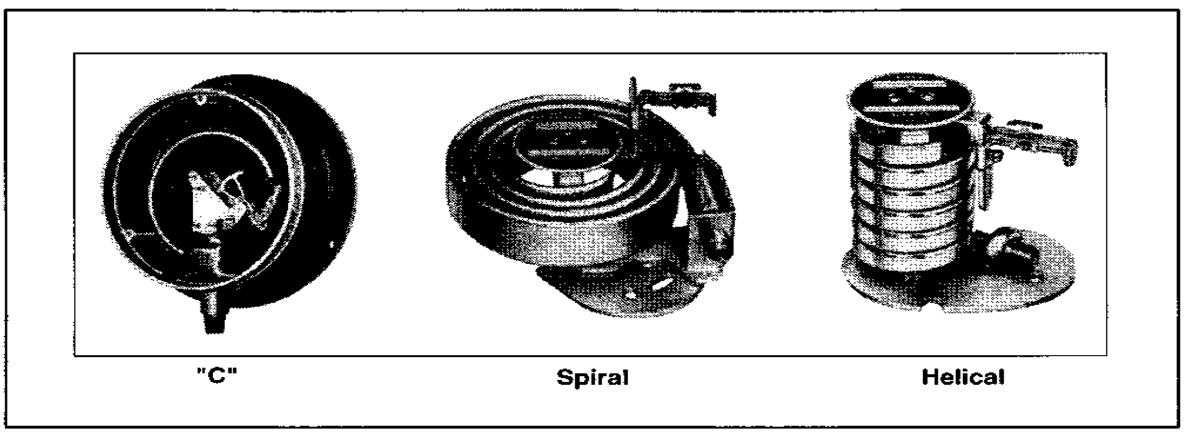
b).Spiral tube

Spiral element is actually a long C- type tube resembling a flat coil. One end is rigid, and the movement of the free end is linked to a pointer of indicator.

c).Helical tube

Helical element is a long C-type spring wound like a vertical spring. It is more sensitive to small changes.

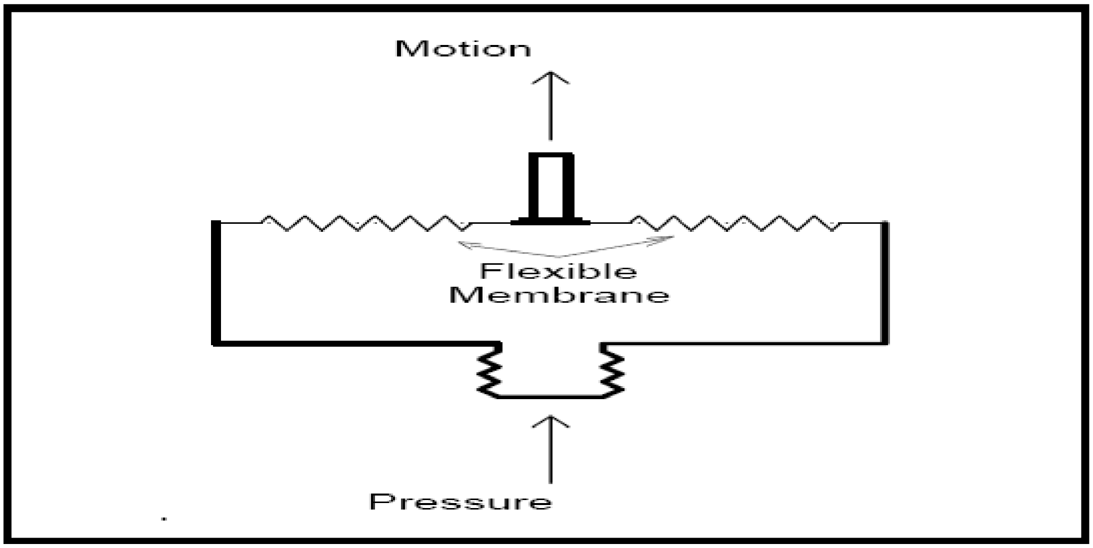
Fig. 2-4. Bourdon tube shapes



Bourdon Tube shapes

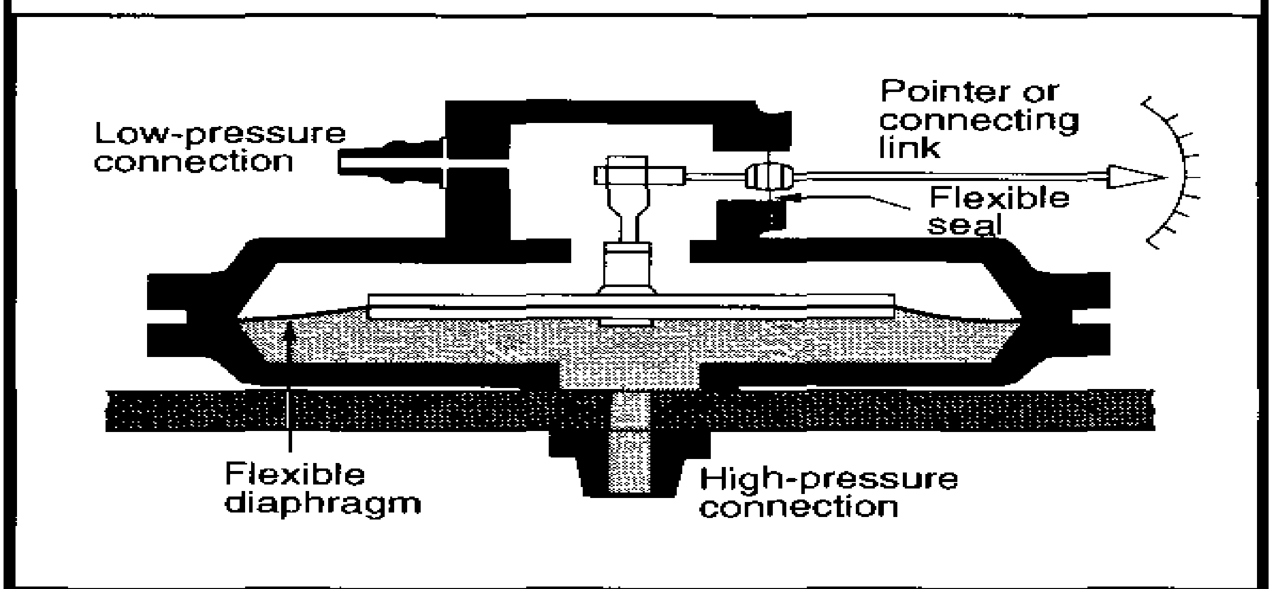
II. Diaphragm pressure sensors

A diaphragm is a flexible disk that changes shape as the process pressure changes. Disk is held firmly all around the outer edge. The process pressure pushes on one side of the disk. Central portion of the disk moves in or out as the process pressure changes. Two types of diaphragms are used.



Diaphragm pressure sensor

Fig. 2-9. Single-diaphragm pressure gauge

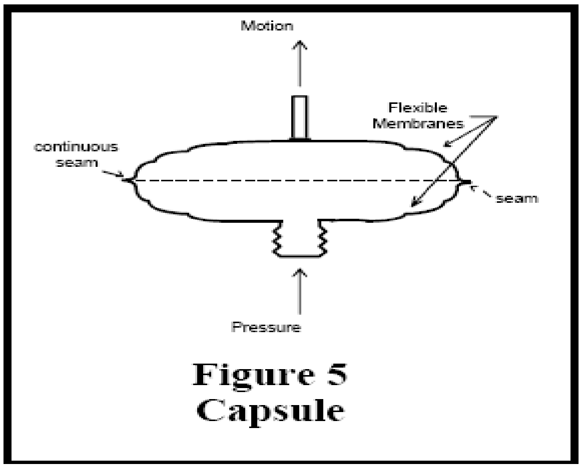


- **Single diaphragm:** uses only one flexible element.

  Single diaphragm

- **Capsule diaphragm:** uses two flexible elements.

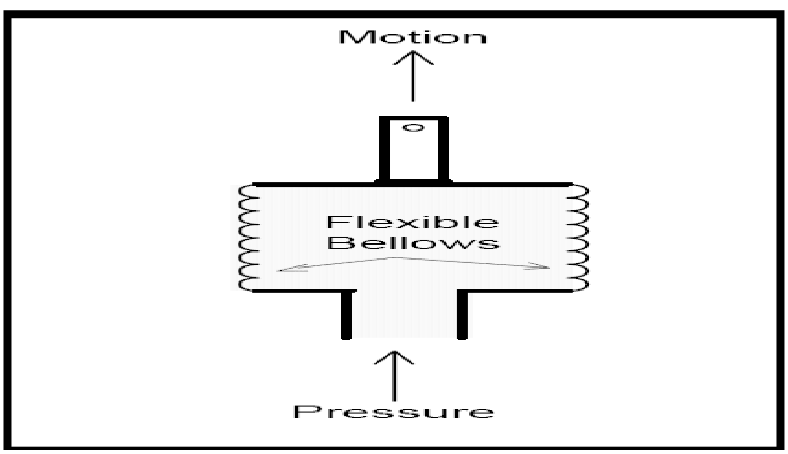
Diaphragm capsule may be made of phosphor bronze, stainless steel or other metal alloys. Two diaphragms are welded together around the edge to make the capsule. The inside of the diaphragm is then connected to the process pressure and outside pressure is the reference. Outside of the capsule is exposed to the atmosphere (for measuring gauge pressure). Capsule can be enclosed in sealed container so that reference can be either a vacuum or one side of a process pressure.



Capsule diaphragm

III. **Bellows pressure sensors**

It is formed from a homogenous piece of seamless tubing. When pressure is applied to one end, the circular sections expand axially and this motion is used as a measure of the pressure. It is usually made of brass or stainless steel.



Bellows pressure sensors

Table 2-1. Sensor applications

Sensor type	Material	Typical measurement ranges* Low	High	Common measurement application
C-shape and helix bourdon	Bronze	0 to 15 A,G	0 to 400 A,G	Gauge and absolute pressure
	Steel	0 to 50 A,G	0 to 10,000 A,G	Gauge and absolute pressure
	Stainless steel	0 to 100 A,G	0 to 10,000 A,G	Gauge and absolute pressure
Spiral bourdon	Bronze	0 to 7 A,C	0 to 15 A,C	Vacuum and compound pressure
		0 to 18 A,C,G	0 to 400 A,C,G	Gauge, absolute, and compound pressure
	Steel	0 to 30 A,C,G	0 to 4,000 A,C,G,	Gauge and absolute pressure
	Stainless steel	0 to 50 A,C,G,	0 to 4,000 A,C,G	Gauge and absolute pressure
Diaphragm	Bronze	0 to 90 W	0 to 15 G	Gauge pressure
		0 to 10 IM	0 to 30 IM	Vacuum
	Stainless steel	0 to 15 G	0 to 100 G	Gauge pressure
Bellows	Brass	0 to 5 W	0 to 90 W	Gauge pressure and vacuum
Sealed bellows	Brass	0 to 100 MM	0 to 50 IM	Absolute pressure
	Stainless steel	0 to 200 MM	0 to 60 IM	Absolute pressure

*These letter codes are used to identify common units of measurement for given range values: A = psia, C = compound, G = psig, IM = inches mercury, MM = millimeters mercury, W = inches water

Note that a compound range is one that goes from a vacuum (negative pressure) to a gauge (positive) pressure.

2.4 Pressure transducers

A device that converts the mechanical output of a pressure sensor to a standard electrical is the transducer.
An electrical pressure transducer consists of three elements

1. **Pressure sensing element:** usually a bellow, diaphragm or bourdon tube.

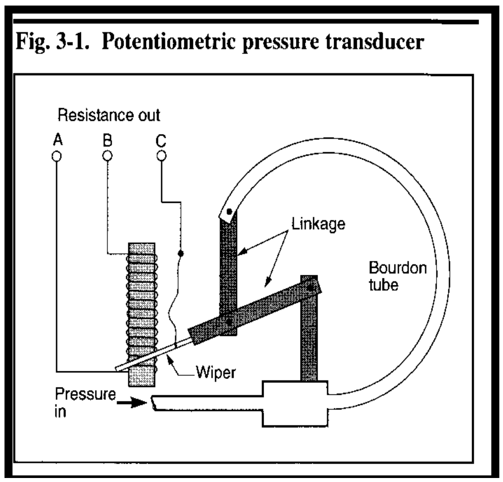
2. **Primary conversion element:** Converts mechanical action of the pressure sensing element into an electrical signal, usually resistance or voltage.

3. **Secondary conversion element:** It produces a standard signal according to the needs of the control system.

Potentiometric pressure transducers:

Potentiometer is a variable resistor. It is made by winding resistance wire around an insulated cylinder. A movable electrical contact (a wiper) slides along the cylinder, touching the wire at one point on each turn. The position of wiper determines how much resistance between the end of wire and the wiper.

Disadvantage is that it generates discrete output i.e. the wiper does not move continuously along the wire.



Potentiometric pressure transducers

Capacitive pressure transducers

It is based on the principle of capacitor. The transducer contains two metal plates. One plate, the stator, is stationary. The other plate is a flexible metal diaphragm that moves closer to the stator when the pressure rises. As the pressure changes, the diaphragm moves and changes the capacitance of the device.

C = K A/d where, C = capacitance,

K = Di-electric constant, A = Cross sectional area of plates, d = Distance between plates.

The transducer is connected in an ac bridge circuit. Changes in the measured pressure cause changes in the capacitance of the capacitor and in the bridge circuit's response. These changes cause changes in the voltage output of the bridge circuit.

Response time of capacitance transducer is very fast, as ten milliseconds.

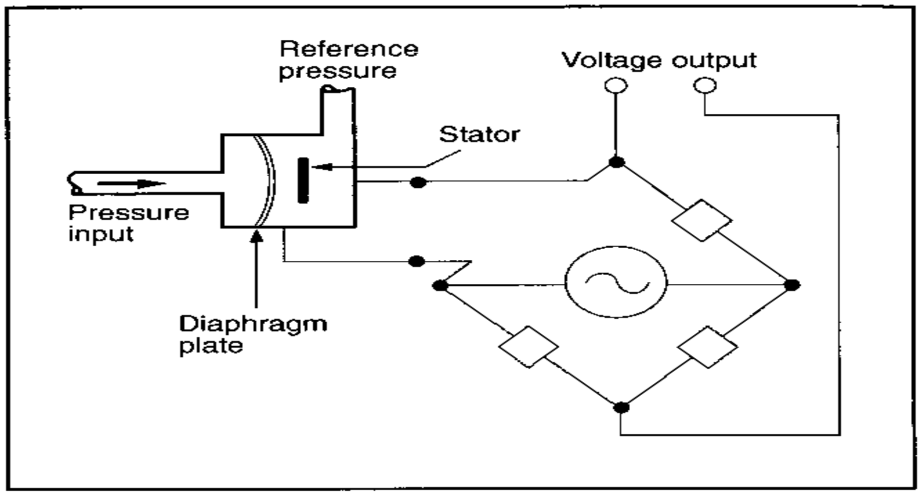


Fig. 3-4. Capacitive pressure transducer and ac bridge circuit

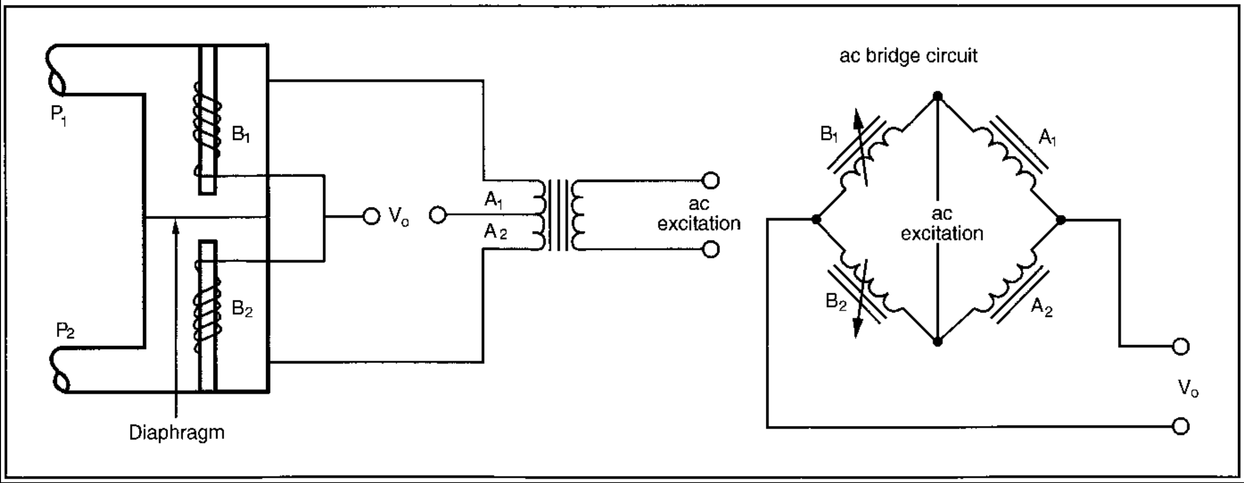
Capacitive pressure transducers

Reluctive pressure transducer

Coupled coils: two coils, each wound on an iron core, placed near each other. Ac in one coil induces ac in other coil, so the coils are said to be coupled.

It works by changing the reluctance (resistance in magnetic circuit) between two coils. The diaphragm between coils B1and B2 is made of a flexible magnetic material. As pressure P1 changes compared to P2, the diaphragm moves and changes the reluctance between coils B1 and B2, in turn changing the output voltage, Vo, which indicates pressure. It is used to measure pressure between 10 psi to 10000 psi.

Fig. 3-6. Reluctive pressure transducer

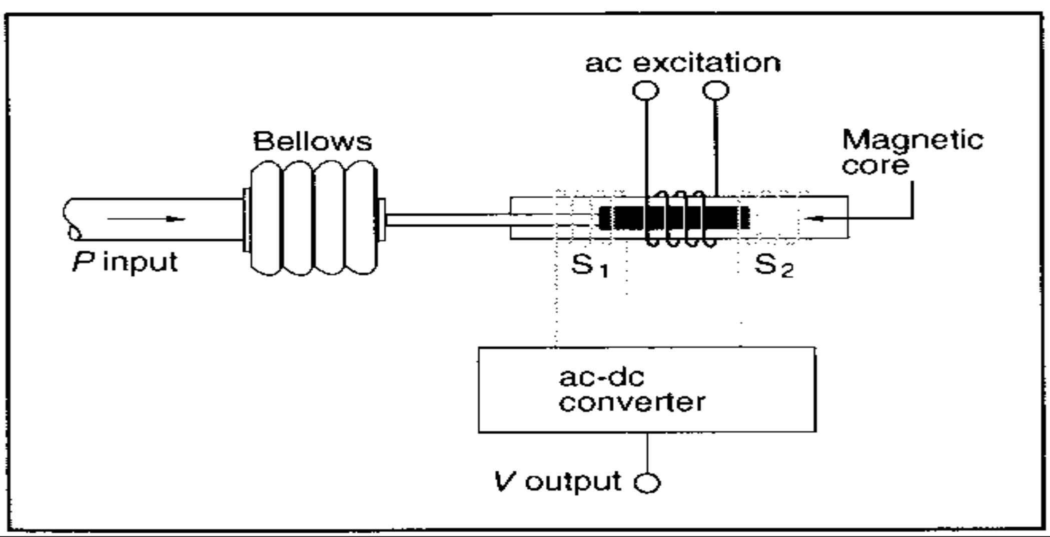


Reluctive pressure transducer

Linear variable differential transformer (LVDT) pressure Transducer

Change in pressure causes the bellow to expand or contract, which moves a magnetic core inside a primary and two secondary coils. The output voltage from this device varies in proportion to the position of the core. The LVDT is often used to convert a pneumatic signal to a proportional electrical signal.

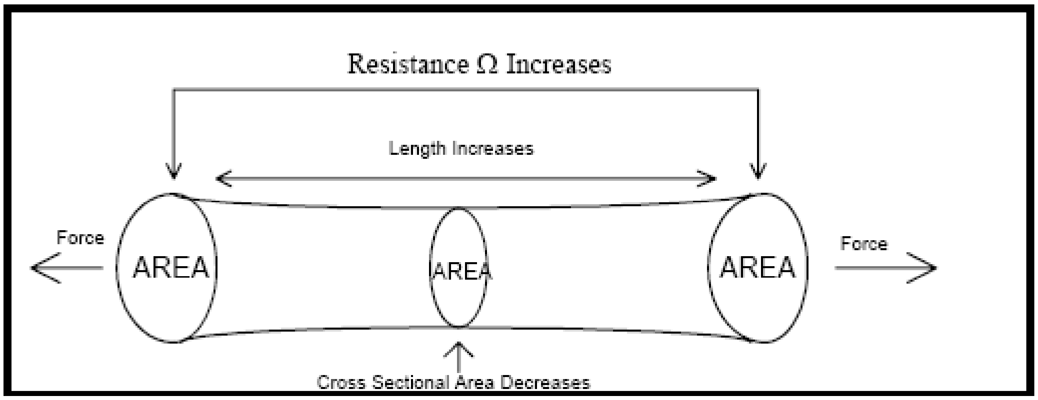
Fig. 3-8. LVDT pressure transducer



Linear variable differential transformer (LVDT) pressure Transducer

Strain gauge pressure transducers

A strain gauge changes its electrical resistance as it is stretched and relaxed. It can be attached to a pressure-sensing diaphragm. When diaphragm flexes, the strain gauge stretches or relaxes, in turn converting pressure changes to electrical changes. Strain gauges are all force balance devices.



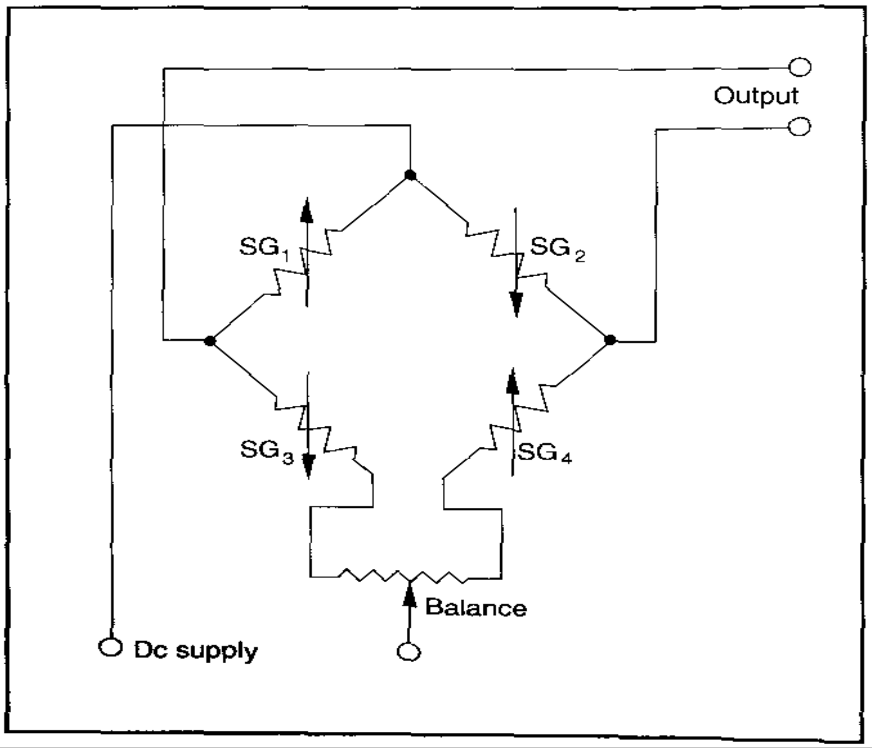
Strain gauge pressure transducers

The **metal wire strain gauge** is made of very fine wire. The wire is fastened to a pressure diaphragm or other flexing element.

A **semiconductor strain gauge** is connected to an electronic circuit to indicate pressure. It is classified into two types.

P-type: resistance increases directly with applied strain or pressure.
N-type: resistance decreases as applied strain or pressure increases.

Fig. 3-10. Strain-gauge bridge circuit



Strain gauge pressure transducers

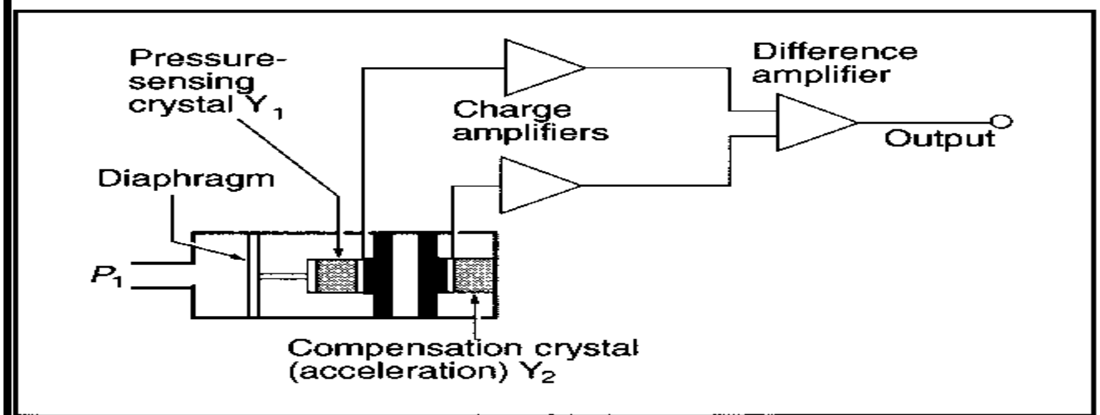
Piezoelectric pressure transducers

A material that produces electric voltage when pressure is applied is referred to as **piezoelectric material**, like barium titanate powder and crystals of quartz, tourmaline, and Rochelle salts.

- Piezoelectric pressure transducers are force balance transducers.
- To amplify the voltage signal, amplifier input impedance should be high (greater than 100 M ohms).
- It can measure up to 50000 psi. The instrument can indicate a pressure increase over the full range in a period of time as short as 1 micro seconds.
- Piezoelectric transducers cannot measure steady pressures. They respond only to changing pressures.

Pressure at P1 is transmitted to the piezoelectric crystal, Y1, by a diaphragm. The signal is amplified by a charge amplifier. A second piezoelectric crystal, Y2, is included to compensate for any acceleration of the device during use. Signals from the compensating crystal are amplified by a second charge amplifier. A difference amplifier subtracts the amplified compensating signal from the amplified signal produced by the pressure crystal. The difference indicates the resulting pressure.

Fig. 3-12. Compensated piezoelectric pressure transducer



Piezoelectric pressure transducers

Response time

The time required for an output to make the change from an initial value to a large specified percentage, usually 90, 95 or 99% of the final value.

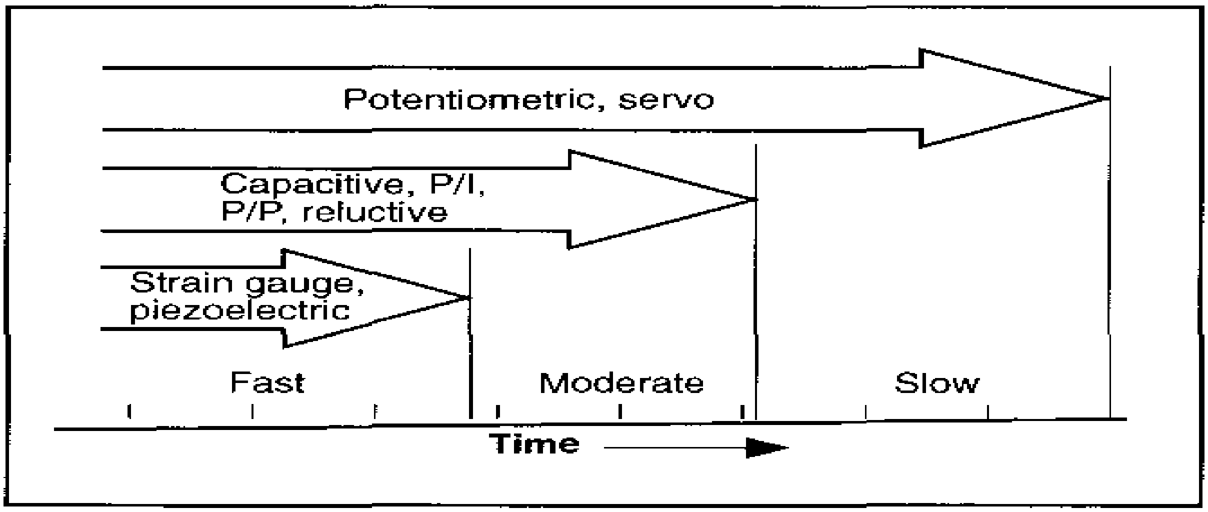
2.5 Environmental conditions affecting a transducer

Ambient temperature: temperature of air surrounding a device.

Relative humidity: a measure of the moisture content of the air, specified as a range of percent RH at a reference temperature. Temperature and relative humidity combine to produce condensation.

Vibration: Oscillation or motion of device about its position of rest.

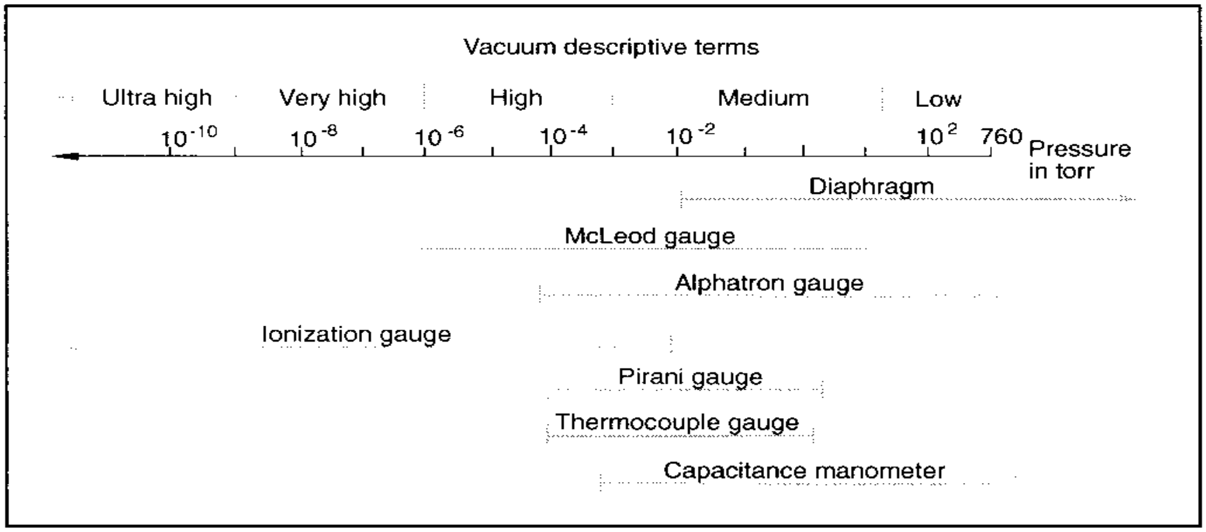
Fig. 3-14. Comparison of transducer response times



2.6 Low pressure measurement

Vacuum: pressure below atmospheric pressure is called vacuum or absolute pressure. One atmosphere of pressure is equal to 760 mm Hg. One torr (shorter name of Torricelli, scientist) is equal to 1 mm Hg.

Fig. 4-1. Ranges of low-pressure instruments



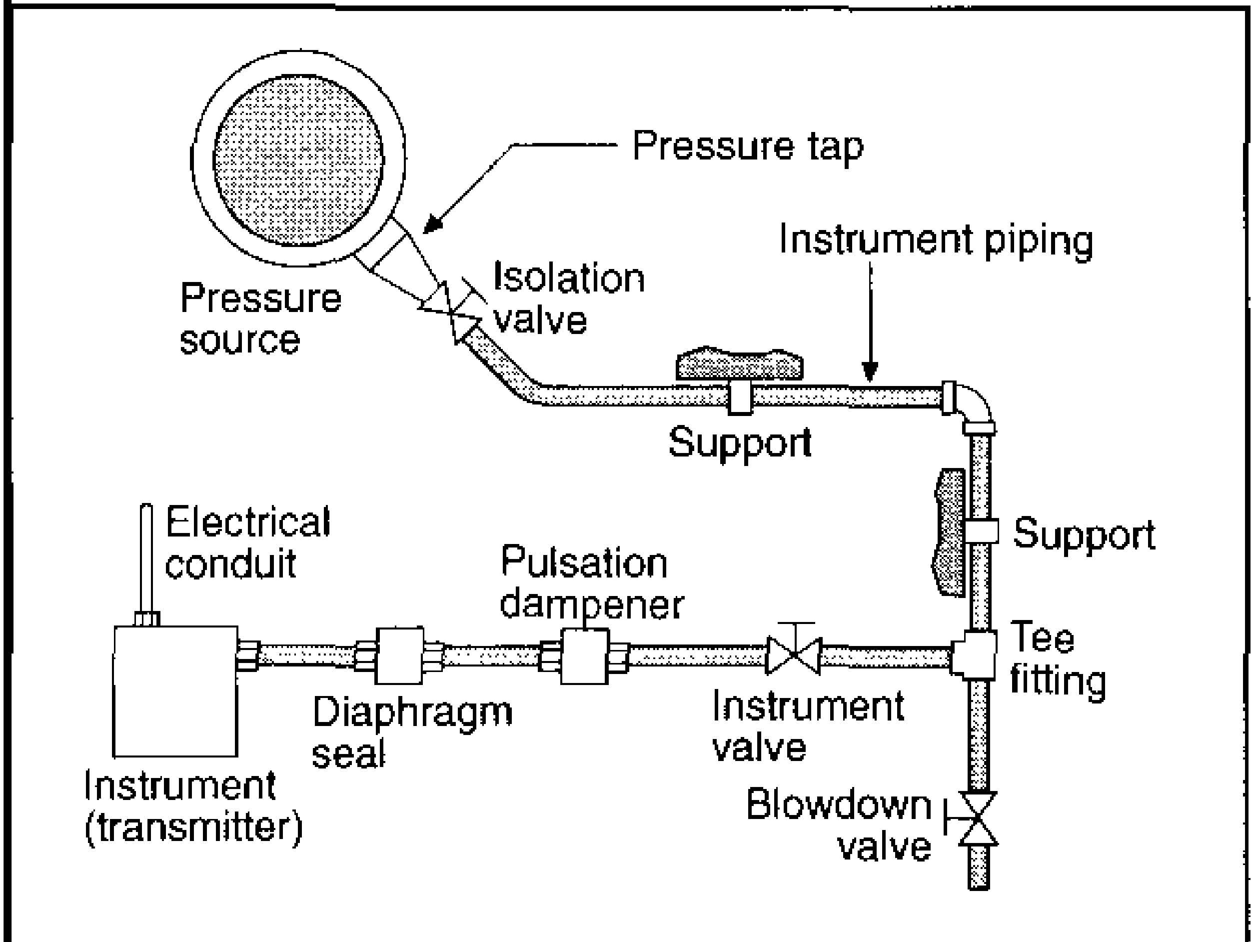
Low pressure measurement

2.7 Pressure switch

A pressure switch turns an electric circuit on or off at a preset pressure. This pressure is referred to as the set point of the switch. The contacts in a switch may be normally open or normally close.

Dead band is the difference between the value at which a control action occurs (set point) and the value at which the control action is cancelled (reset point).

Fig. 5-1. Typical pressure transmitter installation



2.8 Liquid or Steam Pressure measurement

When a liquid pressure is measured, the piping is arranged to prevent entrapped vapors which may cause measurement error.
When steam pressure is measured, the steam should be prevented from entering the Bourdon tube. If the gauge is below the point of measurement, a "siphon" is provided in the pressure line to the gauge.

2.9 Failures and Abnormalities

Over-Pressure:

All of the pressure sensors we have analyzed are designed to operate over a rated pressure range. Plant operating systems rely on these pressure sensors to maintain high accuracy over that given range. Instrument readings and control functions derived from these devices could place plant operations in jeopardy if the equipment is subjected to over pressure (over range) and subsequently damaged. If a pressure sensor is over ranged, pressure is applied to the point where it can no longer return to its original shape, thus the indication would return to some value greater than the original.

Diaphragms and bellows are usually the most sensitive and fast-acting of all pressure sensors. They are also however, the most prone to fracture on over-pressuring. Even a small fracture will cause them to read low and be less responsive to pressure changes. Also, the linkages and internal movements of the sensors often become distorted and can leave a permanent offset in the measurement. Bourdon tubes are very robust and can handle extremely high pressures although, when exposed to over-pressure, they become slightly distended and will read high. Very high over-pressuring will of course rupture the tube.

Faulty Sensing Lines:

Faulty sensing lines create inaccurate readings and totally misrepresent the actual pressure, When the pressure lines become partially blocked, the dynamic response of the sensor is naturally reduced and it will have a slow response to change in pressure. Depending on the severity of the blockage, the sensor could even retain an incorrect zero or low reading, long after the change in vessel pressure. A cracked or punctured sensing line has the characteristic of consistently low readings. Sometimes, there can be detectable down-swings of pressure followed by slow increases.

Loss of Loop Electrical Power:

As with any instrument that relies on AC power, the output of the D/P Transmitters will drop to zero or become irrational with a loss of power Supply.

3. FLOW

OBJECTIVES:

Upon Completion of this topic one should be able to understand:

1. Concept of flow and its related terms
2. Direct and Indirect flow measurement
3. Flow measurement through displacement
4. Flow measurement using differential pressure
5. Velocity Flow Meters
6. Mass Flow Meters
7. State the effect on the flow measurement in process with Abnormalities: Vapor formation in the throat, clogging if throat by Foreign material, Leaks in HI or LO pressure sensing lines

3.1 Flow Definition:

Flow is defined as the volume of material that passes a specific place in a specified time interval. Units of flow are gallons per minute (gpm), cubic feet per second (ft3/s), tons per hour (t/h) and so on.

Terms used in flow measurement

Density

It is defined as mass of a unit volume of that fluid. Its units are g/cm3, Kg/m3, g/l.

Relative density (Specific gravity)

It is ratio of two densities. It is the ratio between the density of a certain liquid and the density of water or it is the ratio between the density of a certain gas and the density of air. It is a unitless number.

Compressibility

It is the ability of a substance to decrease in volume when pressure is applied.

Viscosity

Viscosity of a fluid is defined as its resistance to flow. It is affected by the temperature. In metric system its unit is poise (1 dyne-s/cm2); while in English system its unit is lb-s/ft2.

Laminar flow

It is a smooth, layered flow. Laminar flow pattern in a pipe looks like the concentric rings. The flow lines are called streamlines. An object that disrupts the flow pattern only slightly is said to be streamlined.

Turbulent flow

It is rough and irregular. It is made up of many small currents, swirling and weaving in all direction, forming miniature whirlpools called eddy currents. It causes considerable frictional resistance to fluid flow. An object placed in flow path creating turbulence is called blunt object.

Bernoulli Effect

It states that as the fluid velocity increases, the pressure on the walls decreases. This inverse relationship between fluid velocity and the pressure of containments is called Bernoulli Effect.

It can be expressed as,

$$V = K\sqrt{(\Delta P/D)}$$

The square root relationship between the flow velocity and the pressure differential causes a nonlinear output in many flow meters.

Head pressure of any liquid is calculated by,

$P = DH$

The liquid's weight density in lb/ft3 divided by 144 in2 gives pressure in psi at bottom of a cubic foot of that liquid.

Static suction lift

The vertical distance from the center line of the pump to the surface of the liquid to be pumped (source is below pump) is the static suction lift.

Static suction head

The vertical distance from the center line of the pump to the surface of the liquid to be pumped (source is above pump) is the static suction lift.

Total static head

Total static head is the vertical distance (in feet) between the surface on the input side and the surface on the discharge side. If the point of discharge is above the surface of the liquid, the horizontal upper arm of the pipe is considered the level of the free surface of the water.

Volume flow rate is calculated by equation:

Q (vol) = Ax V

Where, Q (vol) = volume flow rate

A = cross-sectional area of the pipe carrying the fluid

v = flow velocity.

Mass flow rate is calculated by:

Q (m) = D x Q (vol)

Where, Q (m) = mass flow rate

D = fluid density (mass per unit volume)

Conditions Affecting Flow Rate

The rate at which a fluid flows through a channel or pipe depends on three conditions: head, viscosity, and frictional resistance.

Reynolds Number

A Reynolds number is the ratio of a liquid's (or gas's) inertial forces to its drag forces. It is calculated by multiplying the velocity of the fluid by the diameter of the pipe and by the density of the fluid, and then dividing that value by the viscosity of the fluid. Reynolds numbers are low at low velocities and high viscosities.

Rn = (Vel x Dp x D) / Visc

At a low Reynolds number (up to about 2000), the viscosity and velocity of the fluid produce a smooth, laminar flow. Flow changes between laminar and turbulent in the range of Reynolds numbers between 2000 and 4000. At a Reynolds number above 4000, flow is turbulent

Total flow is the amount of fluid that flows over an extended time interval. A totalizer accumulates and stores flow- rate values received from a primary flow meter.

Flow rate is the instantaneous flow reading at a particular time. It can change greatly from one second to the next. To measure flow rate, an in-line flow meter could be used.

Direct flow measurement: the volume of material that passes a certain location in a specified time interval. If an instrument directly measures the volume of fluid passing a certain location in a specified time interval, volume flow rate is measured directly.

Indirect flow measurement: it provides instantaneous flow-rate values, but it does not measure accumulated volume. Instead, it measures changes in properties of flowing liquids— changes in velocity, depth, or pressure. Indirect flow measurement requires both a primary and a secondary measuring device, A primary device interacts with the flowing fluid to produce a signal that is measured by the secondary measuring device. This measurement is then used as the indicated flow rate. Normally the function of the primary measuring device is to create a difference in pressure, or a pressure differential, in a flowing fluid (liquid or gas).

Invasive primary device: A device whose sensing elements come in direct contact with the fluid.

Non-invasive primary device: A device whose sensing elements remain outside the wall of the pipe, never touching the flowing fluid.

A **secondary device** measures or reads the differential to determine the flow velocity or volume flow rate of the fluid.

Rangeability

The rangeability of a flow meter is defined as:

Maximum flow rate / minimum flow rate

This ratio tells the range of flow that a certain flow meter can effectively measure, from the lowest value to the highest value.

Turndown

Turndown is defined as:

Applied maximum flow rate / applied minimum flow rate

Turndown is similar to rangeability, but turndown refers to the flow range of a flow meter in an installed system. The maximum flow rate in the application may be well below the meter's maximum limit.

3.2 Fluid flow measurement is accomplished by Displacement

a. Positive displacement meters
b. Metering pumps

Flow measurement using differential pressure

a. Orifice plate
b. Venture tube
c. Flow nozzle
d. Pitot tube
e. Elbow-mounted
f. Target (drag force)
g. Variable area (rotameter)

Velocity Flow Meters

a. Magnetic
b. Turbine
c. Vortex or Swirl
d. Ultrasonic
e. Thermal

Mass Flow Meters

a. Weight types
b. Head and Magnetic types compensated for temperature, pressure and density.
c. Gyroscope precision type

The factors such as Accuracy, Pressure loss, material to be measured, ease of changing capacity, ease of installation, and cost of flow meter must be considered before selecting the flow meter.

3.3 Positive displacement meters

Positive displacement meters are measurement devices that trap a known volume of fluid and allow it to pass from meter inlet to outlet. Then the numbers of trapped volumes passing through the meter are counted to obtain the total flow.

Displacement means that the fluid flowing through the meter replaces (displaces) the volume of fluid that passed through the meter immediately before.

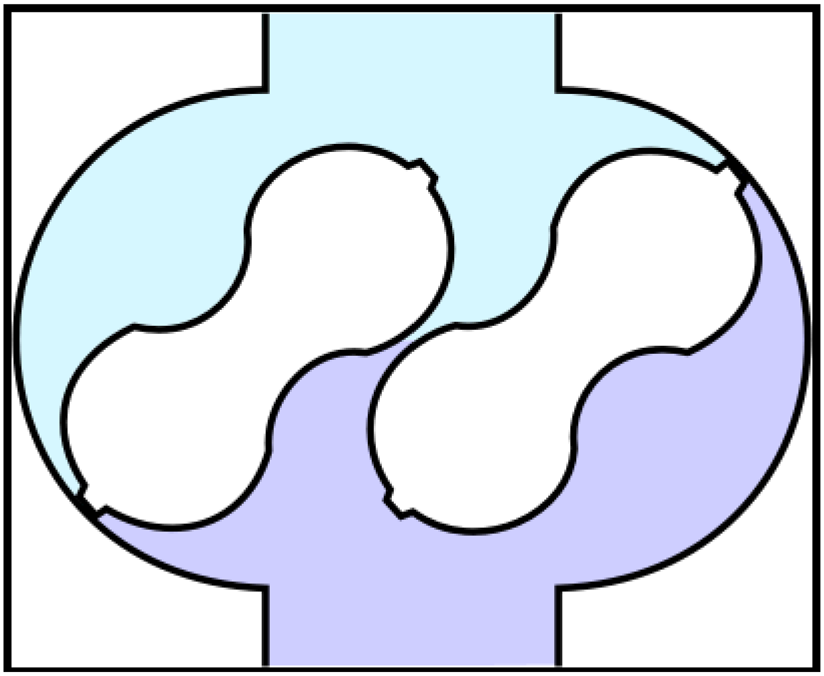
Piston meters (reciprocating and oscillating) are normally used as positive displacement meters.

They are accurate, precise, and have a wide flow range. These are ideal for measuring low rates of flow. These are expensive, susceptible to corrosion, and can be damaged by excessive flow.

Metering Pumps

Lobbed impeller flow meter:

Its two lobes (rotors) are mounted on parallel shafts and rotate in opposite directions. Fluid enters the inlet and fills the space between lobes and case. The pressure of the fluid against the lobes causes the lobes to rotate as fluid moves through the meter. A revolution counter on the shaft of one lobe determines total flow. To determine the flow rate, multiply the revolutions per minute (rpm) of the shaft by the volume per revolution.

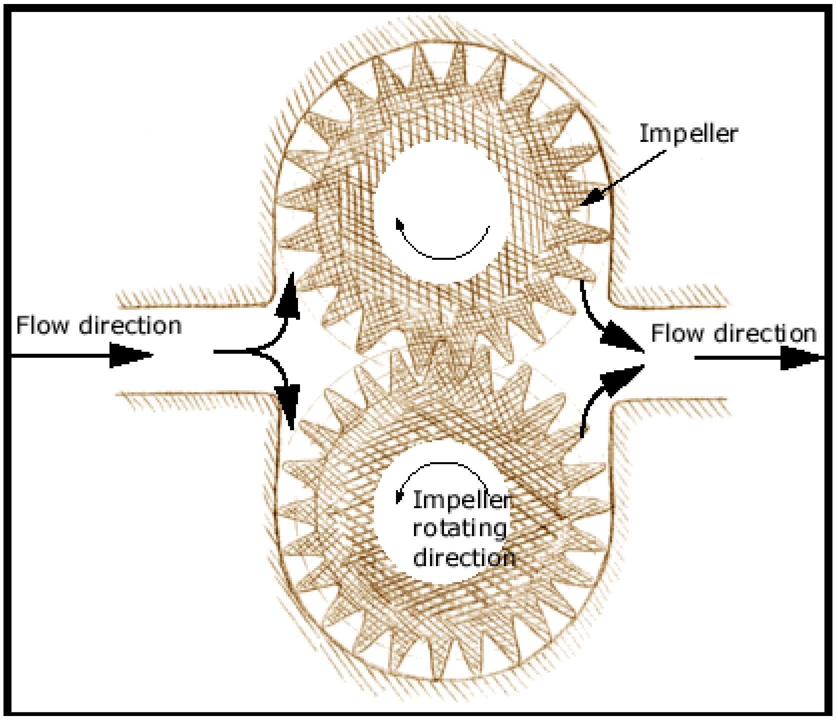


Lobbed impeller flow meter

These meters are normally used to measure gases but can be used for clean liquids.

Meshed Oval gear:

In this meter two meshed oval gears are used. They seal the inlet from the outlet flow and also keep the oval impellers in the correct relative positions. As the mesh gears rotate, they trap precise quantities of fluid in the gaps between the gears and the measuring chamber. The total volume of fluid passing through the meter each time the two gears make one revolution is four times the volume in the gap between the gear and the measuring chamber. These meters are used to measure liquid flow like oil, water, and gasoline.



Meshed Oval gear

3.4Flow measurement with Differential pressure

Flow measuring system (flow meter) consists of primary and secondary devices. Primary device or restriction in the flow line creates a change in fluid velocity that is sensed as a differential pressure (head). Secondary device measures this differential pressure and this measurement is related to flow rate. Head type flow measuring system depends on Bernoulli theorem "the total energy at a point in a pipe line is equal to the total energy at a second point if friction between the points is neglected.

PRIMARY DEVICES

ORIFICE PLATE:

Orifice plate is used for all clean fluids, but not used for fluids containing solids in suspension. A conventional orifice plate consists of a thin circular plate containing a concentric hole. It is normally made of stainless steel or Monel metal. Most common orifice plate is sharp-edged, concentric type.

Other two types of orifice plates are eccentric and segmental, to accommodate limited amounts of suspended solids.

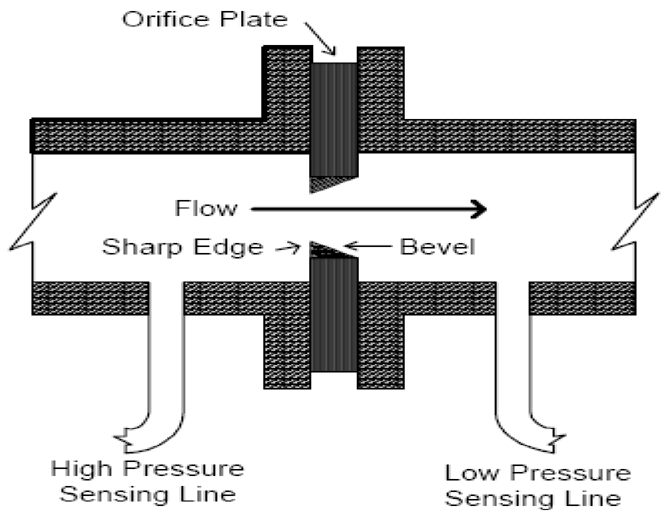


Figure 1
A Typical Orifice Plate

ORIFICE PLATE

Within the orifice plate, the change in cross sectional area between the pipe and the orifice produces a change in flow velocity. The velocity head at the throat increases, causing a corresponding decrease in static head. Therefore there is a head difference between a point immediately ahead of the restriction and a point with in the restriction or downstream from it. The resulting differential head or pressure is a function of velocity that can then be related to flow.

Most of the primary devices operate satisfactorily at high flow rates due to the change in flow coefficient that occurs when the flow rate changes from high to very low.

If the orifice is not very smooth and flat, the flow measurement will be affected. In some orifices a small drain hole (weep hole) is provided to permit condensate (or vapors) to pass through the plate without interfering with the flow measurement. For reversible flow measurement orifice plates are beveled on both faces, and they are installed in fittings where the pressure taps are the same distance upstream and downstream from the plate.

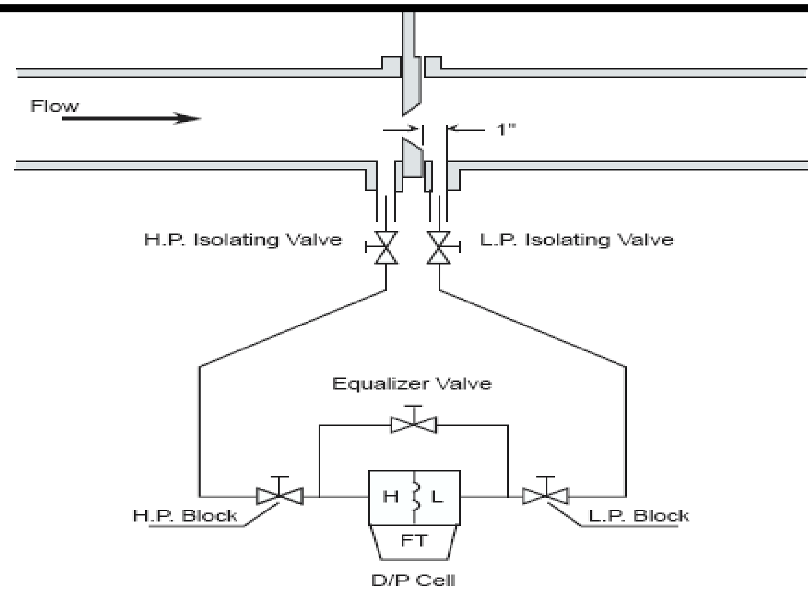


Figure 3
Orifice Plate with Flange Taps and Three Valve Manifold

Advantages and Disadvantages of Orifice Plates

Advantages of orifice plates include:

- High differential pressure generated
- Exhaustive data available
- Low purchase price and installation cost

Disadvantages include:

- High permanent pressure loss implies higher pumping cost.
- Cannot be used on dirty fluids, slurries or wet steam as erosion will alter the differential pressure generated by the orifice plate.

VENTURI TUBE:

It consists of a tapered, narrowing section of pipe joined to a tapered, enlarging section. As the liquid or gas flows through the tube, its velocity increases, causing a pressure differential between the upstream and downstream flow. Fluid pressure is lowest at the point where the tube is most restricted. Venturi tubes can be round, rectangular or irregular in shape. These are used to measure the flow rate of steam, air, or other gases.

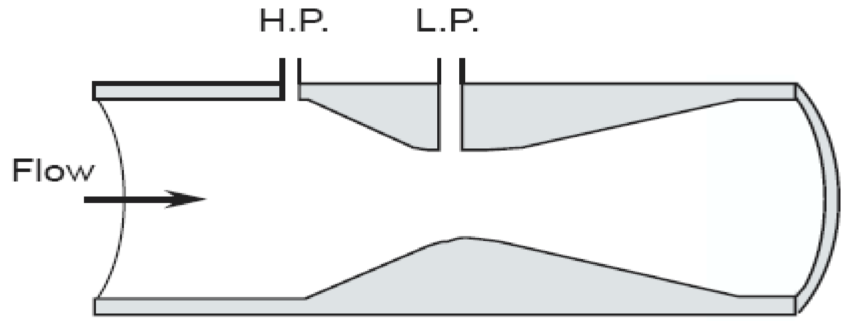


Figure 6
Venturi Tube Installation

VENTURI TUBE

It produces a large differential with a minimum permanent pressure loss. It measures flows containing suspended solids. Its disadvantage is its high cost.

FLOW NOZZLE:

In flow nozzle, the nozzle constricts the flowing stream and fluid moves faster to pass through it. The velocity increases through the nozzle and causes a drop in the internal pressure of the fluid flowing through it. Overall pressure loss in the flow nozzle is greater than in a Venturi tube because of increased turbulence at the nozzle exit. Its accuracy is greater than orifice but less than Venturi. It is costly than orifice but not as compared to Venturi.

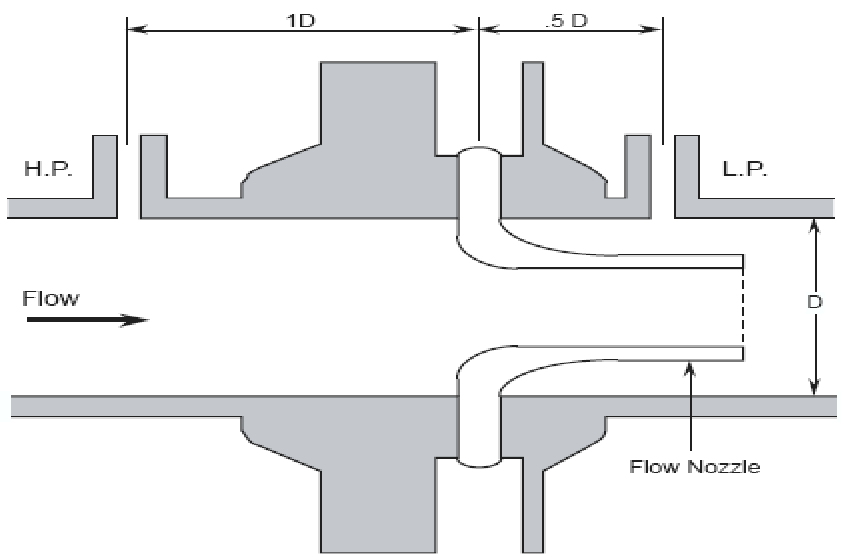


Figure 7
Flow Nozzle Installation

PITOT TUBE:

It is a hollow tube-within-a-tube device, designed to be pointed upstream in the fluid flow. It operates on the principle that a pressure differential exists in the fluid between the spot where the flow impinges on the front opening and the place where higher-velocity fluid speeds past the lateral openings.

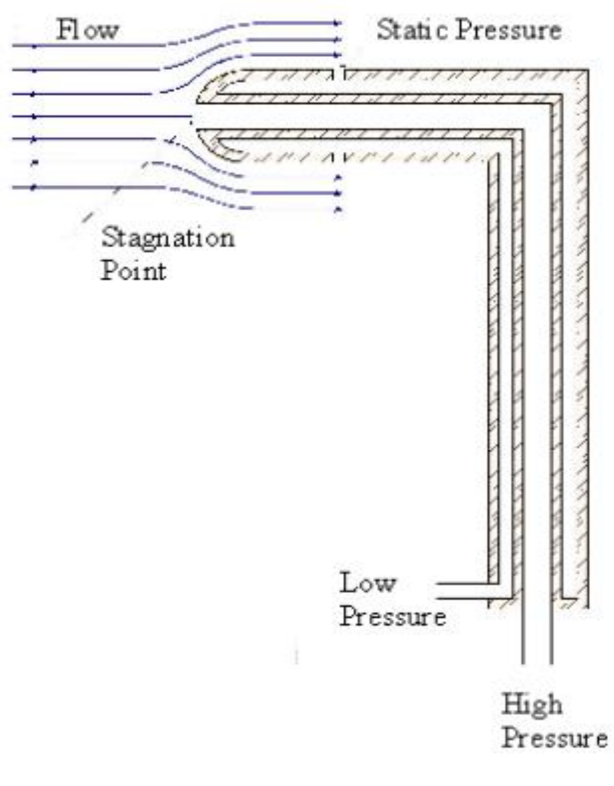


Figure 9
Pitot Tube

Pitot tube is used in clean liquids, free of solid contaminants, or its openings will clog. It must be properly positioned within the pipe where fluid velocity is average otherwise the derived flow rates will be inaccurate. Its advantages are:

They are inexpensive
They have no moving parts
They cause minimal pressure drop

Annubar:

An annubar is very similar to a pitot tube. The difference is that there is more than one hole into the pressure measuring chambers. The pressure in the high-pressure chamber represents an average of the velocity across the pipe.

Annubars are more accurate than pitots as they are not as position sensitive or as sensitive to the velocity profile of the fluid.

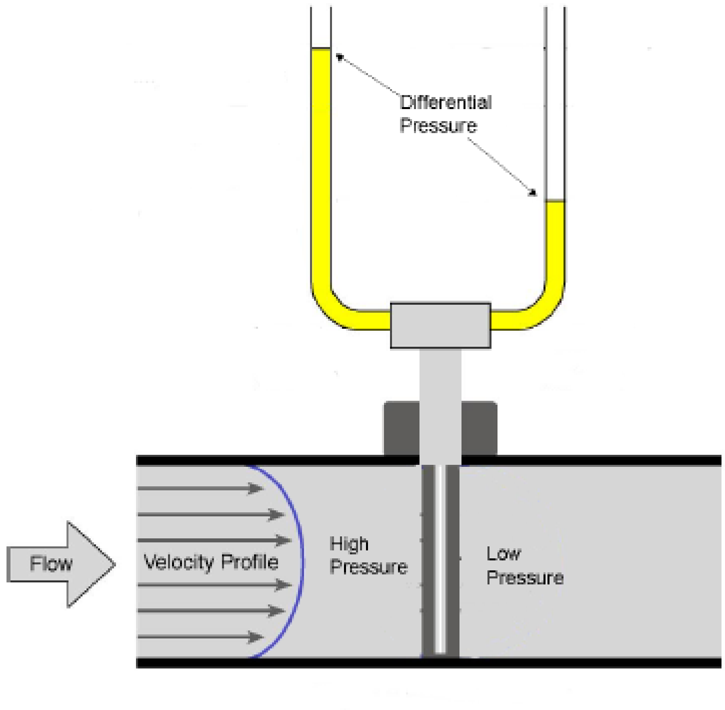


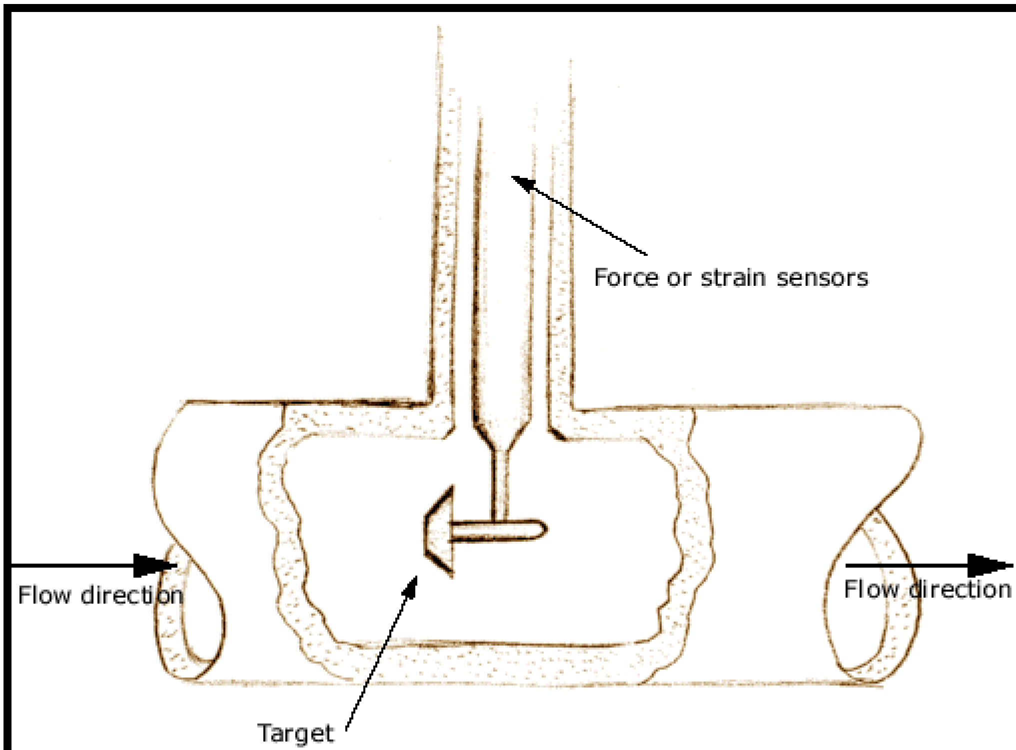
Figure 10
Annubar

Target Meter:

In target meter the fluid flows around a disk (target) suspended in the tubular section of the meter. The orifice, then, is the annular space between the target and the walls of the tube.

It does not measure a pressure differential. Instead, it measures the force of the fluid flow against the target. This force is converted to an output of 3 to 15 psi or 4 to 20 mA.

The target meter is mostly used for measuring viscous, dirty, or hot fluids. Its use is limited to pipe with a diameter of 4 inches or less.



Target flowmeter places a target into the flow pass and measures the force applied by the passing fluid to calculate the volume flow rate.

Elbow-Mounted Measuring Device

It measures pressure differential without creating a restriction in the flow. It measures the DP across a 90° elbow. The DP is created by the acceleration of the fluid flowing through the elbow. This kind of measurement is not as accurate as that obtained with a thin sharp-edged orifice plate, but its repeatability is good. Therefore, if a system can be calibrated against a known flow, the accuracy of this arrangement is quite acceptable.

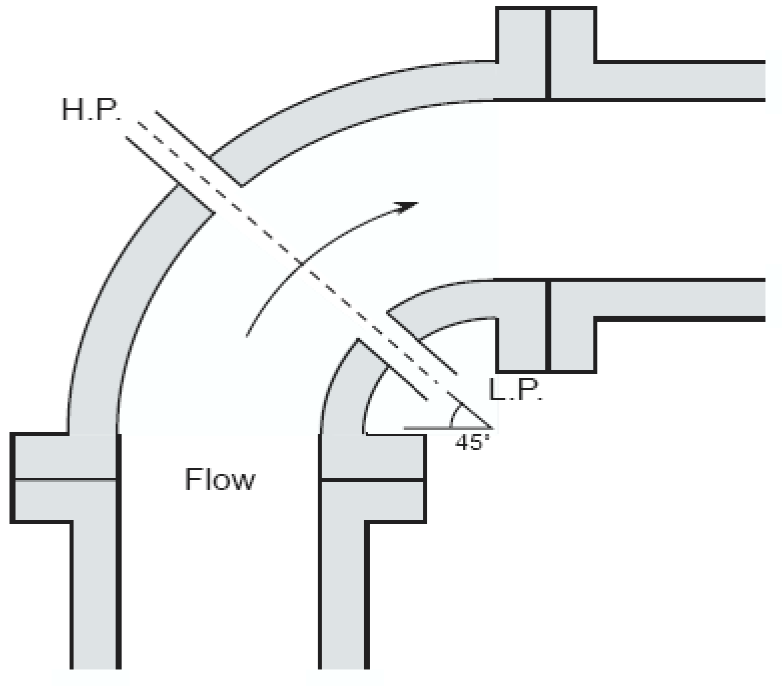


Figure 8
Elbow Tap Installation

SECONDARY DEVICES

Secondary instruments measure the differential produced at the primary devices and convert it into a signal for transmission. Secondary instruments include mercury manometer and various types of force balance and motion balance pneumatic and electronic transmitters.

Accuracy: It is the overall degree to which the measurement system can determine the actual value of the measured variable.

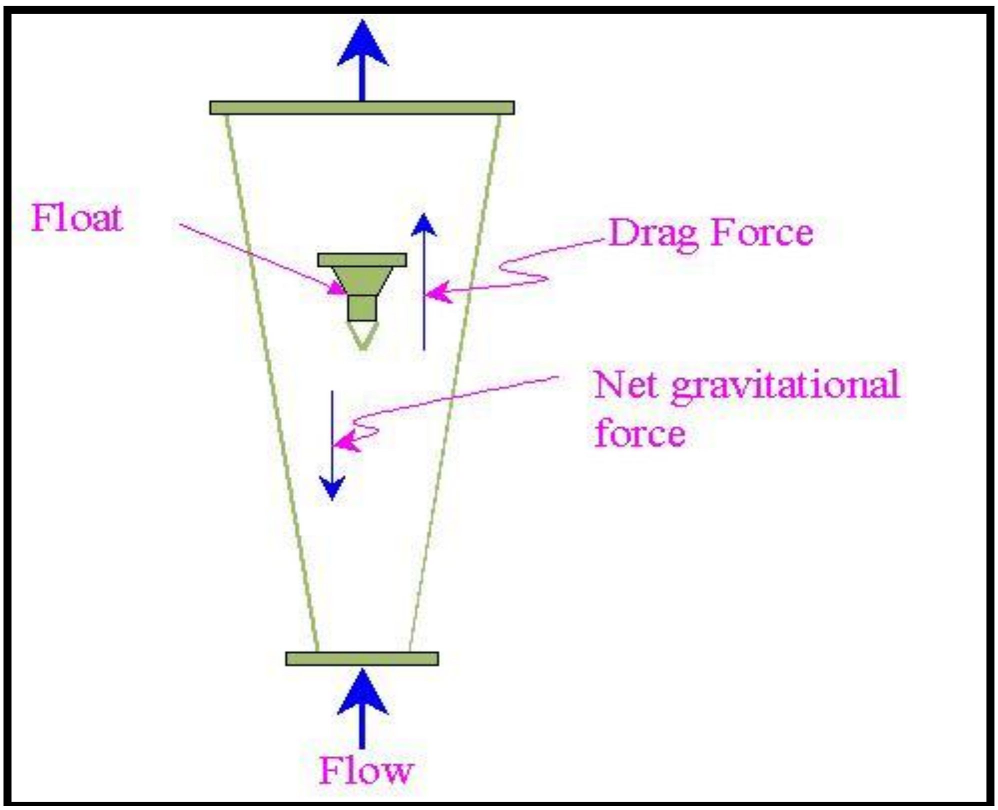
Precision: It refers to the ability of the measuring instrument to agree with itself repeatedly in response to the same input. In other words, precision is the degree of repeatability in a series of successive measurements.

Lack of precision or accuracy causes measurement errors.

VARIABLE AREA METERS (ROTAMETER)

Variable-area instrument for flow measurement is the rotameter. It consists of a tapered vertical tube with a float inside. The tube is usually made of borosilicate glass. The diameter of the tube is smallest at the bottom and increases toward the top. The fluid to be measured enters at the narrow bottom end and flows upward.

The float inside the tube is made so that its largest diameter almost equals the diameter of the tube at the bottom. The density of the float is greater than the density of the fluid. This means that the float sinks to the bottom of the tube if the fluid is not flowing. As fluid flows upward through the tube, the float rises.
The area available for the flow of fluid through the rotameter is the ring-shaped area between the tube and the float. If the float rests on the bottom point in the tube, the area between the float and the tube is nearly zero. If the float is higher in the tube, the area between the float and the tube is larger. As the float rises or falls in the tube, the area available for the passage of fluid increases or decreases. This variation is the reason the rotameter is called a variable-area instrument.



Measuring Gas Flow:

Gas flow rates are measured in standard cubic feet per minute (usually abbreviated scfm). One standard cubic foot of gas is a specific quantity of gas — one ft^3 measured at standard conditions, which usually are 14.7 psia and 70°F. This quantity of gas will occupy a different volume if either the pressure or the temperature changes. But it is still called one standard cubic feet, because it is still the same amount of gas and will still occupy one ft^3 at standard conditions. It weighs the same amount and contains the same number of gas molecules as it does under standard conditions.

A rotameter measures the amount of gas flowing per unit of time. If the flow rate is 100 scfm, the amount of gas flowing out of the rotameter in one minute occupies 100 ft3 if the pressure is 14.7 psia and the temperature is 70°F.
A rotameter measures a gas flow rate as though the calibration gas were flowing at standard pressure and temperature. The actual flow rate is different from the indicated flow rate if the actual gas is different from the calibration gas, or if the pressure or temperature varies from standard conditions

3.5 Factors affecting differential flow measurement:

Effect of Relative density:

If we replace the calibration gas usually air with a different gas having twice the density of air. The relative density of the gas is therefore twice the relative density of the calibration gas. This gas has a greater effect on the rotameter. At a specified flow rate, the denser gas causes the float to rise higher in the tube. As a result, the actual volume of gas that flows from the meter in one minute is equal to the indicated flow rate multiplied by the square root of 1/2. This relationship can be expressed as:

$Qa = Qi \sqrt{(Drc/Dra)}$

Where, Qa = actual flow rate

Qi = indicated flow rate

Drc = relative density of the calibrated gas

Dra = relative density of the actual gas.

Effect of Pressure:

If the calibration gas is at the calibration temperature, but the pressure of the gas is twice the standard pressure. The actual flow rate is then equal to the indicated flow rate multiplied by the square root of 2. That is:

$Qa = Qi \sqrt{(Pa/Pc)}$

Where, Pa = actual pressure

Pc = calibration pressure.

Effect of Temperature:

If we use the calibration gas at the calibration pressure, but at twice the calibration temperature. The actual flow rate of gas is then equal to the indicated flow rate multiplied by the square root of 1/2. That is:

$Qa = Qi \sqrt{(Tc/Ta)}$

Where, Tc = calibration temperature (absolute)

Ta = actual temperature (absolute).
We can combine these three equations into a single equation for gas-to-gas conversions. This equation enables us to convert any reading from a flow meter into the correct reading for the specific gas and the specific conditions under which it is measured. The master equation is:
$Qa = Qi \sqrt{(Drc)(Pa)(Tc) / (Dra)(Pc)(Ta)}$
It is assumed that the gas being measured is an ideal or perfect gas. A perfect gas is one in which the molecules are infinitely small and exert no forces of attraction or repulsion on each other. A real that is non-perfect gas has molecules of a finite size that exert forces on each other. To adjust these equations for non perfect gas effects, apply a compressibility factor. The compressibility factor for a perfect gas is 1.00. For a non perfect gas, the correction factor might be 0.85.

3.6 VELOCITY FLOW METERS

Turbine Flow meter:
Fluid enters the meter from one side, first passing through the flow straightener. The straightener dampens the turbulence in the fluid. The fluid then strikes the rotor smoothly, causing it to spin. The rate at which the rotor spins, sometimes referred to as rotational velocity, is directly proportional to the velocity of the fluid passing through the meter.
As the rotor spins, its blades cause a pulsating electrical signal to be produced in the pickup unit. The pickup unit is mounted in line with the rotor. Each time a blade passes the head of the pickup unit, its presence is sensed and a voltage is produced. As the blade moves past the pickup head, the voltage decreases until another blade moves into position. The voltage signals are called pulses.
The velocity of fluid flowing through the meter is proportional to volumetric flow rate.

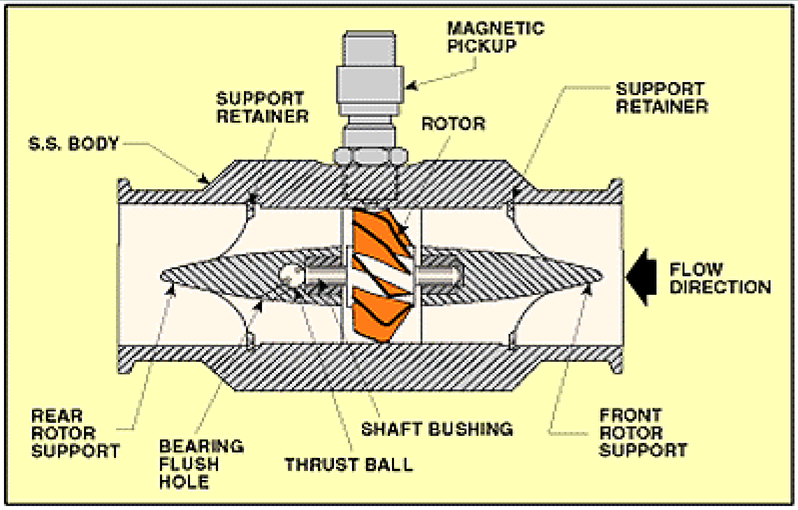


Figure 5: Turbine flowmeter consists of a multiple-bladed, free-spinning, permeable metal rotor housed in a non-magnetic stainless steel body. In operation, the rotating blades generate a frequency signal proportional to the liquid flow rate, which is sensed by the magnetic pickup and transferred to a read-out indicator

The rotational velocity of the rotor is proportional to fluid velocity.

The frequency of the electrical signal produced by the magnetic pickup unit is proportional to the rotor's speed (rpm).

The pickup acts as the transducer. It converts the rotary motion of the rotary vanes into electrical energy.

There are **two** kinds of pickups.

Inductance pickups have magnet-tipped rotor vanes. As the vanes pass the coil, a voltage is induced and current flows in the pickup coil. The induced current pulses a receiver, each time a vane passes the coil. A disadvantage is possible weakening of the magnets, causing errors in the measurement.

Reluctance pickups use an electromagnet as the coil. As the rotor vanes pass the pickup, they interrupt the magnetic field. The interruptions cause variations in the strength of the field, seen as pulses by the receiver.

Both kinds of pickup are mounted at a right angle to the turbine rotor, and both kinds produce a pulse out-put.

The turbine output signal is conditioned and sent to either a flow totalizer or rate indicator. The flow totalizer accepts the conditioned signal and provides readout in liters, gallons, barrels, or other units

Advantages of turbine flow meter are:

High accuracy—most turbine meters are accurate within ±0.5% of reading.

Repeatability—±0.25% is normal, and meters with ±0.02% repeatability are available.

Wide flow range—turbine meters can accurately meter flows ranging from 0.001 to 40,000 gpm

Linear output—the meter's output varies directly with flow rate.

Fast response—a turbine meter responds quickly to changes in the flow rate. A response time of 0.005 seconds is typical.

Turbine meters are also small in size and weight and are easy to install and maintain.

Disadvantages of turbine flow meter are:

They are expensive and unsuitable for very dirty or viscous (thick) fluids. Also, they are damaged by over speed and the bearing is subject to wear. In addition, they require a sophisticated signal conditioning and flow readout system and filters are required for almost every application.

Magnetic Flow meters:

Magnetic flow meters are very nearly ideal, because they offer no restriction to fluid flow and can meter fluids that other instruments cannot handle. Important metering applications include sludge in sewage-treatment plants, or slurries in mining operations, and liquid metals (liquid sodium) in various industrial processes.

When an electrical conductor moves at right angles to a magnetic field, a voltage is induced in the conductor. The voltage induced is proportional to the strength of the magnetic field and the velocity of the conductor. If there is an increase in the intensity of the magnetic field or in the velocity of the conductor, the voltage induced in the conductor also increases. These relationships are in accordance with Faraday's law of electromagnetic induction.

The electrodes penetrate the meter flow tube, make contact with the fluid, and measure the induced voltage across the conductive fluid.

The magnitude of induced voltage is proportional to the strength of the magnetic field, or flux, and to the conductor velocity.

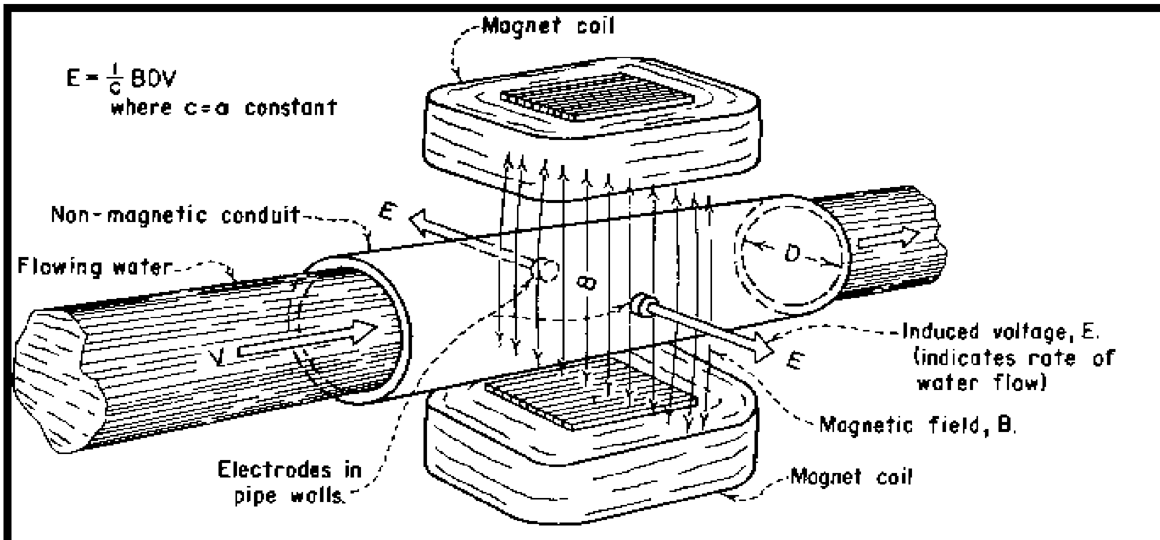


Figure 14-8.—Schematic view of a magnetic flowmeter.

If the magnetic flux increases, the voltage measured by the electrodes also increases. If the velocity of the fluid moving down the pipe increases, the voltage measured by the electrodes increases. In fact, the induced voltage is linearly proportional to flow velocity—if flow velocity doubles, electrode voltage doubles. Or, in general terms:

E = CV

Where, E = voltage

C = a constant determined by magnetic field strength, flow tube diameter and other fixed characteristics of the flow meter

V = flow velocity.

As the electrode voltage changes, the electrical conductivity of the fluid also changes.

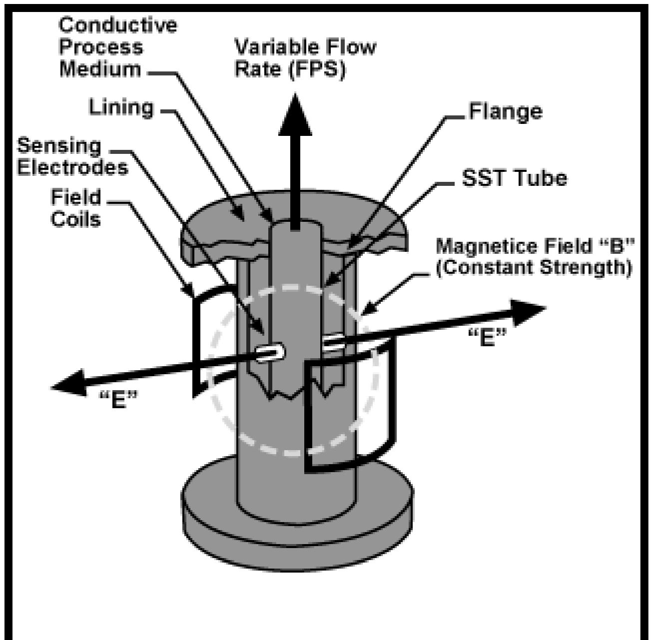


Figure 2.21 - The Magnetic Head Flow Meter

Conductivity means that an electric current can pass through the fluid. The unit of conductivity is the Siemens, formerly the mho. A Siemens is equivalent to 1/ohm where an ohm is a unit of electrical resistance. (Mho is ohm spelled backwards).

Hydrocarbons and non-aqueous (not watery) solutions have little or no conductivity and cannot be metered by magnetic flow meters. Distilled or de-ionized water also may not be conductive enough.

Vortex shedding meter:

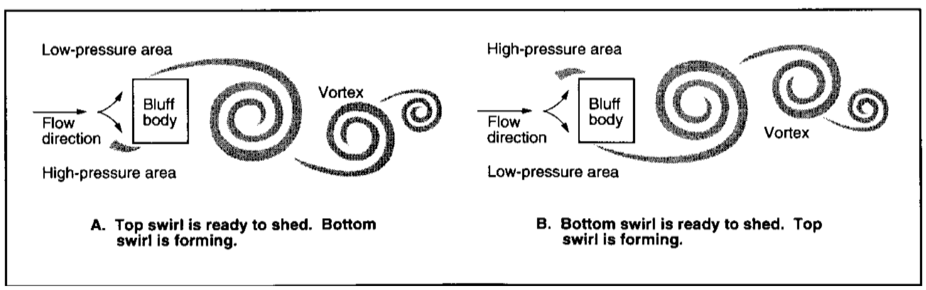
The phenomenon referred to as vortex shedding is the basis for the vortex-shedding meter. When flowing fluid passes an un-streamlined body (referred to as a bluff body or strut) the flow cannot follow the sharp contours of the obstruction. The fluid separates into layers and rolls around the bluff body. The rolling action creates vortices that form on the sides of the body and move downstream. The formation of vortices by the bluff body is a naturally occurring phenomenon caused by the shape of the obstruction in the flow path.

The vortices alternately spin clockwise and then counterclockwise. This is the natural way vortices form and is the basis for the meter's operation. As a vortex forms on one side of the body, a low-pressure area is created. At the same time, the effect of the spinning fluid behind the obstruction starts a vortex on the opposite side.

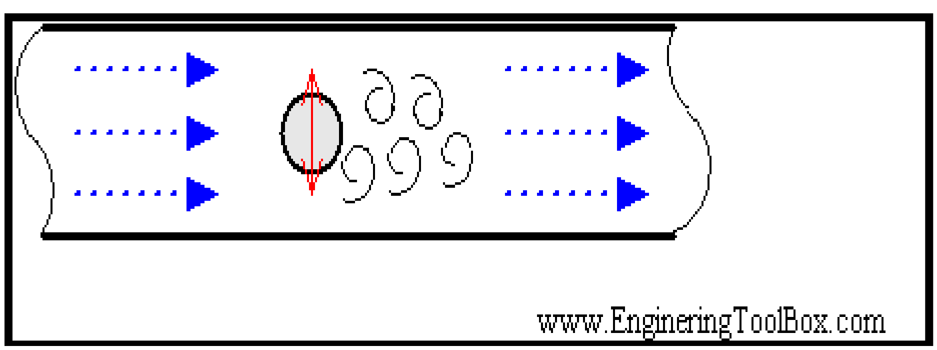
When the vortex on top of the bluff body breaks away from the body, the beginning of a new vortex forms on the bottom. In turn, it also sheds and is followed by another vortex on top.

It is the alternate shedding of vortices from one side of the bluff body to the other that forms the basis of the meter's operation. Remember that pressure decreases when a vortex is formed. When the vortex is shed, pressure increases until the next vortex forms, at which time pressure again decreases.
On the opposite side of the bluff body, pressure also increases and decreases due to vortex formation and shedding. The result is a measurable increase and decrease of pressure across the bluff body. One kind of vortex-shedding meter is designed with sensors on opposite sides of the bluff body to detect this change in pressure

Fig. 8-5. Vortex formation in flow around bluff body



The vortex-shedding frequency (the time between formation of vortices) is a function of flow velocity. Suppose fluid flows through the meter at a velocity of 5 ft/s and a vortex forms and sheds 100 times each second (shedding frequency is 100 Hz).



The sensors mounted on each side of the bluff body detect the change in pressure that accompanies the shedding of a vortex. The output of the pressure sensors is a noisy sine wave. Its frequency is identical to the vortex-shedding frequency

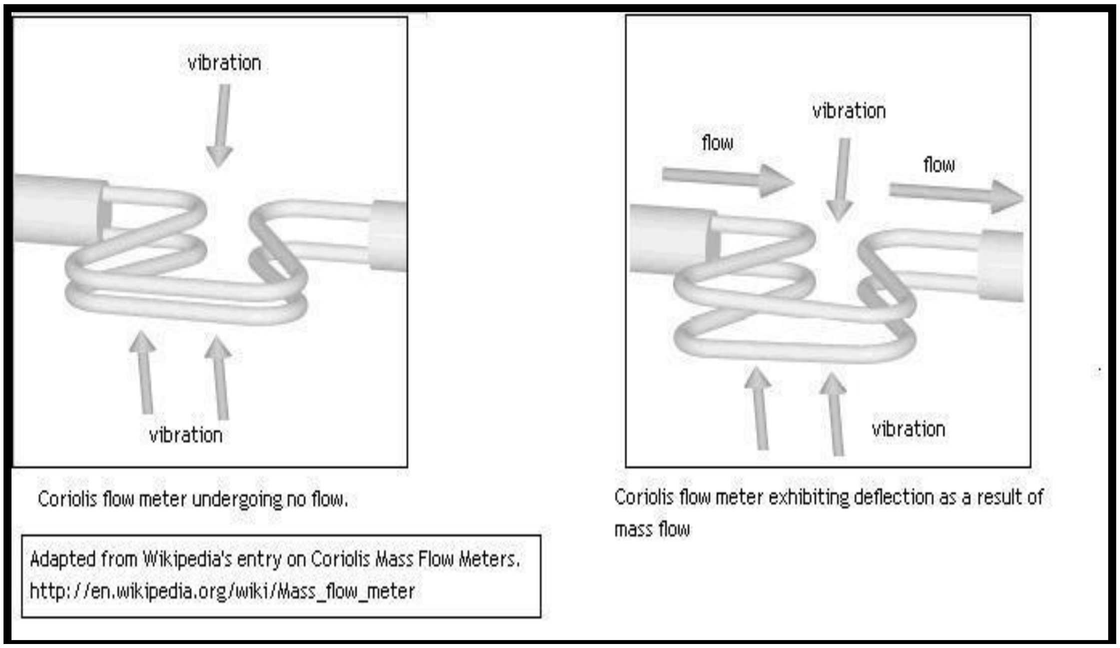
Some kind of vortex-shedding flow meters use a piezoelectric element that detects small movements of the strut as vortices are shed.
The ultrasonic, thermal, and piezoelectric flow meters use a preamplifier to send a signal to a remote converter. Others include a converter mounted with the flow meter.

3.7 Mass Flow

Real gases roughly follow the ideal gas law, which states that pressure, temperature, and volume of a gas are interrelated. The gas law is:
PV = nRT
Where, P= pressure of the gas
V= volume of the gas
n = amount of gas
R = ideal gas constant
T = temperature of the gas.
If the pressure is increased, with the temperature held constant, the volume decreases. If the temperature is increased, with the volume held constant, the pressure increases. The only constant is the mass of the gas, which therefore does not change.
Mass flow is the molecular measurement of the gas flow rate. Mass flow is usually expressed in units of mass per unit time kilograms/hour (kg/hr), for example. However, gas flow is usually measured by volume—for example, liters/hour (L/hr). Because volume depends on temperature and pressure.

Mass Flow meters:

Coriolis meter is most commonly used for liquids.
Its operation is based on the natural phenomenon referred to as the Coriolis force.



Coriolis unit consists of a U-shaped flow tube enclosed in a sensor housing connected to an electronics unit. The U shaped tube is vibrated by a magnetic device located at the bend of the tube. As the liquid flows through the tube, it takes on the vertical movement of the tube. The force of the flowing liquid resists the force of the tube movement, causing the tube to twist. The amount of twist is directly proportional to the mass flow rate of the liquid flowing through the tube. Magnetic sensors on the sides of the tube measure the tube velocity, which changes as the tube twists. The electronics unit converts the sensor readings to a voltage that is proportional to mass flow rate. These meters are useful for measuring liquids whose viscosity varies with the velocity (adhesives, for example), but because of the relatively small U-tube, the Coriolis meter causes a substantial pressure drop.

3.8 Flow Measurement Errors:

We have already discussed the pros and cons of each type of flow detector commonly found in a generating station. Some, such as the orifice, are more prone to damage by particulate or saturated steam then others. However, there are common areas where the flow readings can be inaccurate or invalid

Erosion:

Particulate, suspended solids or debris in the piping will not only plug up the sensing lines, it will erode the sensing device. The orifice, by its design with a thin, sharp edge is most affected, but the flow nozzle and even venturi can also be damaged. As the material wears away, the differential pressure between the high and low sides of the sensor will drop and the flow reading will decrease.

Over ranging Damage to the D/P Cell:

Again, as previously described, the system pressures are usually much greater than the differential pressure and three valve manifolds must be correctly used.

Vapour Formation in the Throat:

D/P flow sensors operate on the relation between velocity and pressure. As gas requires less pressure to compress, there is a greater pressure differential across the D/P cell when the gas expands on the LP side of the sensor. The flow sensor will indicate a higher flow rate than there actually is. The turbulence created at the LP side of the sensor will also make the reading somewhat unstable. A small amount of gas or vapour will make a large difference in the indicated flow rate.

The opposite can occur if the vapour forms in the HP side of the sensor due to cavitations or gas pockets when the fluid approaches the boiling point. In such an instance there will be a fluctuating pressure drop across the D/P cell that will give an erroneously low (or even negative) D/P reading.

Clogging of Throat:

Particulate or suspended solids can damage the flow sensor by the high velocities wearing at the flow sensor surfaces. Also, the build-up of material in the throat of the sensor increases the differential pressure across the cell.

The error in flow measurement will increase as the flow increases.

Plugged or Leaking Sensing Lines:

The effects of plugged or leaking D/P sensing lines is the same as described in previous modules, however the effects are more pronounced with the possible low differential pressures. Periodic maintenance and bleeding of the sensing lines is a must. The instrument error will depend on where the plug/leak is:

On the HP side a plugged or leaking sensing line will cause a lower reading.

The reading will become irrational if the LP pressure equals or exceeds the HP sensing pressure.
On the LP side a plugged or leaking sensing line will cause a higher reading.

4. LEVEL

OBJECTIVES:

Upon Completion of this topic one should be able to understand:

1. Explain how a level signal is derived for: an open vessel, a closed vessel with dry reference leg, a closed vessel with wet reference leg.
2. Explain how a bubbler derives level signal for an open and closed tank;
3. Explain the need for zero suppression and zero elevation in level measurement installations;
4. Describe the effects of varying liquid temperature or pressure on level indication from a differential pressure transmitter;
5. Explain how errors are introduced into the DP cell signal by abnormalities: leaking sensing lines, dirt or debris in the sensing lines.

4.1 Level measurement:

Level measurement is important for proper process operation and also for cost accounting and inventory purposes.
Liquid measurement needs two reference points.
Surface of liquid being measured
Datum point (fixed reference point), either bottom or top of tank.

4.2 Methods of Level measurement:

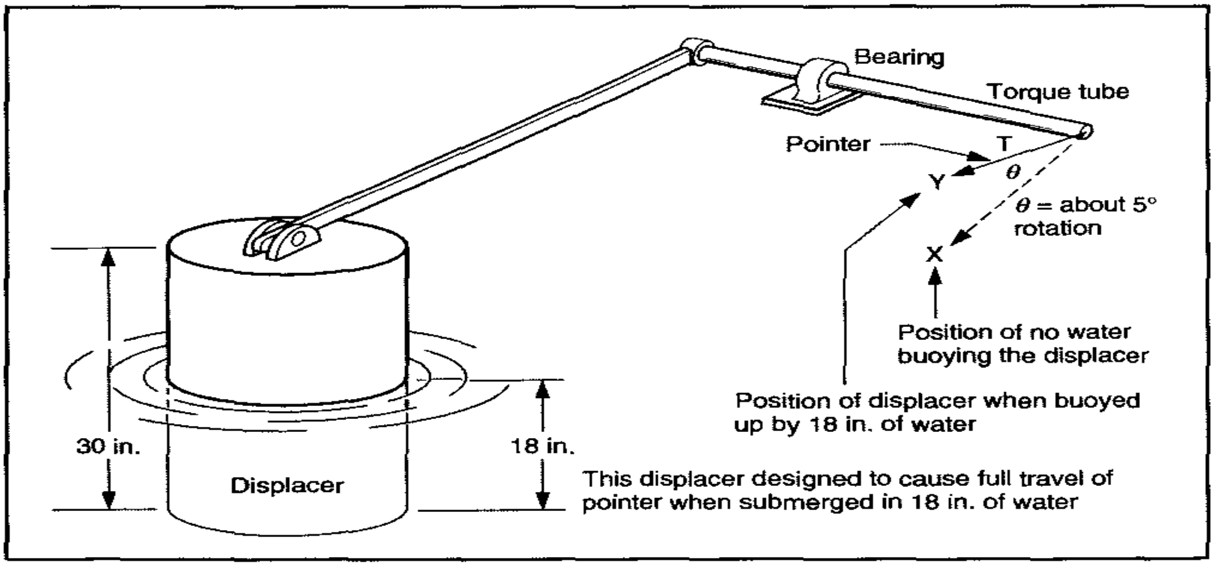
The common methods employed for automatic continuous liquid level measurement are as follows.

- Displacement (Buoyancy)
- Head (Bubble tube, Diaphragm box, Pressure, Differential pressure)
- Capacitance
- Radiation (Nucleonic)
- Ultrasonic

4.3 Displacement Buoyancy method:

It is a type of force balance transmitter. It is based on Archimedes's principle which states as "A body immersed in a liquid will be buoyed upward by a force equal to the weight of liquid displaced". This method is used to measure liquid level by sensing the buoyant force exerted on a displacer by the liquid in which it is immersed.
The buoyant force on an object depends on how much liquid is displaced and the density of the liquid. The buoyant force always equals the weight of the displaced liquid. If the buoyant force becomes equal to the object's weight, the object floats.
Displacer element is a cylinder of constant cross sectional area and heavier than the liquid displaced.
This method is used for both open and closed tanks. Buoyancy transmitter is normally used in vessels where lower connection is not possible/permissible, fluctuating pressures or levels and high temperature service.

Fig. 1-8. Typical displacer gauge



4.4 Magnetic Reed Switches:

If the liquid is hazardous chemical or at high temperature or pressure, magnetic reed switches are used. It is normally in open state. When the floating magnet outside the tube comes near the switch, it attracts the magnetic pole piece in the switch. This action closes the switch until the floating magnet moves away. These switches are not sealed in the tube, and they never come into contact with the liquid in the tank.

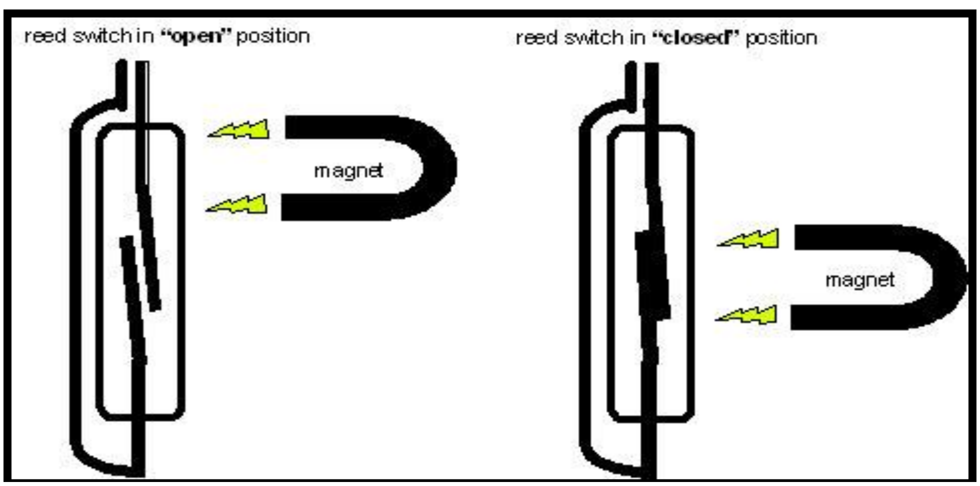
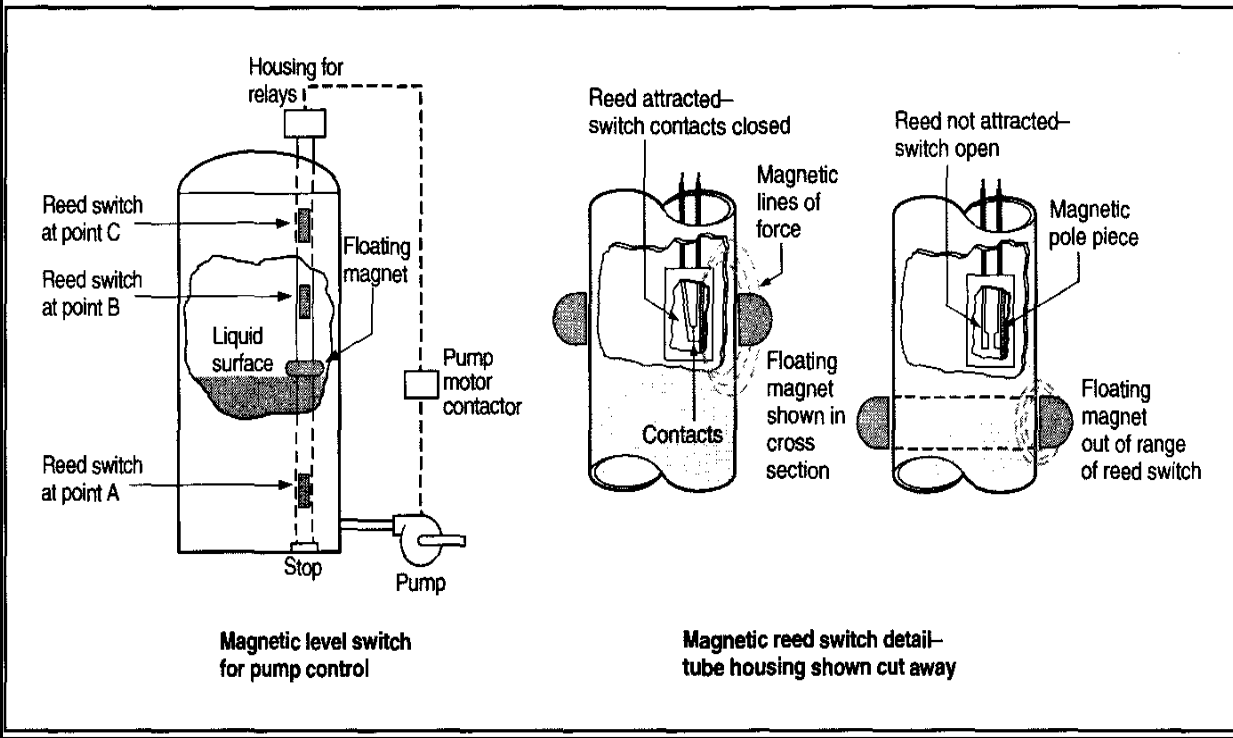


Fig. 1-14. Magnetic reed switch



HEAD PRESSURE:

Pressure of a liquid in an open tank depends on two factors.

The elevation or height of the liquid above the point at which the measurement is to be taken.

- The relative density (specific gravity) of the liquid.
- Head Pressure measurement for any liquid

Pressure= Head (ft) × Specific gravity × 0.433 (psi/ft)

Or, P = PCF × H × RD

Where P = pressure (psi), PCF = pressure conversion factor (0.433 psi/ft), a constant, H = height of liquid above the measurement point (ft), RD = relative density of liquid.

Head pressure of mercury with 10 ft depth is,

Pressure = 10 ft × 13.60 × 0.433 (psi/ft) = 58.9 psi

In a closed tank, pressure is proportional to the liquid elevation above the measurement point plus any additional pressure applied to the liquid.

For head pressure measurement of corrosive liquids, liquid seal is used to separate process fluid from transmitter. The liquid seal should meet three conditions.

- It should be non-compressible.
- It should have a higher density than the process liquid.
- It should not react with process liquid.

4.5 Open Tank Measurement:

The simplest application is the fluid level in an open tank. Figure 2 shows a typical open tank level measurement installation using a pressure capsule level transmitter.

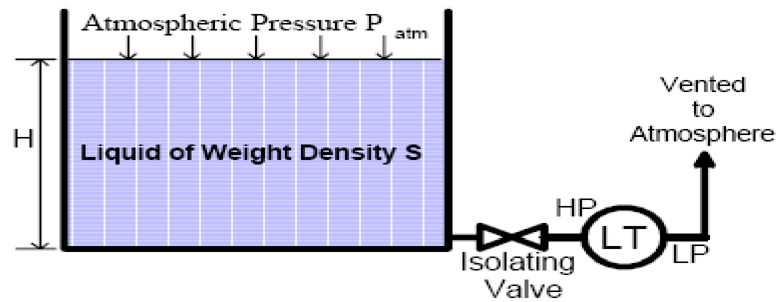


Figure 2
Open Tank Level Measurement Installation

If the tank is open to atmosphere, the high-pressure side of the level transmitter will be connected to the base of the tank while the low-pressure side will be vented to atmosphere. In this manner, the level transmitter acts as a simple pressure transmitter. We have:

Phigh = Patm + S·H

Plow = Patm

Differential pressure ΔP = Phigh - Plow = S·H

The level transmitter can be calibrated to output 4 mA when the tank is at 0% level and 20 mA when the tank is at 100% level.

4.6 Closed Tank Measurement:

Should the tank be closed and a gas or vapour exists on top of the liquid, the gas pressure must be compensated for. A change in the gas pressure will cause a change in transmitter output. Moreover, the pressure exerted by the gas phase may be so high that the hydrostatic pressure of the liquid column becomes insignificant. For example, the measured hydrostatic head in a CANDU boiler may be only three meters (30 kPa) or so, whereas the steam pressure is typically 5 MPa. Compensation can be achieved by applying the gas pressure to both the high and low-pressure sides of the level transmitter.

This cover gas pressure is thus used as a back pressure or reference pressure on the LP side of the DP cell. One can also immediately see the need for the three-valve manifold to protect the DP cell against these pressures.

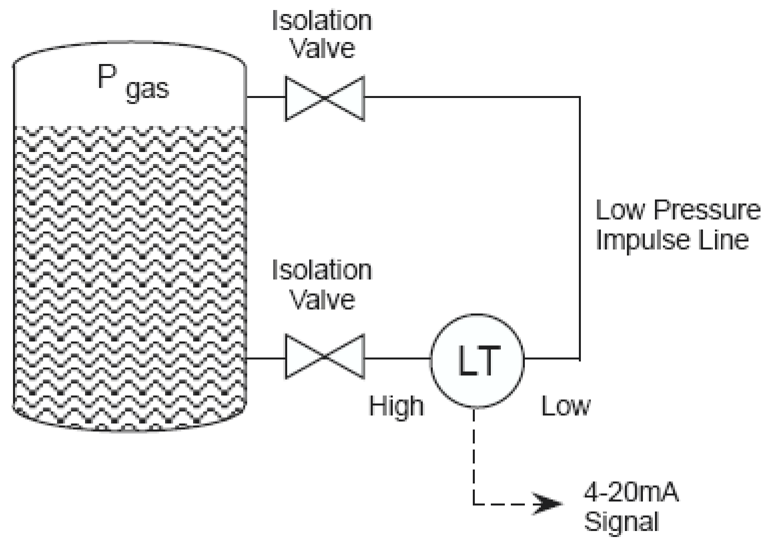


Figure 3
Typical Closed Tank Level Measurement System

We have:

Phigh = Pgas + S·H

Plow = Pgas

ΔP = Phigh - Plow = S·H

The effect of the gas pressure is cancelled and only the pressure due to the hydrostatic head of the liquid is sensed. When the low-pressure impulse line is connected directly to the gas phase above the liquid level, it is called a dry leg.

4.7 Bubble tube/Air purge method:

In this method, liquid level is determined by measuring the pressure required to force a gas into the liquid at a point beneath the surface. By this method liquid level is obtained without liquid entering the piping or instrument.

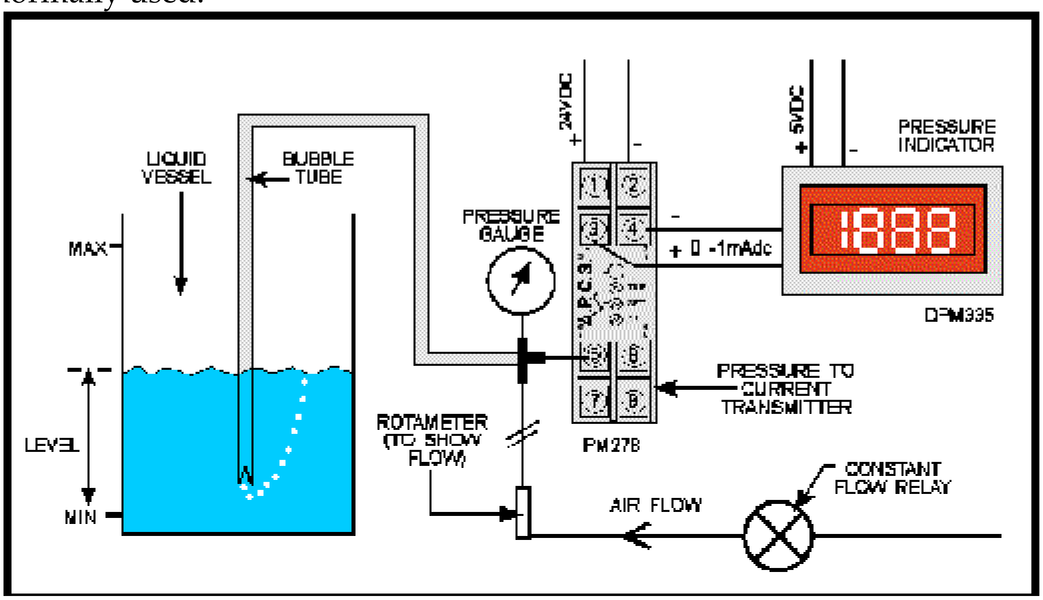
Clean air or gas in connected through a restriction to a bubble tube immersed a fixed depth in tank. Restriction reduces air flow and builds up pressure in bubble tube until it just balances the fluid pressure at end of bubble tube. Pressure is kept at this value by air bubbles escaping through liquid. Changes in level cause air pressure in bubble tube to build up or drop. This pressure can be measured by an instrument connected to bubble tube. It is used for corrosive liquids and solid bearing liquids. For processes that react with air, nitrogen can be used as a purge gas.

Primary maintenance problems with air purge system are,

- A plugged tube causes the pressure indicator to read high.
- A hole in the tube causes the indicator to read low. If the hole is halfway up the tube, the indicator will work correctly from 0 to 50% (actually 50% to 100%) of the scale reading, but the reading will not go above 50%.

In situation where air purge system is not suitable due to contaminations, liquid purge system is used.

Water is mostly used as purge liquid. A pressure regulator and flow restrictor are piped to the bubbler tube. The supply pressure is determined by the range of liquid level to be monitored, and a self-regulating "purge meter" is normally used.



DIAPHRAGM BOX:

In this method a diaphragm box is suspended from a chain. Diaphragm is filled with air. The instrument that senses pressure changes and relates to level measurement is mounted above vessel. This method is normally used for open vessels.

4.8 DIFFERENTIAL PRESSURE METHOD:

Dry Leg System:

A full dry leg installation with three-valve manifold is shown in Figure 4 below.

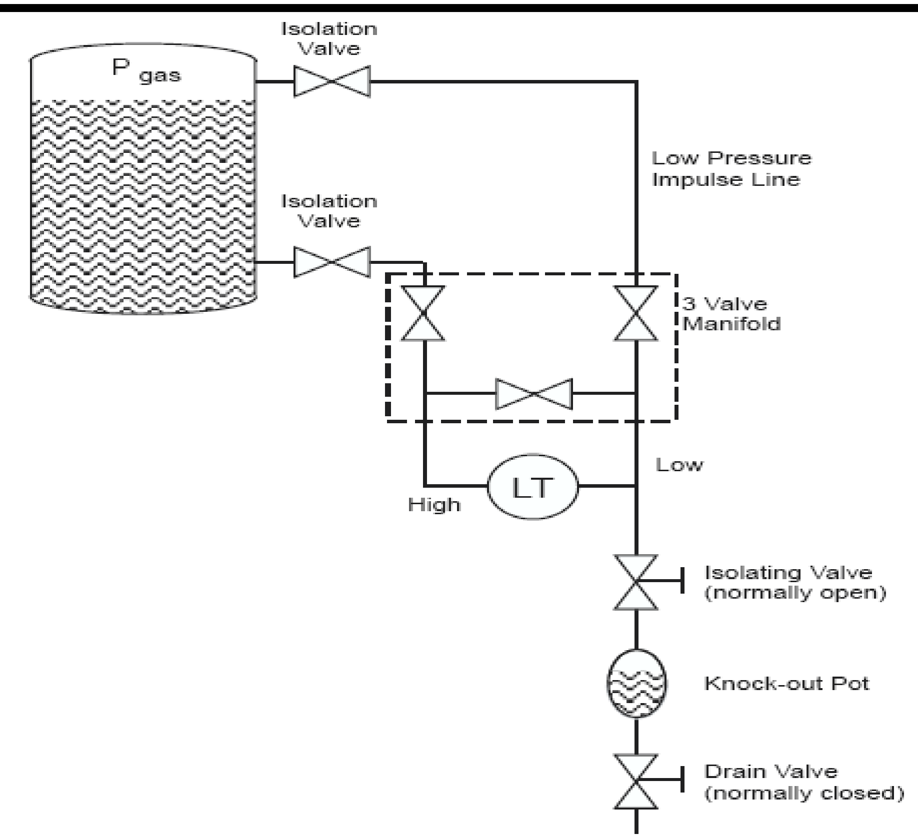


Figure 4
Dry Leg Installation with Three-Valve Manifold

If the gas phase is condensable, say steam, condensate will form in the low pressure impulse line resulting in a column of liquid, which exerts extra pressure on the low-pressure side of the transmitter. A technique to solve this problem is to add a knockout pot below the transmitter in the low pressure side as shown in Figure 4. Periodic draining of the condensate in the knockout pot will ensure that the impulse line is free of liquid. In practice, a dry leg is seldom used because frequent maintenance is required. One example of a dry leg application is the measurement of liquid poison level in the poison injection tank, where the gas phase is non-condensable helium. In most closed tank applications, a wet leg level measurement system is used.

Wet Leg System:

In a wet leg system, the low-pressure impulse line is completely filled with liquid (usually the same liquid as the process) and hence the name wet leg. A level transmitter, with the associated three-valve manifold, is used in an identical manner to the dry leg system.

At the top of the low pressure impulse line is a small catch tank. The gas phase or vapour will condense in the wet leg and the catch tank. The catch tank, with the inclined interconnecting line, maintains a constant hydrostatic pressure on the low-pressure side of the level transmitter. This pressure, being a constant, can easily be compensated for by calibration.

If the tank is located outdoors, trace heating of the wet leg might be necessary to prevent it from freezing. Steam lines or an electric heating element can be wound around the wet leg to keep the temperature of the condensate above its freezing point.

4.9 Level Compensation:

It would be idealistic to say that the DP cell can always be located at the exact the bottom of the vessel we are measuring fluid level in. Hence, the measuring system has to consider the hydrostatic pressure of the fluid in the sensing lines themselves. This leads to two compensations required.

Zero Suppression:

In some cases, it is not possible to mount the level transmitter right at the base level of the tank. Say for maintenance purposes, the level transmitter has to be mounted X meters below the base of an open tank. The liquid in the tank exerts a varying pressure that is proportional to its level H on the high-pressure side of the transmitter. The liquid in the high pressure impulse line also exerts a pressure on the high-pressure side.

However, this pressure is a constant ($P = S \cdot X$) and is present at all times. When the liquid level is at H meters, pressure on the high-pressure side of the transmitter will be:

$P_{high} = S \cdot H + S \cdot X + P_{atm}$

Plow = Patm

ΔP = Phigh - Plow = S·H + S·X

That is, the pressure on the high-pressure side is always higher than the actual pressure exerted by the liquid column in the tank (by a value of S·X). This constant pressure would cause an output signal that is higher than 4 mA when the tank is empty and above 20 mA when it is full. The transmitter has to be negatively biased by a value of -S·X so that the output of the transmitter is proportional to the tank level (S·H) only. This procedure is called Zero Suppression and it can be done during calibration of the transmitter. A zero suppression kit can be installed in the transmitter for this purpose.

Zero Elevation:

When a wet leg installation is used (see Figure 7 below), the low-pressure side of the level transmitter will always experience a higher pressure than the high-pressure side. This is due to the fact that the height of the wet leg (X) is always equal to or greater than the maximum height of the liquid column (H) inside the tank.

When the liquid level is at H meters, we have:

Phigh = Pgas + S·H

Plow = Pgas + S·X

ΔP = Phigh - Plow = S·H - S·X

= - S (X - H)

The differential pressure ΔP sensed by the transmitter is always a negative number (i.e., low pressure side is at a higher pressure than high pressure side). ΔP increases from P = -S·X to P = -S (X-H) as the tank level rises from 0% to 100%.

If the transmitter were not calibrated for this constant negative error (-S·X), the transmitter output would read low at all times. To properly calibrate the transmitter, a positive bias (+S·X) is needed to elevate the transmitter output. This positive biasing technique is called zero elevation.

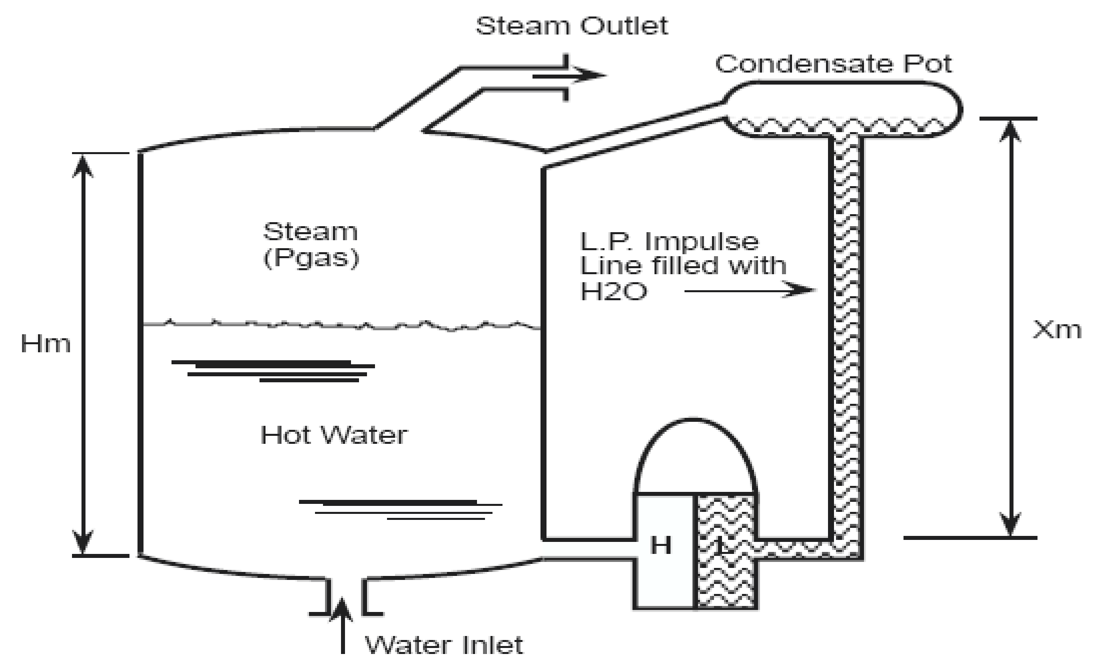


Figure 7
Requirement for Zero Elevation

4.10 Capacitance type level measurement:

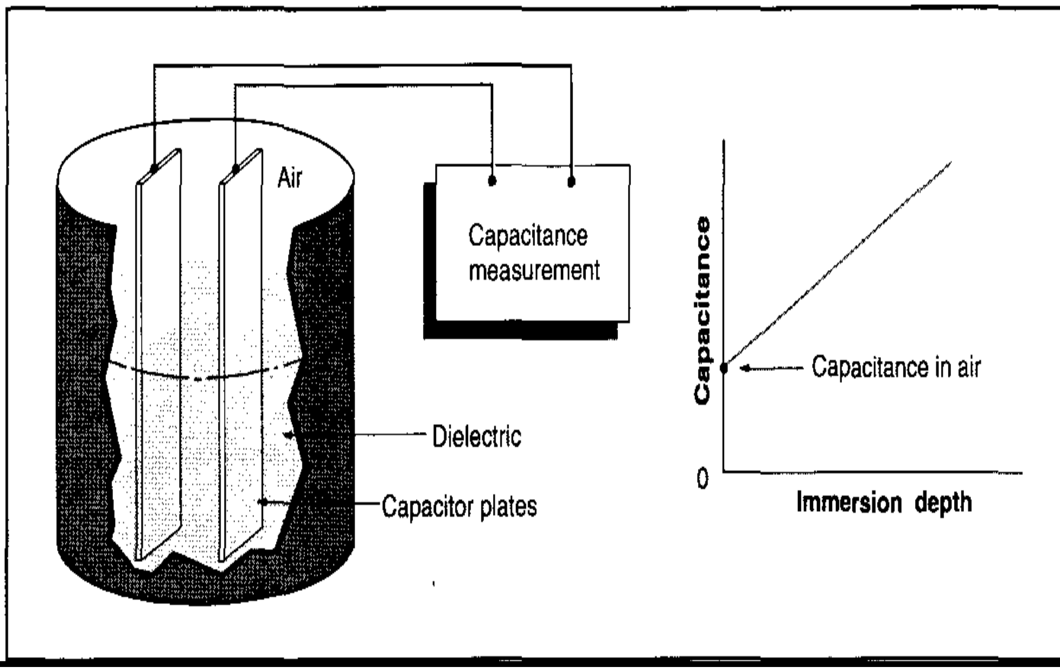
The amount of capacitance depends on the distance between the plates, the area of the plates, and the height of the dielectric between the plates. The equation is,

$C = K (A/D)$

Where, C = capacitance, K = dielectric constant, A = area of plate,D = distance between plates.

In this method a probe is inserted in a tank and capacitance is measured between probe and tank. Capacitance varies with respect to tank level. This phenomenon is due to the difference between dielectric constant of air and liquid in tank. This method is normally used for non conductive liquids.

Fig. 2-5. Capacitance as function of liquid level



In applications where liquid conduct, the electrode is encased in an insulating material. The liquid acts as the capacitor's ground electrode, and the insulated conductor serves as the other electrode.

4.11 Radiation type level measurement:

In this method a radioactive source is kept on one side of tank and detector on other side. As radiation passes through the tank, its intensity varies with amount of material in tank and can be related to level. Its advantage is that nothing comes in contact with liquids. It is very costly and difficult to handle.

4.12 Ultrasonic type level measurement:

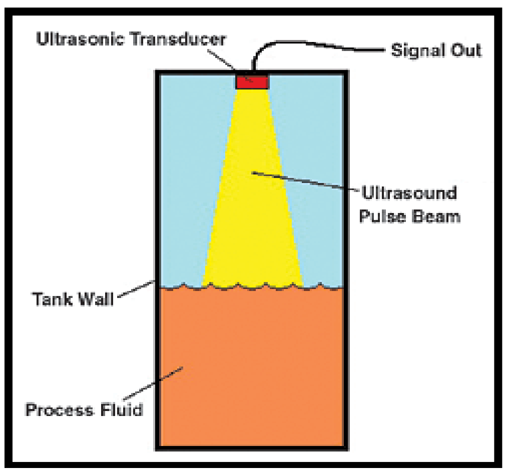
Ultrasonic sound waves with frequencies of 1 to 5 MHz can be used to detect liquid or solid levels. Ultrasonic are sound waves but at higher frequencies than 20 KHz (detected by human ear).
It consists of an ultrasonic transducer (piezoelectric crystal). When voltage is applied to plates, the piezoelectric crystal expands or contracts. The crystal

vibrates, and these vibrations can be transferred to a diaphragm to produce ultrasonic sound waves. The liquid surface acts as a reflector, and the transducer receives the reflection of its transmitted pulses. The transmitter and receiver are both connected to an echo timer, which measures the amount of time between the emission of sound wave and the reception of the echo. Time required by sound wave to travel to the liquid and back to receiver is carefully measured and this time is related to level.

In case transmitter could not be installed in tank, a noninvasive (not in contact with liquid) sensor transmits an ultrasonic signal through the walls of a vessel. When the vessel is filled with liquid, the signal travels through the liquid and the opposite wall to a receiver transducer, where it is converted to and electrical signal.

It has good accuracy.

It is costly.



4.13 Level Measurement System Errors:

The level measurement techniques described in this module use inferred processes and not direct measurements. Namely, the indication of fluid level is based on the pressure exerted on a differential pressure (DP) cell by the height of the liquid in the vessel. This places great importance on the physical and environmental problems that can affect the accuracy of this indirect measurement.

Connections:

As amusing as it may sound, many avoidable errors occur because the DP cell had the sensing line connections reversed. In systems that have high

operating pressure but low hydrostatic pressure due to weight of the fluid, this is easy to occur. This is particularly important
for closed tank systems. With an incorrectly connected DP cell the indicated level would go down while the true tank level increases.

Over-Pressuring:

Three valve manifolds are provided on DP cells to prevent over-pressuring and aid in the removal of cells for maintenance. Incorrect procedures can inadvertently over-pressure the differential pressure cell. If the cell does not fail immediately the internal diaphragm may become distorted. The measurements could read either high or low depending on the mode of failure.
Note that if the equalizing valve on the three-valve manifold is inadvertently opened, the level indication will of course drop to a very low level as the pressure across the DP cell equalizes.

Sensing lines:

The sensing lines are the umbilical cord to the DP cell and must be functioning correctly. Some of the errors that can occur are:

Obstructed sensing lines:

The small diameter lines can become clogged with particulate, with resulting inaccurate readings. Sometimes the problem is first noted as an unusually sluggish response to a predicted change in level. Periodic draining and flushing of sensing lines is a must.

Draining sensing lines:

As mentioned previously, the lines must be drained to remove any debris or particulate that may settle to the bottom of the tank and in the line. Also, in closed tank dry leg systems, condensate must be removed regularly to prevent fluid pressure building up on the low-pressure impulse line. Failure to do so will of course give a low tank level reading. Procedural care must be exercised to ensure the DP cell is not over-ranged inadvertently during draining. Such could happen if the block valves are not closed and equalizing valve opened beforehand. False high level indication can be caused by a leaking or drained wet leg.

A leaking variable (process) leg can cause false low-level indication.

5. TRANSMITTERS

OBJECTIVES:

Upon Completion of this topic one should be able to understand:

1. Function of transmitters
2. Types of transmitters
3. Pneumatic transmitter and its applications
4. Electronic transmitter and its applications
5. How to take transmitter into and out of service

5.1 Definition of transmitter:

A transmitter is used to transmit signal from field to control room or if anywhere else is required. A transmitter takes signal from the primary measuring element and transmits that proportional signal at required place. A transmitter can transmit signal over very wide ranges.

5.2 Types of transmitters:

Transmitters are divided into two types:

1. Pneumatic transmitters
2. Electronic transmitters

5.3 Pneumatic Transmitters:

To measure the signal of hazardous chemicals remotely, a pneumatic signal transmission system is used. The pneumatic transmitter output is piped to the recording or control instrument. Standard output range for a pneumatic transmitter is 3 to 15 psi, 20 to 100 Kpa, or 0.2 to 1.0 bar or Kg/cm2. Transmitter output signal is carried by tubing, usually ¼ inch copper or plastic, to the control room. The live zero makes it possible to distinguish between true zero and a dead instrument.

Pneumatic transmitters use a force balance principle that balances an input force change to an output force change to nullify internal motion and increase accuracy. Pressure transmitters usually apply process pressures to diaphragms or bellows to generate linear force that is sensed by a pneumatic pilot that facilitates the output change to the control instrument while internally rebalancing the forces between input and output. Temperature transmitters employ sealed helium bulb elements and bellows to convert temperatures to pressures and linear forces according to the Ideal Gas Law that states that a fixed amount of gas in a fixed volume will increase its pressure proportionately to an increase in temperature. Pneumatic flow transmitters most often use a differential pressure principle which resolves a balance between two opposing pressure diaphragms which is then fed as a single force to the output section of the device, similarly to the simple pressure transmitter. Level sensors may use the differential pressure principle that measures liquid head, or a proportional float mechanism that measures the force change of a partially submerged float as liquid level goes up and down.

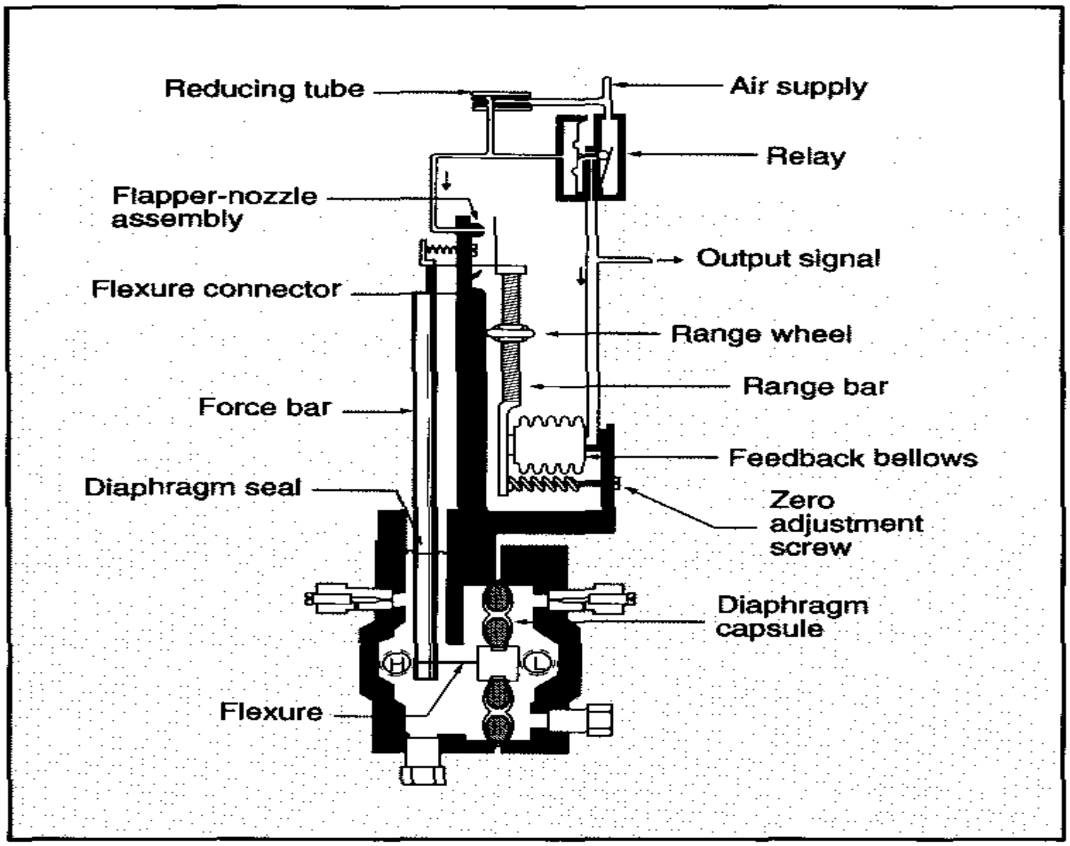
PNEUMATIC RELAY (Booster relay)

A relay is a pneumatic amplifier. The function of the relay is to convert a small change in the input signal to a large change in the output signal. Typically a 1 psi change in the input will produce approximately a 12 psi change in output.

5.4 Differential Pressure Transmitter:

Pneumatic DP transmitter, or DP cell, receives a supply of air at 20 psig (the metric equivalent is 138 kPa) and reduces it to an output of 3 to 15 psig (20 to 100 kPa) that is directly proportional to the measured DP.
The electronic transmitter has output (normally 4 to 20 mA) that is proportional to the differential pressure.
In the DP transmitter, process fluid (if not harmful to the instrument) is piped to each side of a capsule containing twin diaphragms. Any pressure increase in the high-pressure chamber causes the capsule to move toward the low- pressure side and, in turn, to impart this motion to a laminated force bar. In the pneumatic transmitter, the upper end of the bar reacts by moving the flapper toward the nozzle, which is the source of supply air.
The nozzle feed line is connected to one side of a diaphragm in the air relay.

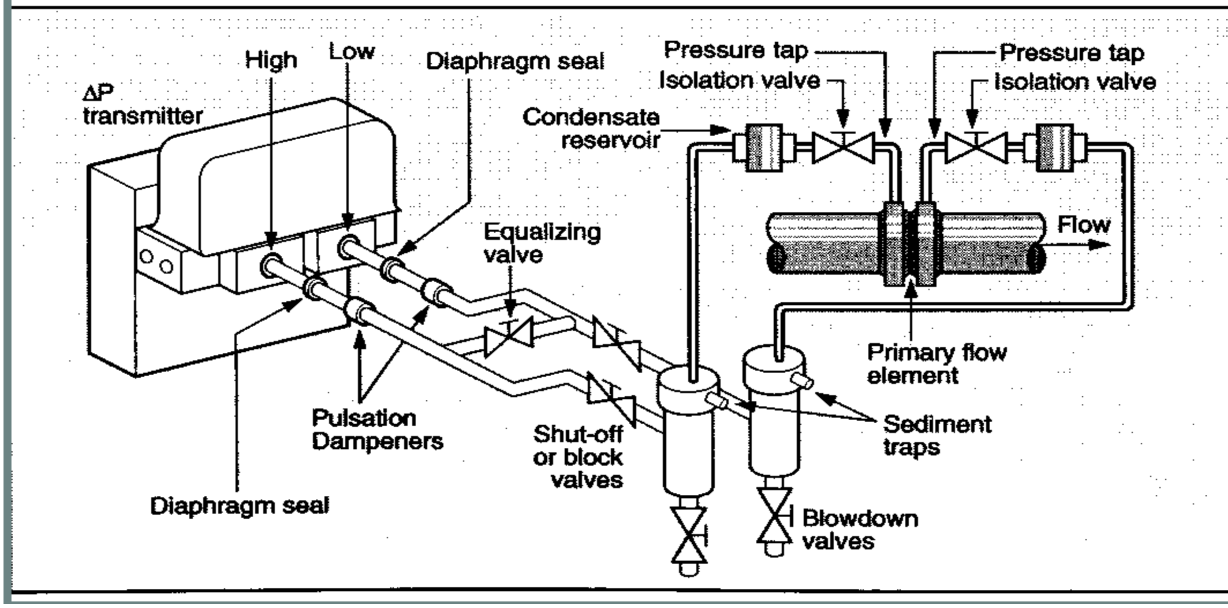
Fig. 3-9. Operating components of a pneumatic ΔP transmitter



As the flapper covers the nozzle, a pressure build-up acts on the air relay diaphragm. This opens the relay and delivers more air pressure to both the feedback bellows and the output. This action continues until the pressure exerted against the range rod by the bellows counterbalances the original pressure of the force bar. The zero adjustment spring establishes a starting value (0 DP = 20 kPa). The adjustable range wheel is the pivot point for the range rod's motion.

The first step in calibrating this kind of transmitter is to vent the low side of the transmitter to atmosphere. Then apply a known pressure to the high side. If the transmitter range is 0 to 205 in of water, apply a pressure of 205 in of water and expect the transmitter output to be 15 psi or 20 mA, depending on the kind of transmitter. Position the adjustable range wheel to obtain the correct output. With no pressure applied to the high side of the transmitter, the output should be 3 psi or 4 mA. Now adjust the zero screw to obtain the correct output.

Fig. 10-1. ΔP flow-measurement system



5.5 Electronic Transmitter:

In the 1950's electric and electronic controls made their debut. The new 4-20 mA current signaling emulated the 3-15 psi pneumatic signal. Current signaling quickly became the preferred method because wires are easier to install and maintain than pneumatic pressure lines and energy requirements are a lot lower – you no longer needed a 20 to 50 horsepower compressor for instance. Also, electronics allowed for more complicated control algorithms.

The 4-20 mA current loop is a very robust sensor signaling standard. Current loops are ideal for data transmission because of their inherent insensitivity to electrical noise. In a 4-20 mA current loop, all the signaling current flows through all components; the same current flows even if the wire terminations are less than perfect. All the components in the loop drop voltage due to the signaling current flowing through them. The signaling current is not affected by these voltage drops as long as the power supply voltage is greater than the sum of the voltage drops around the loop at the maximum signaling current of 20 mA.

Figure 1 shows a schematic of the simplest 4-20 mA current loop. There are four components:

1. A DC power supply;
2. A 2-wire transmitter;
3. A receiver resistor that converts the current signal to a voltage;
4. The wire that interconnects it all.

The two "R wire" symbols represent the resistance of the wires running out to the sensors and back to the power supply and HVAC/R controller.

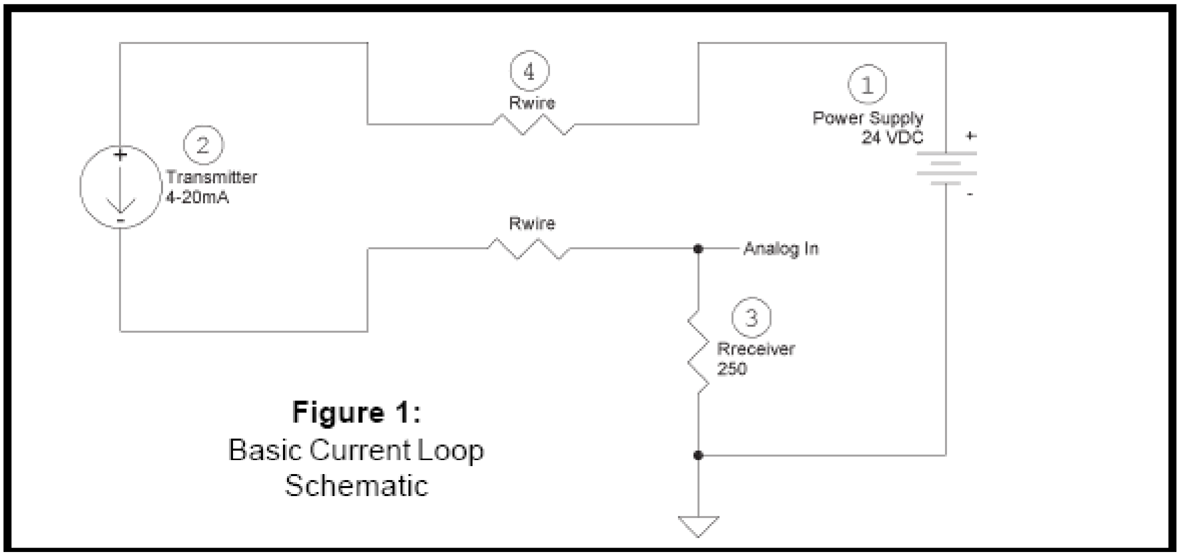


Figure 1:
Basic Current Loop
Schematic

Current supplied from the power supply flows through the wire to the transmitter and the transmitter regulates the current flow within the loop. The current allowed by the transmitter is called the loop current and it is proportional to the parameter that is being measured. The loop current flows back to the controller through the wire, and then flow through the Receiver resistor to ground and returns to the power supply. The current flowing through Receiver produces a voltage that is easily measured by an analog input of a controller. For a 250◎◎resistor, the voltage will be 1 VDC at 4 mA and 5 VDC at 20 mA.

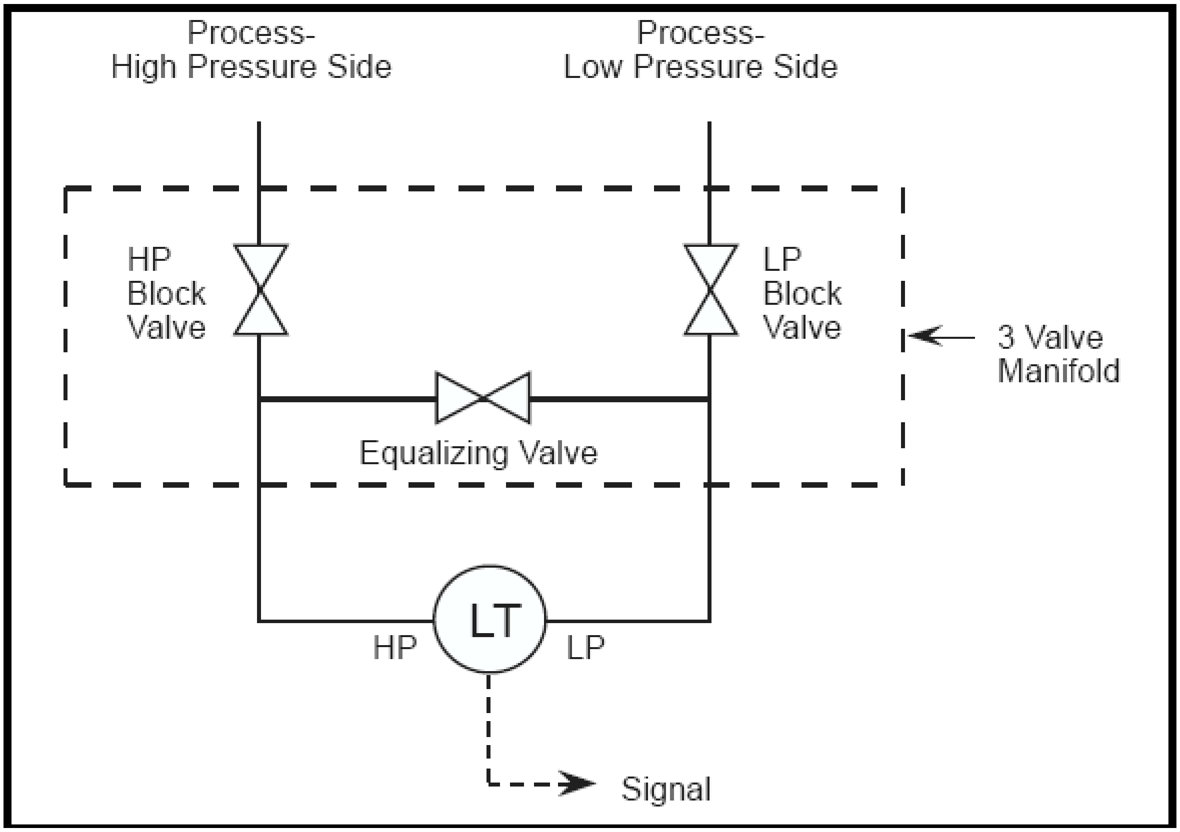
The transmitter is the heart of the 4-20 mA signaling system. It converts a physical property such as temperature, humidity or pressure into an electrical signal. This electrical signal is a current proportional to the temperature, humidity or pressure being measured. In a 4-20 mA loop, 4 mA represents the low end of the measurement range and 20 mA represents the high end

The Receiver Resistor:

It is much easier to measure a voltage than it is to measure a current. Therefore, many current loop circuits (such as the circuit in Figure 1) use a Receiver Resistor to convert the current into a voltage. In Figure 1, Rreceiver is a 250◎◎precision resistor. The current flowing through it produces a voltage that is easily measured by an analog input of a controller. For the 250◎◎resistor, the voltage will be 1 VDC at 4 mA of loop current and 5 VDC at 20 mA of loop current. The most common Receiver Resistor in a 4-20 mA loop is 250◎; however, depending upon application, resistances of 100◎◎to 750◎◎may be used.

5.6 Three Valve Manifold:

A three-valve manifold is a device that is used to ensure that the capsule will not be over-ranged. It also allows isolation of the transmitter from the process loop. It consists of two block valves - high pressure and lowpressure block valve - and an equalizing valve. Figure 1 shows a three valve manifold arrangement.



During normal operation, the equalizing valve is closed and the two block valves are open. When the transmitter is put into or removed from service, the valves must be operated in such a manner that very high pressure is never applied to only one side of the DP capsule.

5.7 Operational Sequences of Three-Valve Manifold Valving Transmitter into Service:

To put a DP transmitter into service an operator would perform the following steps:

1. Check all valves closed.
2. Open the equalizing valve . this ensures that the same pressure will be applied to both sides of the transmitter, i.e., zero differential pressure.
3. Open the High Pressure block valve slowly, check for leakage from both the high pressure and low-pressure side of the transmitter.

4. Close the equalizing valve . this locks the pressure on both sides of the transmitter.
5. Open the low-pressure block valve to apply process pressure to the low-pressure side of the transmitter and establish the working differential pressure.
6. The transmitter is now in service.
Note it may be necessary to bleed any trapped air from the capsule housing.

Removing Transmitter from Service:

Reversal of the above steps allows the DP transmitter to be removed from service.
1. Close the low-pressure block valve.
2. Open the equalizing valve.
3. Close the high-pressure block valve.
The transmitter is now out of service.
Note the transmitter capsule housing still contains process pressure; this will require bleeding.

5.8 Accessories:

1) **Pulsation Dampener**

If the instrument is intended for use with a fluid under pressure and subject to excessive fluctuation or pulsations, a dampener should be installed which provides a steady reading.

2) **Isolation valve**

It allows to isolate the instrument and the sensing line for maintenance, or to stop a leakage.

3) **Instrument valve**

It is installed in addition to or instead of an isolation valve. It isolates the instrument from both the process and instrument line.

4) **Blow down valve**

It allows purging the instrument line of any accumulated sediments.

Fittings:

Flared fitting: It is formed by making a clean, square cut at the end of the tubing and then flaring the end. A threaded connector forces the flared end of the tubing onto a mating part.

Compression fitting: Made by slipping a ring (a sleeve or ferrule) over the end of the tubing. Tightening the threaded connector compresses the ring around the tubing, forcing it against a mating part.

Pipe fitting: A normal pipe thread is tapered i.e. the depth of male thread becomes shallower as moved away from pipe. By tightening this fitting, shallow threads form a tight seal with the female threads. This kind of fitting is used for high pressures.

Socket fitting: it is made by soldering or welding each pipe end into a standard connector. Used for high pressures.

Fig. 5-3. Pipe fittings

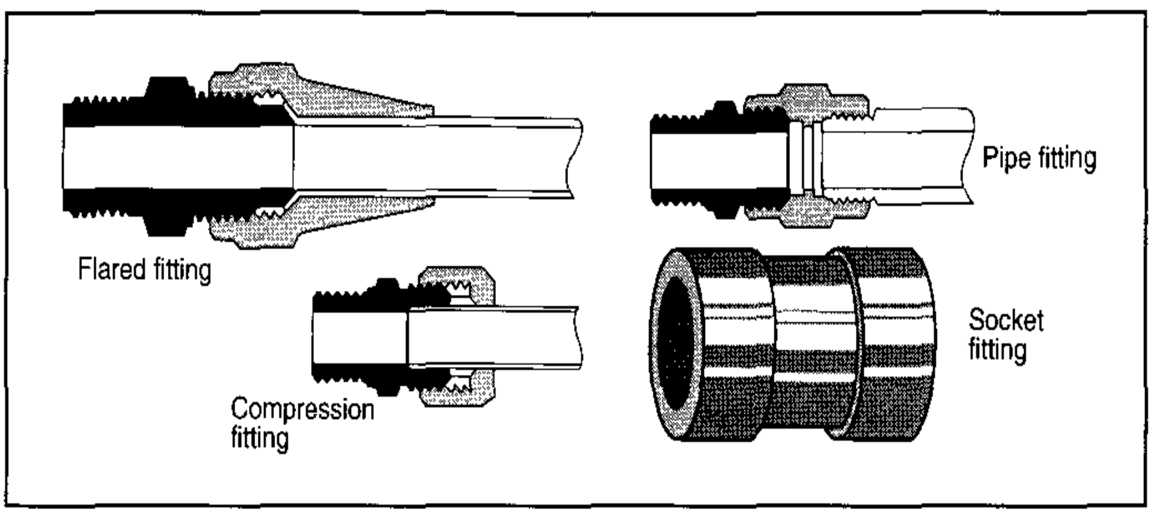
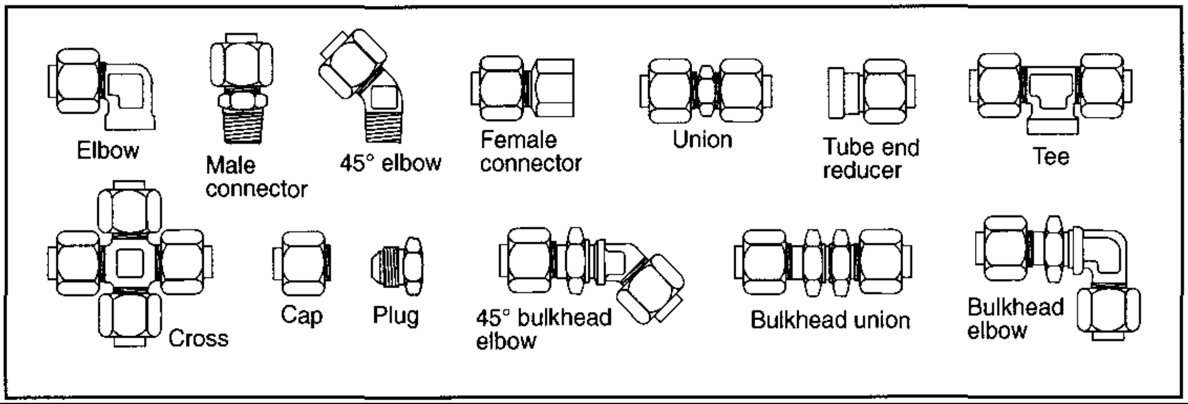


Fig. 5-4. Fitting selection



Piping

Following considerations must be kept in mind when installing the instruments.

Diameter: must be large enough for the instrument to respond quickly when the pressure changes.

Length: keep instrument lines short and tight.

Slope: mount the instrument above pressure tap for gas service while below the pressure tap for liquid service.

Flexibility: changes in temperature cause piping to expand and contract. Keep lines flexible.

Temperature: to keep instrument lines from freezing, wrap electric heating cable around the line or pass low pressure steam through a thin tube wrapped around the line.

6. HART Communication

OBJECTIVES:

Upon Completion of this topic one should be able to understand:

1. Why Hart communicator is required?
2. Types of Hart communicators
3. Tree diagram
4. Different Configurations
5. Benefits of using HART communicator

6.1 Conventional transmitters:

In conventional transmitters, zero and span is adjusted through Push buttons.

6.2 Smart transmitters:

In SMART (Single Modular Auto Ranging Transducer) transmitters, zero and span is fed through hand held communicator, in addition to other features.
Communicator is used to check the parameters of transmitter (Service, location, Span, Damping, and Alarm etc.) remotely.
Protocol is a set of rules/ instructions used for communication between different Medias.
Communication techniques used by different vendors are:

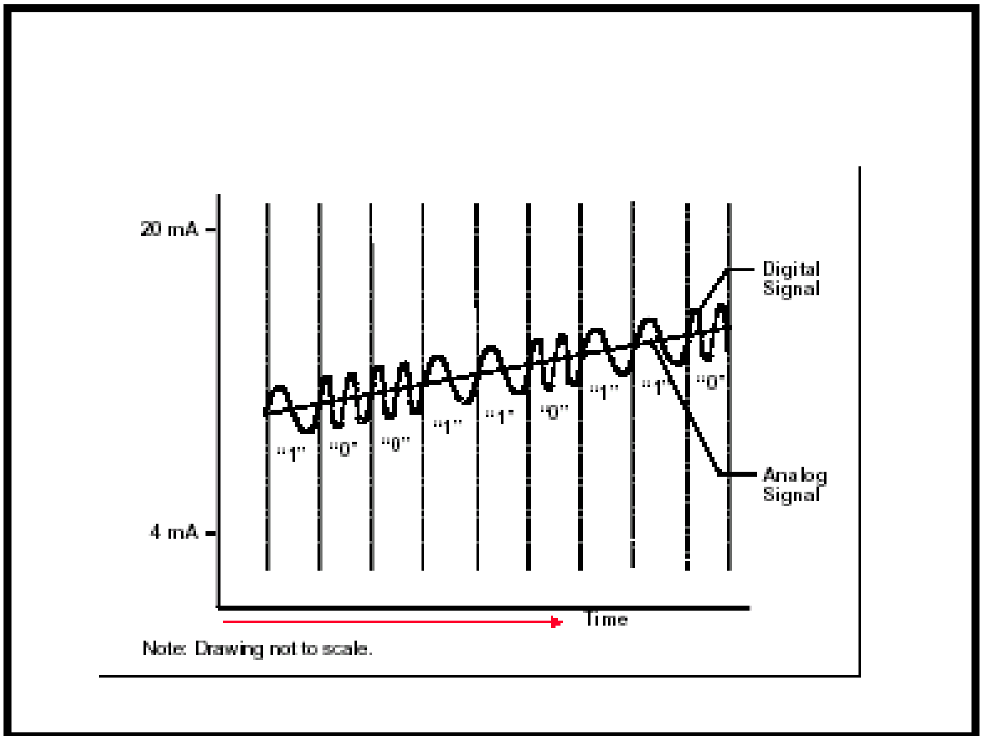
Yokogawa	Brain
Foxboro	Foxcom
Honeywell	Digicom

6.3 Communication technique:

Communication technique common to all vendors is HART (Highway Addressable remote transducer).
HART is a master-slave communication protocol, which means that during normal operation, each slave (field device) communication is initiated by a master communication device. Two masters can connect to each HART loop. The primary master is generally a distributed control system (DCS), programmable logic controller (PLC), or a personal computer (PC). The secondary master can be a handheld terminal or another PC. Slave devices include transmitters, actuators, and controllers that respond to commands from the primary or secondary master.

6.4 HART communication protocol:

The HART communication protocol operates using the frequency shift keying (FSK) principle. The digital signal is made up of two frequencies— 1,200 Hz and 2,200 Hz representing bits 1 and 0, respectively. Sine waves of these two frequencies are superimposed on the direct current (dc) analog signal cables to provide simultaneous analog and digital communications
Because the average value of the FSK signal is always zero, the 4–20 mA analog signal is not affected. The digital communication signal has a response time of approximately 2–3 data updates per second without interrupting the analog signal. A minimum loop impedance of 230 ohms is required for communication.

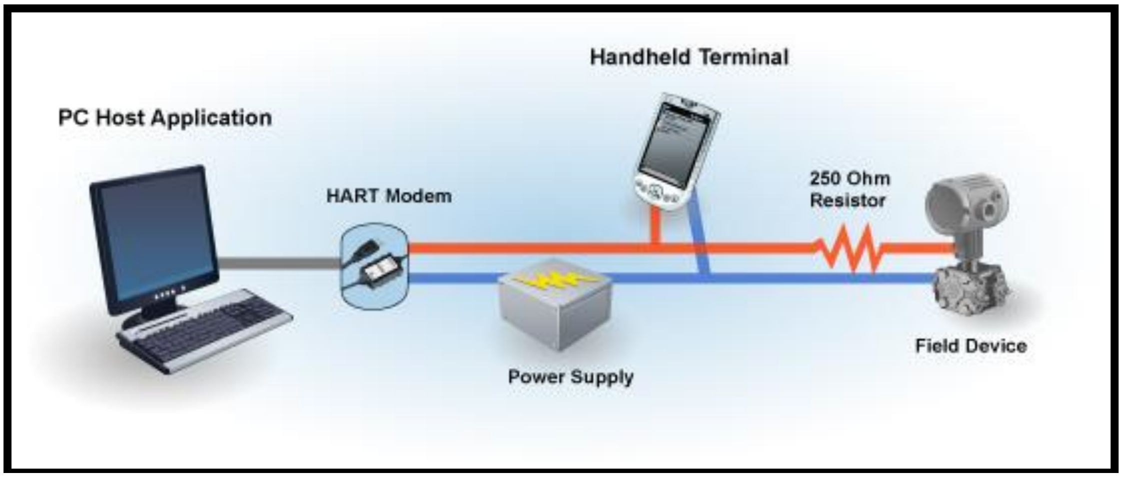


6.5 HART Devices Configuration:

HART devices can operate in one of two network configurations:
Point-to-Point Mode
Multidrop Mode

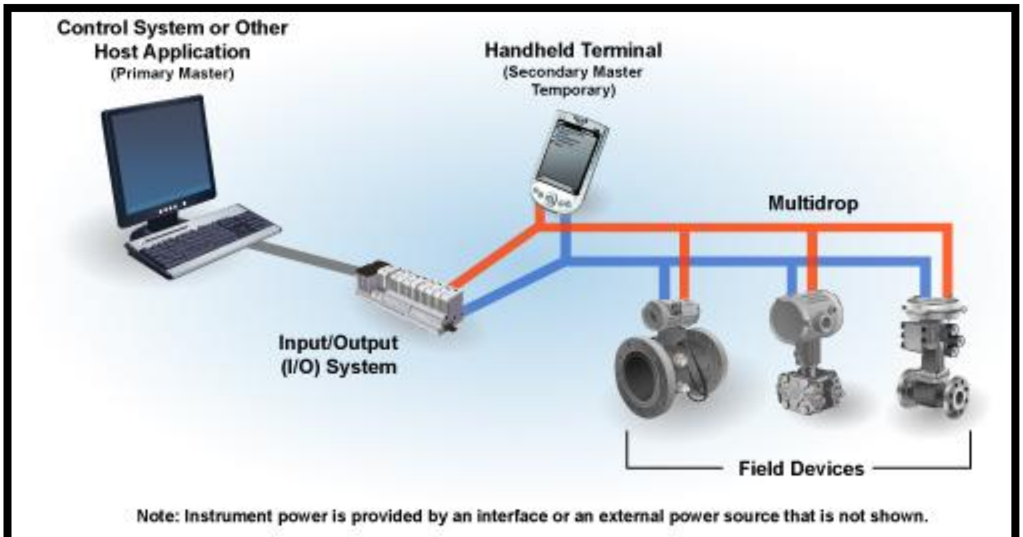
Point-to-point mode:

In point-to-point mode, the traditional 4–20 mA signal is used to communicate one process variable, while additional process variables, configuration parameters, and other device data are transferred digitally using the HART protocol. The 4–20 mA analog signal is not affected by the HART signal and can be used for control in the normal way.



Multidrop Mode:

The multidrop mode of operation requires only a single pair of wires and, if applicable, safety barriers and an auxiliary power supply for up to 15 field devices. All process values are transmitted digitally. In multidrop mode, all field device polling addresses are >0, and the current through each device is fixed to a minimum value (typically 4 mA).



Two Masters

6.6 Benefits of HART Communication:

The HART protocol extends system capabilities for two-way digital communication with smart field instruments. More instruments are available with the HART protocol than any other digital communications technology. Almost any process application can be addressed by one of the products offered by HART instrument suppliers.

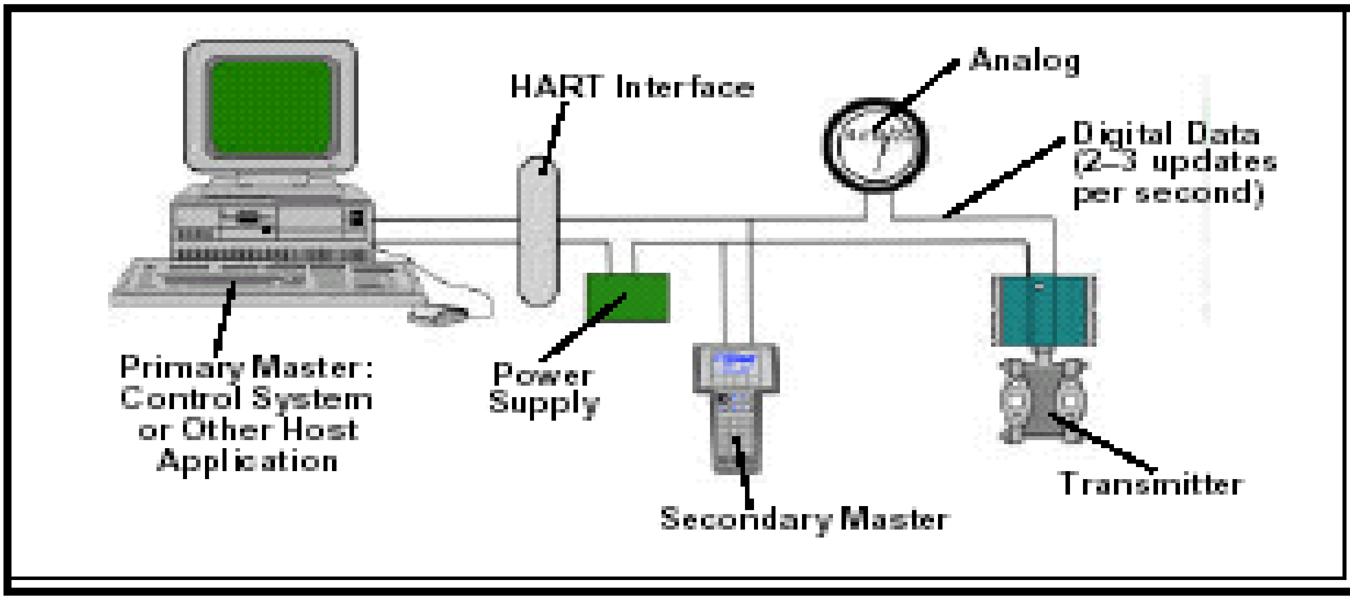
Benefits of HART communicator are:

Improved plant operations

Operational flexibility

Instrumentation investment protection

Digital communication



Cost saving in maintenance:

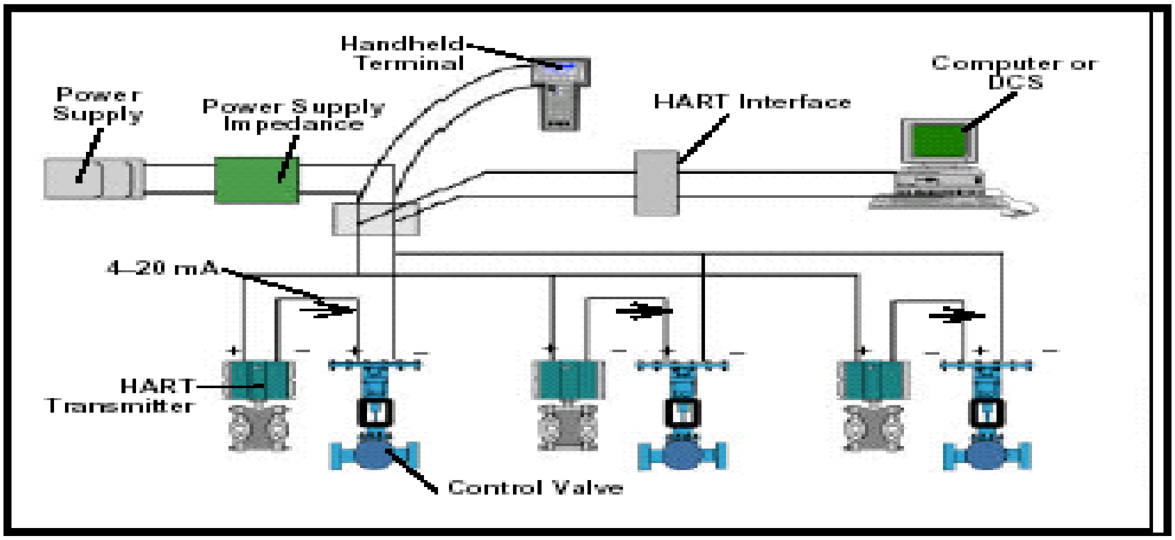
The diagnostic capabilities of HART-communicating field devices can eliminate substantial costs by reducing downtime. The HART protocol communicates diagnostic information to the control room, which minimizes the time required to identify the source of any problem and take corrective action. Trips into the field or hazardous areas are eliminated or reduced.

When a replacement device is put into service, HART communication allows the correct operational parameters and settings to be quickly and accurately uploaded into the device from a central database. Efficient and rapid uploading reduces the time that the device is out of service.

Software applications provide a historical record of configuration and operational status for each instrument. This information can be used for predictive, preventive, and proactive maintenance.

HART field controllers can also be wired in a multidrop network. Each analog output signal from the transmitter/controllers is isolated from every other output signal, which provides a cost-effective HART network configuration.

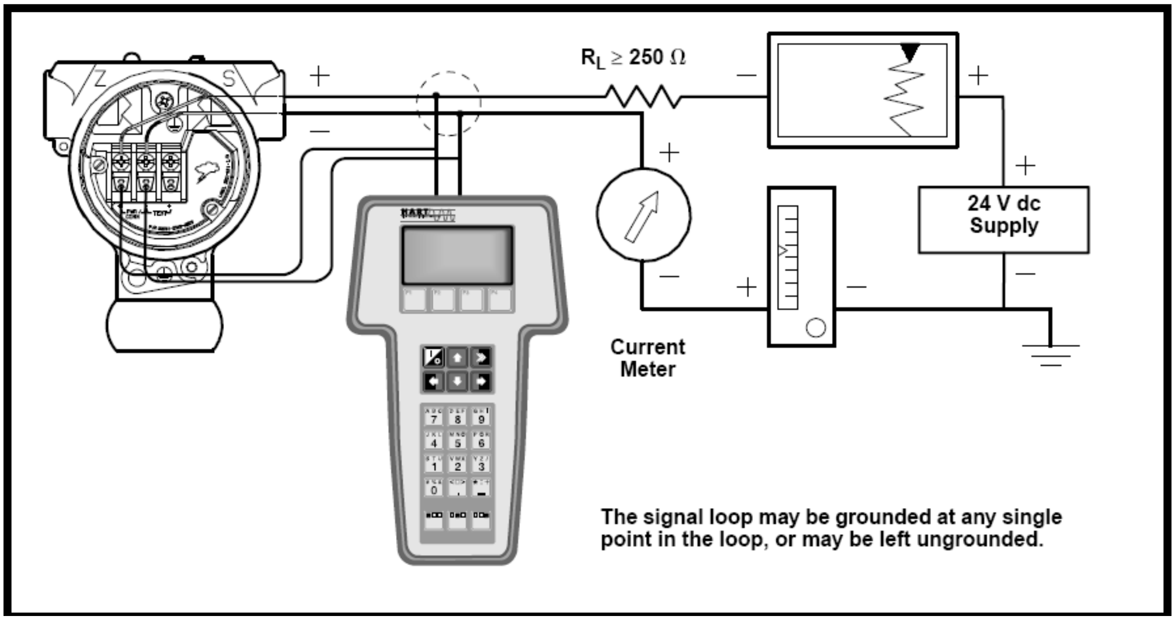
Connecting HART field devices in a multidrop network can provide significant installation savings. The total cable length in a multidrop network is typically less than the maximum cable length in point-to-point connections because the capacitance of the additional devices reduces the distance that the HART signal can be carried.



Configuring devices for multi-drop operation:

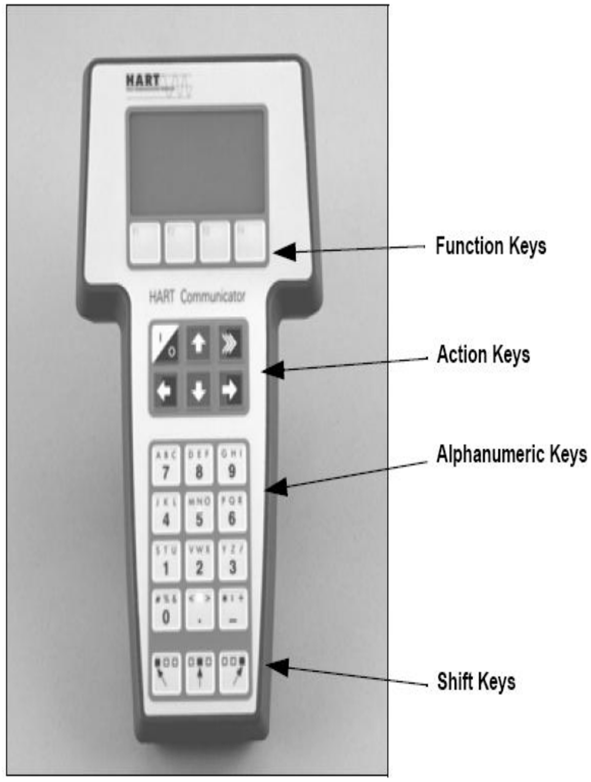
Using the polling address structure of the HART protocol, up to 15 devices can be connected in a multidrop network. The analog current of a HART device can be fixed by setting its polling address to a number other than zero. With the HART protocol, each field instrument should be configured with different polling addresses or tag numbers before being connected to a multidrop network—otherwise, the master will not be able to establish communication with the slave devices.

A HART field controller takes advantage of the HART protocol's simultaneous analog and digital signaling by converting the transmitter's traditional analog measurement output into a control output. The analog signal from the smart transmitter (controller) is used to manipulate the field device. The analog output signal also carries the HART digital signal, which is used for monitoring the process measurement, making setpoint changes, and tuning the controller.



The communication rate of the HART protocol (2–3 updates per second) is generally perceived as too slow to support closed-loop control in the central host. With control in the field, the control function no longer depends on the HART protocol's communication rate. Instead, the control signal is an analog output that is updated at a rate that is much faster than can typically be processed in a conventional control system. Processing rates vary from 2–20 updates per second, depending on the product. The HART digital communication rate remains sufficient for monitoring the control variable and changing setpoint values.

Figure B-4. The HART Communicator.



Difference between 275 and 375 HART Communicator:

There is no significant difference between 275 and 375 HART Communicator except that 375 is a new model with touch screen, It has more memory as compared to 275 and can store and configure more devices than 275 HART.

Fig. 9-1 HART Online Menu

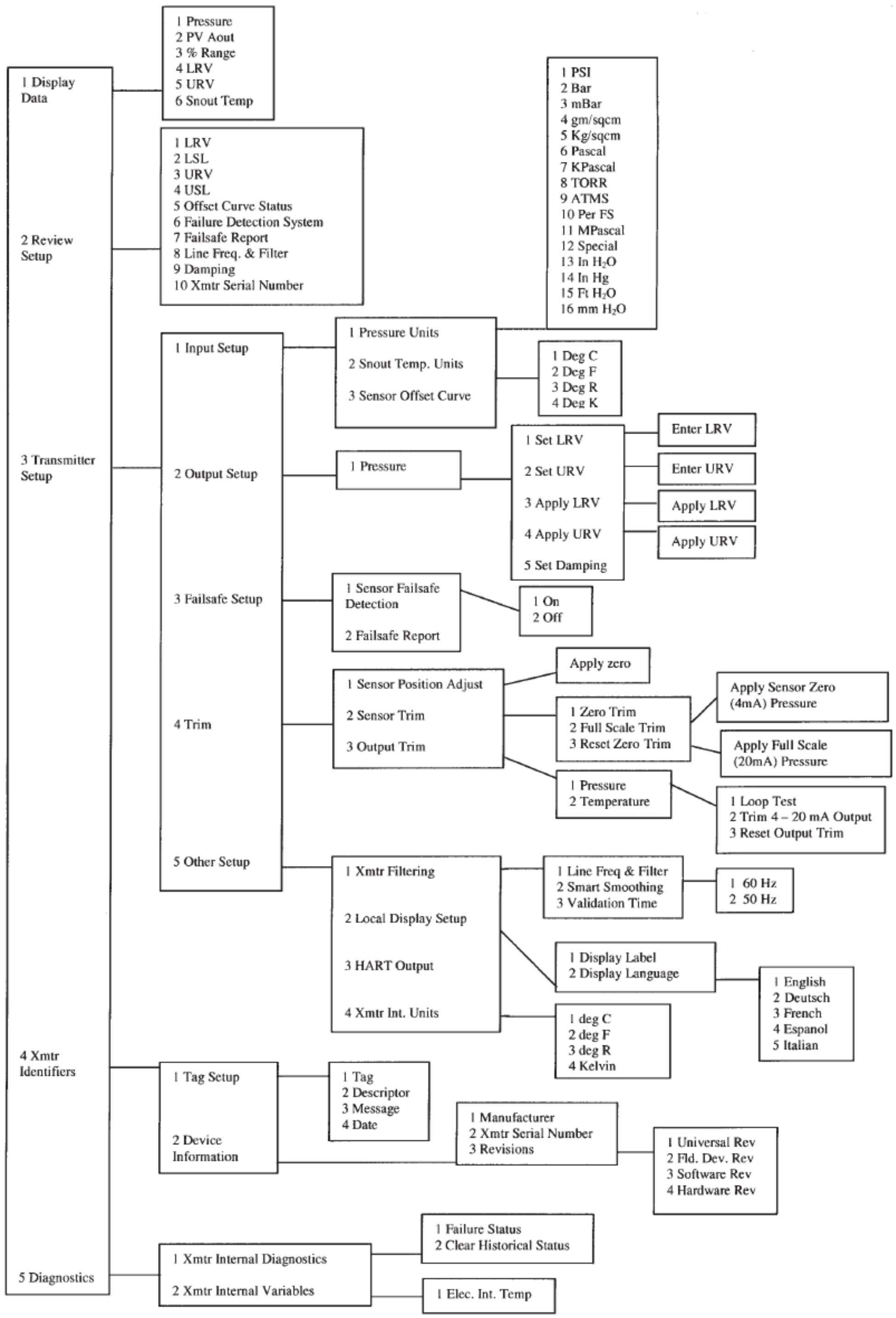
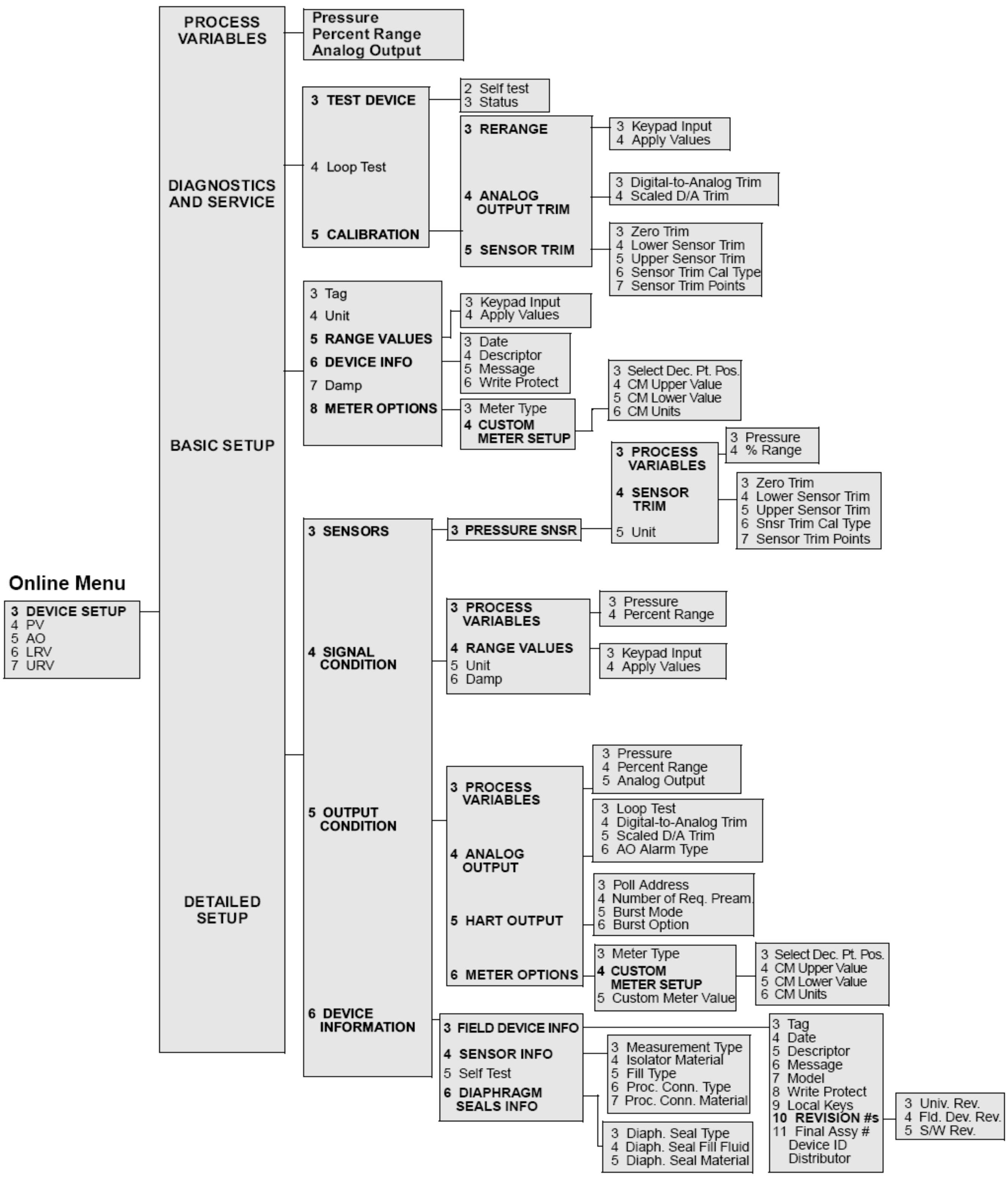


Figure B-1. HART Communicator Menu Tree for the Rosemount 2088 Smart.



7. Analytical Instrumentation

Objectives:

Upon completion of this topic you should be able to understand following concepts about Conductivity and PH analyzers:

1. Concept of conductivity
2. Conductivity measurement
3. PH and ORP concept
4. PH and ORP measurement
5. Wiring of PH electrode
6. Troubleshooting and maintenance

7.1 Conductivity:

Resistance is a measure of the ability of an electrical circuit to oppose current flow. Conductance is a measure of the ability of a circuit to pass current. The symbol for conductance is G. Unit of measurement for conductance is Siemens (or mho), and is the reciprocal of resistance (R) in ohms:

$G = 1/R$

The conductivity of a substance is the conductance of a unit length and unit cross-sectional area of that substance.

Several kinds of sensors, or probes, are used to measure the conductivity of a process liquid. The two main kinds are:

1. Electrode probe
2. Inductive (electrode-less) probe

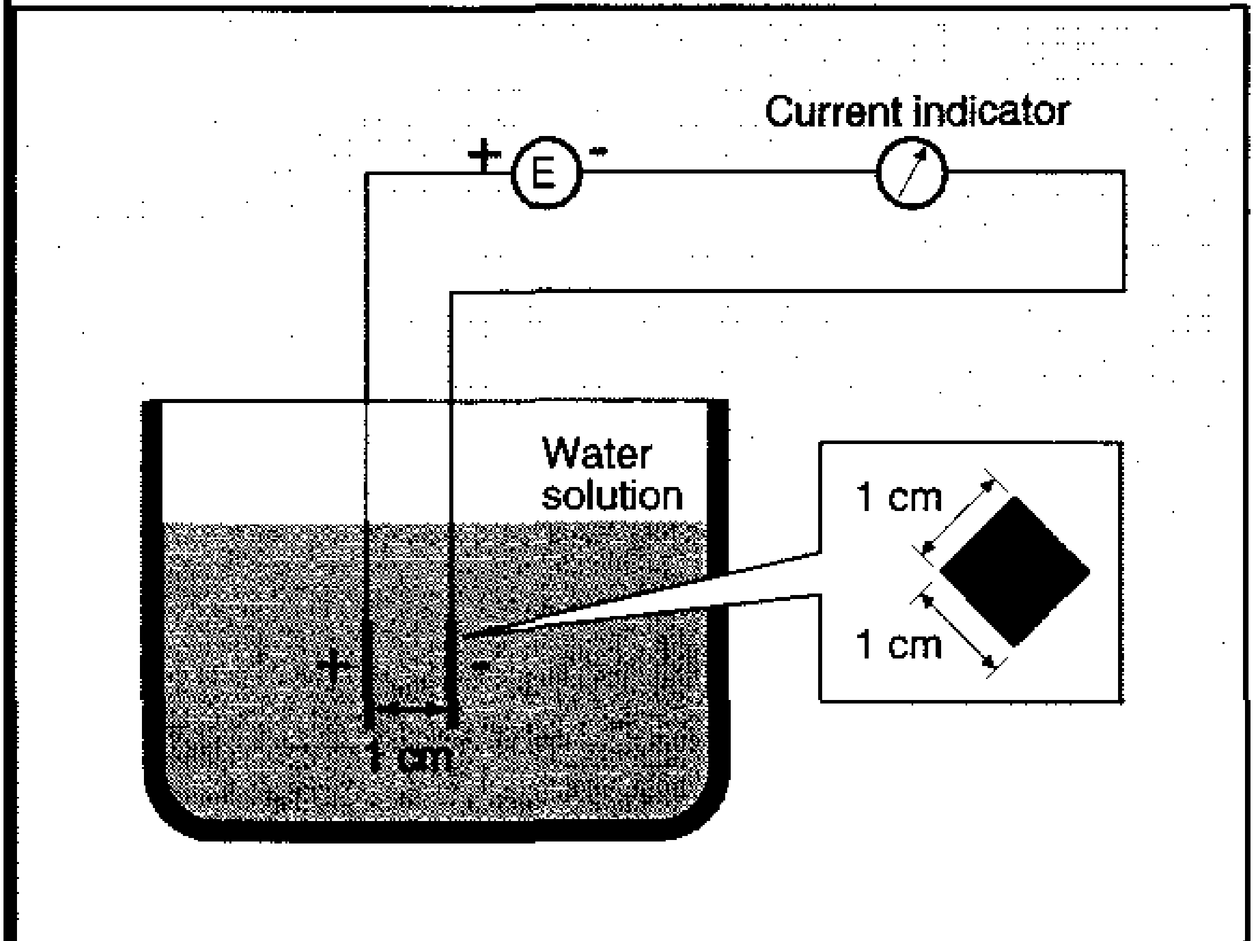
Electrode probe:

The electrode probe operates by applying a fixed-amplitude, square-wave voltage across two electrodes of known size and known separation immersed in the process liquid. If the liquid contains ions, allowing a current to flow, the current is measured and converted to a conductivity reading. An alternating current is used to avoid polarizing the liquid, a condition that would make a reading impossible. Polarization is the production of a gaseous layer on the surface of the electrodes.

If the size of the electrode plates is changed, the amount of current changes. Therefore, the indicated conductivity changes although the voltage has not changed. This procedure is referred to as changing the cell constant of an instrument.

Each cell with fixed electrodes has its own cell constant. Cell constants range from 0.01 to 100 and vary by multiples of ten. An instrument with a cell constant of 0.01 has a range of 1 to 10 micro- Siemens, an instrument with a cell constant of 0.1 has a range of 1 to 100 micro Siemens, and an instrument with a cell constant of 1.0 can measure 1 to 1000 micro- Siemens, and so on.

Fig. 1-1. Electrode probe conductivity measurement



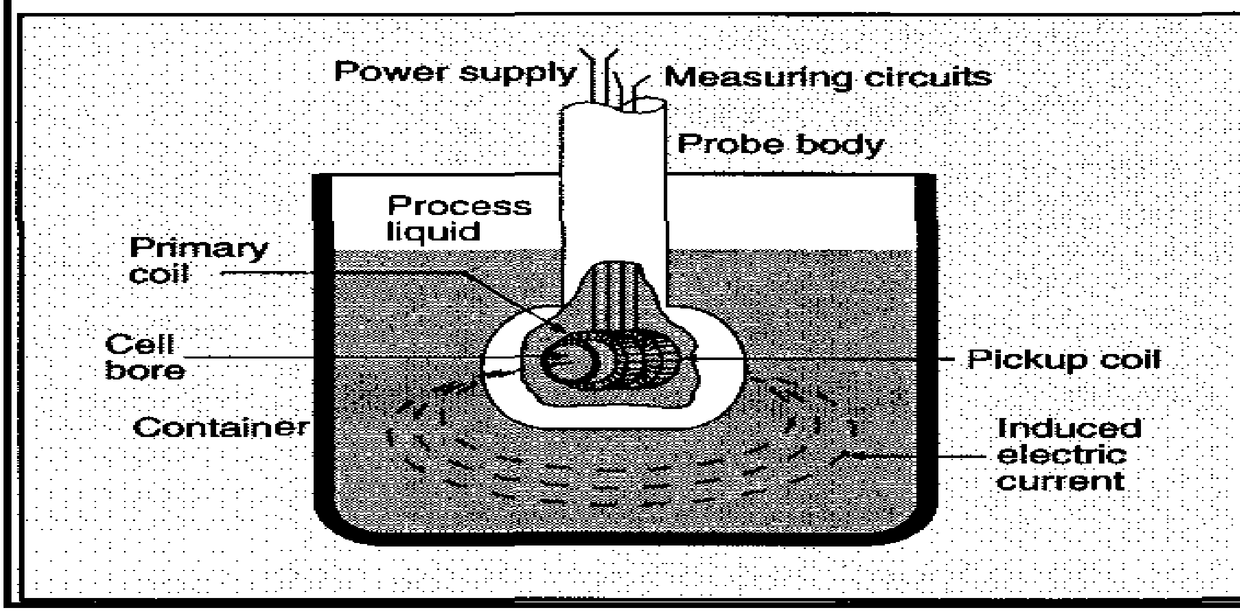
Inductive probes:

The inductive magnetic field probe, also referred to as an electrode-less probe, operates on a different principle from the electrode probe. The inductive probe is made up of two completely enclosed electrical coils. During operation, the probe is entirely immersed in the process liquid. The probe is enclosed in a corrosion-resistant coating.

The instrument sends an alternating current through the primary coil. This current creates an alternating magnetic field that induces an alternating current in the pickup coil. The conductivity of the process liquid affects the magnetic coupling between the coils. The induced current in the pickup coil is directly proportional to the conductivity of the liquid.

No direct contact is necessary between the coils and the solution, thus reducing potential maintenance problems. This system normally transmits a 4 to 20 mA dc signal that is proportional to the measured conductivity. To change the cell constant, change the probe.

Fig. 1-5. Inductive conductivity measurement

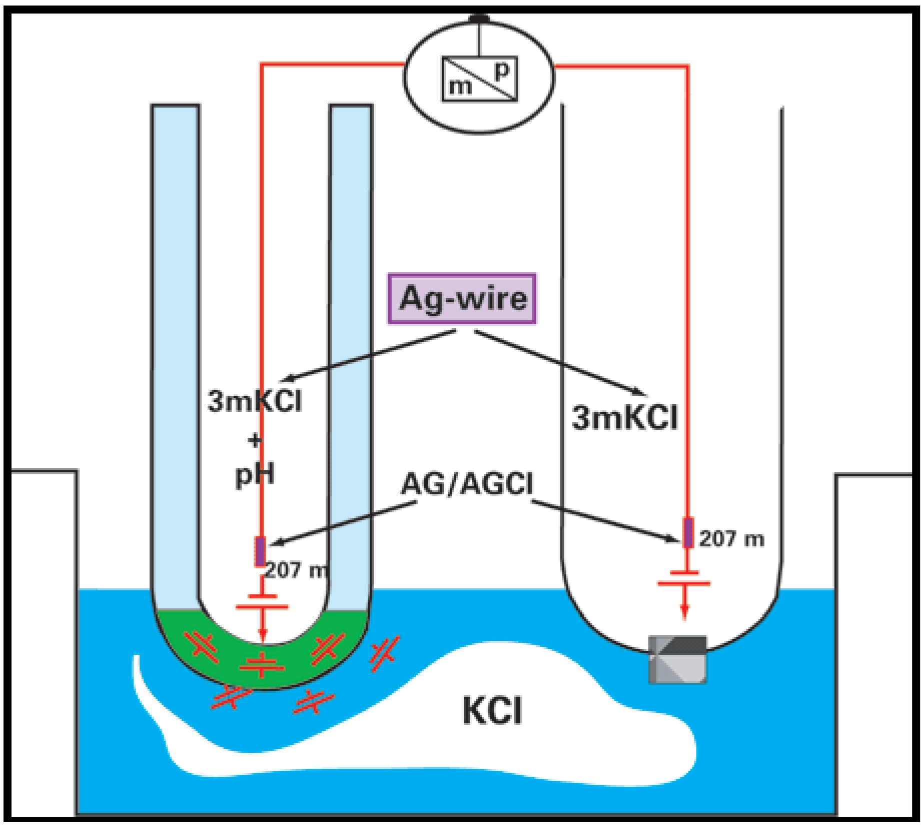


pH and ORP Measurement:

pH is a measure of the number of hydrogen ions in a process liquid. ORP (Oxidation-Reduction Potential) measures the ratio of ions that oxidize to those that reduce other chemicals.

7.2 pH Measurement:

The pH value of an aqueous (water-containing) liquid is an indication of positive hydrogen ion (H+) activity. Readings of pH in non-aqueous liquids are not measures of hydrogen ion activity, but are useful in specific situations. The molecules that make up a liquid, whether water alone or water with another chemical dissolved in it, can be partially broken down into smaller particles referred to as ions. Some of the molecules in water (H2O) break down into two different kinds of ions, H+ (hydrogen) and OH- (hydroxyl).



By definition, pH is the negative log of the hydrogen ion concentration of a solution.
It is important to recognize that pH measures only the concentration of hydrogen ions in a solution, and not the total acidity or alkalinity of the liquid.
Liquids with a pH of less than seven have more H+ than OH- ions. They are referred to as acids. Acid solutions increase in strength as the pH value fall below 7 (down to 0).
Liquids with a pH greater than seven are referred to as bases and have many more OH- ions than H+ ions. Basic solutions increase in strength as the pH values rise above 7 (up to 14).
Temperature has a significant effect on pH, because the dissociation constant (separation into ions) changes with changes in temperature. Instrumentation normally includes a temperature detector and is capable of calculating the pH,

by means of a temperature correction factor, as if the temperature actually were 25°C.

7.3 ORP Measurement:

Oxidation may be defined as the loss of electrons by one molecule and reduction as the absorption of electrons by another. Every liquid has both oxidizing and reducing ions, but their balance varies from liquid to liquid. Those liquids that tend to reduce have an excess of electrons. Those that tend to oxidize have a shortage of electrons.

The ORP of a process liquid indicates by its voltage polarity whether the process liquid has an oxidizing potential or a reducing potential. A liquid with an oxidizing potential has a positive polarity relative to the reference voltage. A liquid with a reducing potential has a negative polarity relative to the reference voltage. The unit of ORP measurement—the voltage potential measured between two electrodes submerged in a liquid—is the milli volt.

7.4 pH and ORP Reference Electrodes:

A pH probe is made up of two separate electrodes, as is an ORP probe. The reference electrode is the same for both pH and ORP probes, but the measurement electrodes are different.

The reference electrode is designed to provide a constant voltage potential despite changes in pH or temperature. This electrode is used to monitor any change in the total liquid potential.

The lead wire is in an inner tube that contains silver metal and silver chloride paste. This paste is in contact with a saturated solution of potassium chloride (KCI), which acts as an electrical bridge to the solution being measured. The potential of the reference electrode depends on temperature and on the KCI concentration.

The KCL slowly migrates from the reference electrode to the solution being measured by means of a liquid junction consisting of a porous ceramic material near the bottom of the electrode. Crystals of solid KCL in the bottom of the electrode ensure that the solution stays saturated. A portal is provided for replenishment of the KCI, and a rubber sleeve protects the portal from contamination.

7.5 pH and ORP Measurement Electrodes:

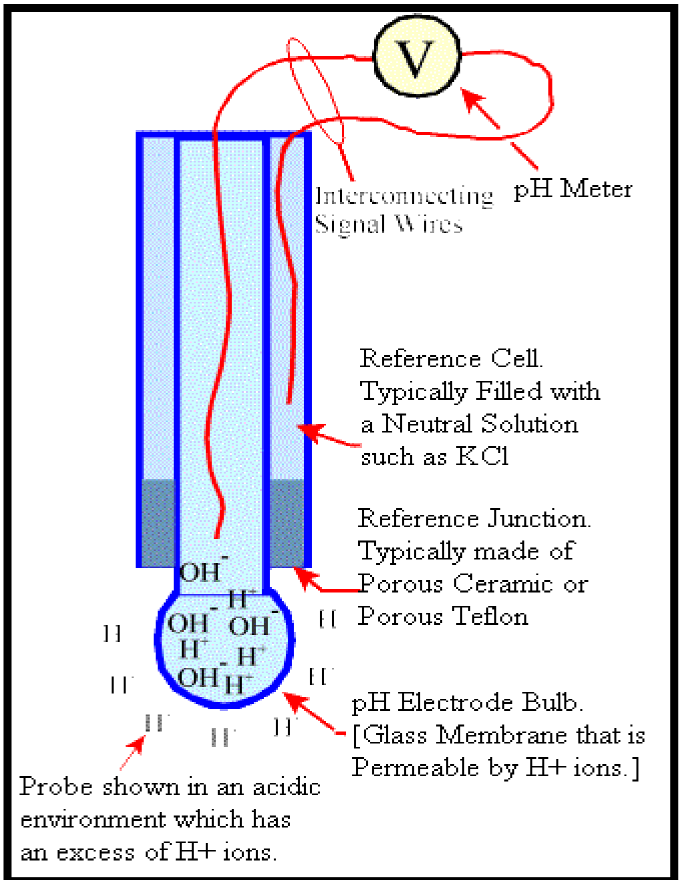
The pH measurement electrode produces a potential of 59.2 mV per pH unit, which relates directly to the solution in which it is submerged. Measurement of the potential requires a current through a very high impedance amplifier and back to the process liquid. Electrical connection of the measuring circuit to the liquid is through a liquid junction—a calibrated leak of liquid from the reference electrode into the process—that is part of the reference electrode.

The pH measurement electrode has a thin walled glass bulb filled with a liquid of known pH, usually potassium chloride. A silver-silver chloride electrode is immersed in the liquid. The hydrogen ions on the inside of the electrode are of a different concentration than the hydrogen ions on the outside. These ions want to reach equilibrium by migrating through the glass wall of the electrode until the concentrations are the same.

This migration is prevented by the glass, and thus a potential is established. A potential difference across the thin bulb will occur when the H+ activity inside the electrode is different from the H+ activity in the liquid to be measured. Because glass is an insulator, the bulb wall must be very thin to permit accurate voltage readings.

The pH measurement electrode (which is usually attached to a high-impedance voltmeter) reacts to any change in voltage and reports it as a pH reading. The pH measurement electrode has a watertight seal at the top to keep out any liquid or moisture that could affect the probe’s operation.

Both reference and measurement electrodes are contained in the same housing in the probe.



The ORP measurement electrode is simply a platinum wire exposed at its bottom end to the process liquid. The ORP measurement electrode reacts to variations in voltage. Voltage variations caused by variations in the activity of the oxidizing and reducing ions in the process liquid are amplified and displayed as the ORP of the liquid.

7.6 Wiring:

Cable Length

When a internal preamplifier is used, the analyzer/transmitter can be up to 152 m (500 ft) away from the sensor. If no preamplifier is used, the distance is limited to 15 m (50 ft).

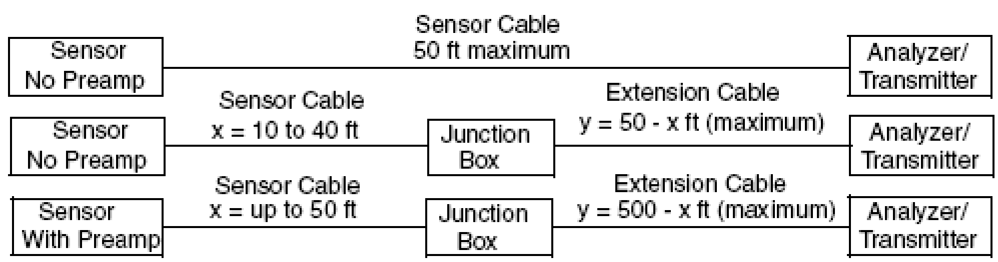


Figure 19. Cable Lengths for Cable With Pin Lugs

Table 12. High Temperature Cable Wiring - Sensor Without Preamplifier

Wire Number	Cable Color	Function
1	Black	RTD
2	Brown	RTD
2A	Orange	RTD 3-Wire (see note)
3	White (Coax)	Measuring Electrode
3A	Clear (Coax Shield)	Coax Shield (screen) for Measuring Electrode
4	Green (Outer Shield)	Solution Ground
5	Red	Reference Electrode

Wire 2A is not present on the cable of a sensor with a 2-wire RTD. Wire 2A on patch cords used with sensors without preamplifiers is only functional when the sensor contains a 3-wire RTD. Do not connect wire 2A to the analyzer/transmitter (tape it back) if the sensor does not contain a 3-wire RTD.
Wire 2A is not used with 873 Analyzers. In such applications, it should be taped back.

7.7 Sensor Troubleshooting:

Table 16. Sensor Troubleshooting

Problem	Possible Cause	Remedy
No response.	1. Broken measuring electrode. 2. Heavily coated electrodes.	1. Replace sensor. 2. Clean and/or replace.
Elongated span.	1. Incorrect instrument calibration 2. Instrument temperature compensation inactive or incorrectly configured. 3. Incorrect temperature measurement.	1. Recalibrate. 2. Refer to instrument manual for proper configuration. 3a. Check that analyzer /transmitter is configured for correct RTD. 3b. Check RTD resistance across leads 1 and 2 (see Table 12) 3c. if OK, calibrate instrument temperature circuit. If bad, replace sensor.
Sluggish response.	1. Aged or dehydrated measuring electrodes. 2. Coated or dirty electrode and reference junction.	1. If sensor is dehydrated, soak in pH 4 buffer or KCl solution.) 2a. Clean electrode and reference junction. 2b. Replace sensor.
Erratic or noisy measurement.	1. Fouled reference junction. 2. Air bubbles in the process.	1. Clean reference junction. 2. Arrange sensor mounting to avoid air bubbles.
Discrepancy between process reading and laboratory grab sample results.	1.Laboratory reading in error. 2. Change in grab sample temperature (that is, sample temperature changed before laboratory measurement was made — causing a change in pH). 3. Incorrect instrument calibration.	1. Verify calibration and/or operation of laboratory pH equipment. 2. Make off-line measurement as soon as possible after collecting gab sample. If sample cooling is inevitable, a change in pH from the process to the lab may be unavoidable. 3. Perform single point calibration to make readings agree.

7.8 Maintenance

Calibration:

Sensor and analyzer/transmitter system should be calibrated regularly. A sensor loses calibration for two general reasons: the slope changes or the offset changes. Slope changes are usually due to aging of the measuring electrode. Offset changes are often due to clogging and contamination of the reference junction. A single point calibration corrects the offset only. A two point calibration corrects both the offset and the slope. Frequency of calibration is dictated by the rigors of the process, such as temperature, pressure, abrasives, harsh chemicals, and so forth. It is also related to your requirement for accuracy. Many users do a single point, grab sample calibration frequently and a two point calibration only occasionally.

Temperature Calibration:

Dolphin sensors include a precision temperature measuring element. Foxboro analyzers and transmitters use this temperature measurement to provide automatic temperature compensation of the pH measurements. ORP measurements do not require temperature compensation. For optimum pH measurement accuracy, the temperature measurement accuracy should be checked and adjusted if necessary. This is especially important when a long cable length is used with sensors that have 2-wire RTD elements. Sensors with 3-wire RTD elements automatically compensate for errors due to cable length. Refer to your analyzer/transmitter instruction for specific calibration procedures.

Electrode Inspection:

Fouling (the build-up of a film) on the measuring electrode and the reference junction can cause erratic output. Inspect the electrodes as needed. Once a week is recommended for new installations. If fouling is evident, clean the electrode as described in the following sections.

Electrode Cleaning:

Cleaning a Glass Electrode

First, consider the contamination you are trying to remove.
In what is it soluble?
What will chemically attack it?
Next, consider the sensor. What cleaner will have little or no effect on the sensor itself?
Choose the solvent, soap, or chemical that is the mildest but removes the contamination. Caustic is a risky choice for glass electrodes. Stronger concentrations can attack the glass. Dilute HCl is frequently a good choice. The concentration of HCl should be as low as possible and still remove the contamination. Consider 4% or 1 N to be a maximum.

Storing a Sensor:

The shelf life of sensor depends on the storage conditions. Although IPS does not specify a shelf life, a reasonable estimate is 6 to 12 months. Under the best conditions, sensors may last well over a year on the shelf. The key to proper storage is keeping both the measuring electrode and the reference junction hydrated at normal room temperature. Store your PH10 or ORP10 Sensor in a 1 M potassium chloride solution or a pH 4 or pH 7 buffer solution. Sensors should not be stored in distilled or de-ionized water. New sensor assemblies are shipped with the measuring and reference junction sealed in a protection cap containing liquid potassium chloride salt solution. The cap should remain in place until you are ready to install your sensor in the process. The protection cap can be reused to store a sensor by replenishing the solution and fitting it on to the sensor. IPS recommends this if the sensor is removed from the process for more than a few hours. Proper storage maximizes both shelf life and service life of a sensor.