Uma Charan Patnaik Engineering School Berhampur

LECTURE NOTES

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Prepared By: Sibasish Mahapatra

Designation: Lecturer (Chemical Engg.)

Department of Chemical Engineering

INSTRUMENTATION & CHEMICAL ANALYSIS

CHAPTER 1: INSTRUMENT

The Meaning of Measurement:

The fundamental and underlying purpose of measurements in industrial manufacturing and processing is to aid in the economics of industrial operations by improving either the quality of product or the efficiency of production. In view of this purpose, one should always bear in mind these questions in regard to measurement:

1. Why is the measurement being made?
2. What should the measurement mean?
3. What measurement is made?
4. What is the result of making this measurement?

In an industrial operation these questions may be difficult to answer. Nevertheless, a measurement that has a definite purpose and a definite meaning and accomplishes a specific result is one that should be made.

Direct measurement is a tremendously important approach in modern instrumentation. Direct measurement can best be illustrated by an example. In manufacturing a mechanical part in a lathe section of a machine shop, the purpose of processing is to produce a part with given physical dimensions. During and after the operation, measurement of its dimensions (called in inspections) are usually made. This is a direct measurement in which the meaning of the measurement (determining a physical dimension) and the purpose of the processing operation (producing a physical dimension) are identical.

Indirect measurement is illustrated by the measurement of temperature in a milk pasteuriser. The purpose of the pasteurising operation is to eliminate bacteria. This is an indirect measurement, wherein the meaning of the measurement (temperature of the milk) and the purpose of processing (eliminating bacteria) are not the same but are related to each other. A direct measurement in this example would be a bacteria count. The point of these examples is to bring out the meaning and intent of a measurement.

If the primary purpose of making a measurement is to determine a quality of a product, then, one should measure that quality directly.

Direct measurement is not always possible, however, and then indirect measurement must be resorted to. In indirect measurement an empirical relation is generally established between the measurement actually made and the results that are desired. There are many factors, however, that result in a change in the relations in indirect measurement, and a breakdown in these relations will cause the measurements to become meaningless.

The Elements of Instruments:

A measuring instrument is simply a device for determining the value of a quantity or condition. The purpose served by the instrument is, first, to determine or ascertain the value (magnitude) of some particular phenomena. The instrument does not necessarily have to indicate, signal, record, or otherwise make known what value it has ascertained. On the other hand, it may be required to indicate, record, register, signal, or perform some operation on the value it has determined. The value determined by the instrument is generally, but not necessarily, quantitative. An instrument for the measurement of the presence of acid in a chemical solution may simply answer yes or no.

The following functions may be fulfilled by an instrument.

Transmitting, in which the instrument is intended to convey information concerning the measured quantity over some distance to a remote point. The value (magnitude) of the measured quantity may never be made known, because it may be used for some other purpose. A homely example is the telephone.

Signaling, where the instrument only indicates the general value or a range of values of its measured quantity. Some grocer's scales, for example, show only that the weight is too little or too great.

Registering, in which the instrument merely indicates, by numbers or some other symbol of discrete increments, the value of some quantity. A cash register and certain water meters only register incremental quantities.

Indicating, in which an instrument provides some kind of calibrated scale and pointer. The value of the quantity may be read on the scale to any fraction within the limitations of the instrument and the human eye. For example, most clocks are indicating instruments.

Recording, in which an instrument makes a written record, usually on paper, of the value of the measured quantity against some other variable or against time.

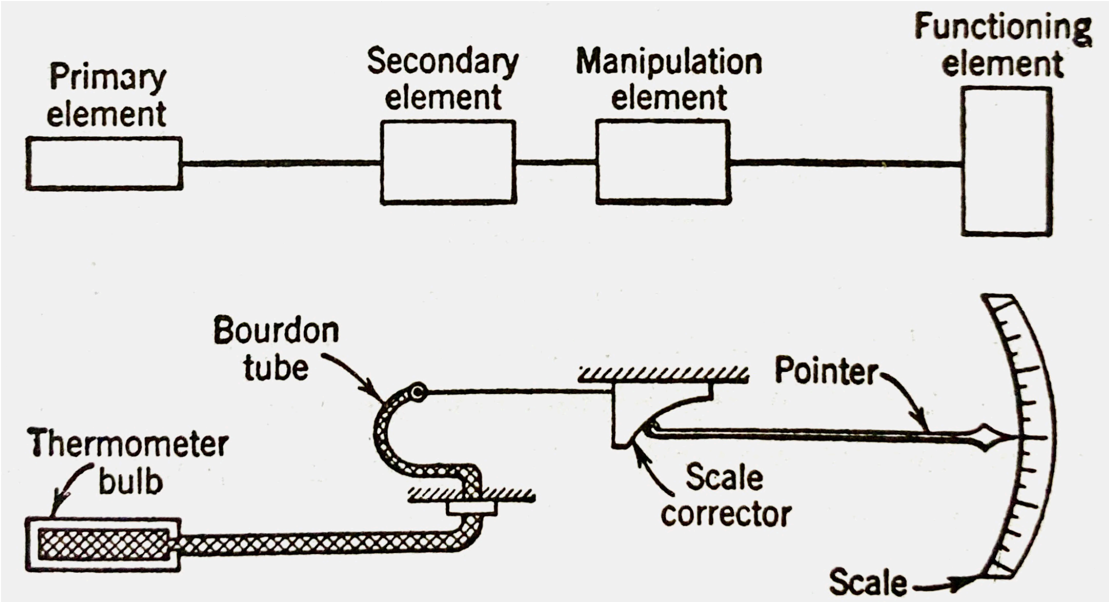
Although this function of an instrument is not fundamentally different from an indicating function, it is classed separately.

Any combination of these functions may be found in a measuring instrument, and no one of them is more important than the others. A great number of each type are used industrially. One of the most important functions of an instrument is found in the automatic controller, every one of which includes a mechanism performing the function of measurement. The quality of automatic control is often determined by the quality of the measuring means.

Another function accomplished in an instrument is to perform various manipulations on a measured variable. This is generally incidental to the main purpose of the instrument but never the less is an important function. Several examples will illustrate these features. A type of instrument much used with combustion furnaces takes the ratio of fuel flow and air flow. A differential pressure instrument may measure the difference in pressure between two points in a process. A flowmeter indicating rate of flow usually integrates the flow rate to obtain quantity. Other examples are easily found showing addition, multiplication, and differentiation. In fact, instruments are used in which the solution of rather complex algebraic or differential equations is involved.

All instruments contain various parts that perform prescribed functions in converting a variable quantity or condition into a corresponding indication. The process of conversion in an instrument is necessary in order to change the measured variable, a temperature, a pressure, a flow, or a chemical composition, into a more useful quantity, such as displacement, pressure, force, or potential. In most cases an instrument ultimately converts the measured variable into a displacement.

The parts of an instrument are indicated by the figure below, together with a simple example of an indicating thermometer.



Elements of an instrument

The primary element is the part of the instrument that first utilizes energy from the measured medium to produce a condition representing the value of the measured variable. In this case the thermometer bulb is the primary element, because it first converts energy in the form of heat into a fluid displacement, which is proportional to the temperature at the bulb.

The secondary element merely converts the condition produced by the primary element into a condition useful to the function of the instrument. In the example the secondary element is the pressure spring, which converts the fluid displacement into a displacement of a link.

The manipulation element performs given operations on the condition produced by the secondary element. In the given figure, motion of the pressure spring is modified by a scale corrector in order to correct for nonlinearity in the preceding conversion processes.

* The manipulation element sometimes precedes the secondary element.

The functioning element simply denotes the part of an instrument used for transmitting, signaling, registering, indicating, or recording.

The parts of an instrument named previously do not necessarily appear in all instruments. Some instruments like the mercury-in-glass thermometer are much simpler and require no dissection such as this. On the other hand, an instrument like the automatic balanced potentiometer, thermocouple pyrometer is much more complex than the example in above figure.

A distinction is sometimes made between automatic instruments and manual instruments. The automatic instrument does not require the services of an operator in fulfilling its function whereas the latter does. A mercury-in-glass thermometer is an automatic instrument because it indicates temperature without requiring any manual assistance. One type of resistance thermometer with a Wheatstone bridge requires manual operation of the bridge in order to indicate the temperature being measured and is therefore a manual instrument.

Another classification of instruments is made according their source of power. The self-operated instrument like the mercury-in-glass thermometer derives its power wholly from the thermal expansion of mercury. The power-operated instrument requires a source of auxiliary power, such as compressed air, electricity, hydraulic supply, or a mechanical source of power.

A further classification of instruments is according to their arrangement. In the self-contained instrument such as a room- temperature thermometer, all parts of the instrument from primary element to indicating element are contained in one physical assembly. On the other hand, there are instruments so used that the primary element is located hundreds of feet from the secondary element. The indicating element may also be remotely located.

Performance characteristics:

The performance characteristics of an instrument are very necessary for choosing the most suitable instrument for specific measuring tasks. It can generally be broken down into two sub-areas:

1. Static characteristics
2. Dynamic characteristics

Static characteristics:

The static characteristics of an instrument are, in general, those that must be considered when the instrument is used to measure a condition not varying with time.

Accuracy..................................Static error
Reproducibility.................................. Drift
Sensitivity..................................Dead zone

The qualities on the left are desirable, and their opposite qualities are undesirable.

Accuracy may be defined as the ability of a device or a system to respond to a true value of a measured variable under reference conditions. In actual practice, accuracy is generally and necessarily expressed as the limit error of a measuring device or system under certain operating conditions that may or may not be specified.

Precision is the degree of exactness for which an instrument is signed or intended to perform. It is composed of two characteristics.
conformity and the number of significant figures to which a measurement may be made. Significant figures convey actual information regarding the magnitude and the measurement precision of a quantity. The more significant the figures, the greater the precision of measurement. Conformity is a necessary, but not sufficient condition for precision because of the lack of significant figures obtained.

The static error of an instrument is the difference between the true value of a quantity not changing with time and the value indicated by the instrument. The static error is expressed as +X units, or -X units. For static error in units,
True value + static error = instrument reading
For plus static errors the instrument reads high, and for minus static errors the instrument reads low. The static correction of an instrument reading is specified in units:
True value = instrument reading + static correction
Therefore, static error and static correction are related as follows:
Static correction = -static error

When we have more than one elements and each element have some error, the we have two methods to deal with that.
The least accuracy is $Within \pm (a + b + c + \dots)$

The square root accuracy is $Within \pm \sqrt{a^2 + b^2 + c^2 + \dots}$

The reproducibility of an instrument is the degree of close ness with which a given value may be repeatedly measured. It may be specified in terms of units for a given period of time. Perfect reproducibility means that the instrument has no drift: that is, the instrument calibration does not gradually shift over a long period of time, such as a week, a month, or even a year.

Drift is an undesired change or a gradual variation in output over a period of time that is unrelated to changes in output, operating conditions, or load. This term most often applies to changes that occur after a specified warm-up period. long-term calibration drift usually occurs because of the ageing of component parts.
E.g. - Drift may occur in thermocouples and resistance-thermometer elements because of contamination of the metal and changes in metallurgical or atomic structure. Drift occurs in orifice flow meters because of wear and erosion of the orifice plate.

Several kinds of drift may occur.

1. The whole instrument calibration may gradually shift by the same amount. This is some times called a zero drift and is usually due to some kind of simple effect, such as permanent set or slippage. In an indicating or recording instrument it is easily corrected by shifting the pen or pointer position.
2. A span drift involves a gradual change in which the calibration from zero upward changes a proportional amount. This may be caused by a gradual change in a spring gradient.
3. A third kind of drift occurs when only one portion of a calibration changes. This may take place at the high end of an instrument scale when some portion of the instrument is at high stress.

Under laboratory conditions, drift of an element is usually determined in one of the following two ways:

1. By maintaining exact operating and load conditions and monitoring output variations for a fixed input signal, as a function of time. This is called point drift.
2. By maintaining input signal, operating conditions, a load approximately constant, and by comparing calibration curves at the beginning and at specified intervals of time. This is called calibration drift.

Drift for a measuring device can either be systematic (i.e. approximately predictable in direction and magnitude as a function of time), random (non predict able), or some combination of the two.

* For most devices, drift is measured and specified as a percentage of output span.

Range & span:

In an indicating or recording instrument the value of the measured quantity is indicated on a scale or a chart by a pointer or some similar means. Suppose that the highest point of calibration is b units and the lowest point a units and that the calibration is continuous between these two points. Then the in instrument range is from a to b. The instrument span is given by, Span = b- a

E.g. - For a pyrometer calibrated 0 to 1000° the range is 0 to 1000 and the span is 1000°. For a thermometer calibrated 200 to 350° the range is 200 to 350°, and the span is 150°.

Sensitivity can be defined as the ratio of a change in output to the change in input which causes it, at steady-state conditions. The ratio must be expressed in the units of measurement of output and input.

Dead zone is the largest range of values of a measured variable to which the instrument does not respond. This is some times called dead spot and hysteresis. Dead zone usually occurs with friction in an indicating or recording instrument, particularly the latter. It may also be found in certain kinds of mechanisms that can only indicate small and discrete changes in value of a measured variable.

Dynamic Characteristics:

Instruments rarely respond instantaneously to changes in the measured variable. Instead, they exhibit a characteristic slow ness or sluggishness due to such things as mass, thermal capacitance , fluid capacitance, or electric capacitance. Furthermore, pure delay in time is often encountered where the instrument "waits" for some reactions to take place. Industrial instruments, such as are discussed here, are nearly always used for measuring quantities that fluctuate with time. Dynamic and transient behaviour of the instrument is therefore as important as and often more important than static behaviour.

The dynamic behaviour of an instrument is determined by subjecting its primary element to some known and predetermined variation in measured quantity. The three most common variations are:

1. Step change, in which the primary element is subjected to an instantaneous and finite change in measured variable.
2. Linear change, in which the primary element is "following" a measured variable, changing linearly with time.
3. Sinusoidal change, in which the primary element follows a measured variable, the magnitude of which changes in accordance with a sinusoidal function of constant amplitude. The physical conditions of imposing these changes on an instrument may cause great difficulty.

The dynamic characteristics are:

Speed of response......................... Lag
Fidelity...........................Dynamic error

The qualities on the left are desirable and those on the right are undesirable.

Speed of response is the rapidity with which an instrument responds to changes in the measured quantity.
Measuring lag is a retardation or delay in the response of an instrument to changes in the measured quantity.

Fidelity is the degree to which an instrument indicates the changes in measured variable without dynamic error.
Dynamic error is the difference between the true value of a quantity changing with time and the value indicated by the instrument if no static error is assumed.

Standard of measurement:

A standard of measurement is a physical representation of a unit of measurement. The term standard is applied to a piece of equipment having a known measure of physical quantity. It is used for obtaining the values of the physical properties of other equipment by comparison methods. A unit is realised by reference to an arbitrary material standard or to natural phenomena including physical and atomic constants.
For example, the fundamental unit of mass in the SI system is the kilogram, defined as the mass of a cubic decimetre of water at its temperature of maximum density of 4°C.
This unit of mass is represented by a material standard: the mass of the International Prototype Kilogram, consisting of a platinum iridium alloy cylinder. This cylinder is preserved at the International Bureau of Weights and Measures at Sèvres, near Paris, and is the material representation of the kilogram. Similar standards have been developed for other units of measurement, including standards for the fundamental units as well as for some of the
derived mechanical and electrical units.

Therefore, standards are always arbitrary, whether they be the length of the 'foot' of a long-dead king, or the duration of a 'second'. Each standard is an invention of human beings to facilitate or make possible the measurements process. One of the most important responsibilities of a government is to set and maintain standards, thereby providing a commonly accepted basis for comparison.

Hierarchy of Standards:

Just as there are fundamental and derived units of measurements, there is a hierarchy of standards of measurements, classified by their function and application in the following categories:

1. International standards
2. Primary standards
3. Secondary standards
4. Working standards

The International standards represent certain units of measurement which are closest to the possible accuracy attainable with present-day technological and scientific methods. They are defined on the basis of international agreements. International standards are regularly evaluated and checked against absolute measurements in terms of the fundamental units. International standards are maintained at the International Bureau of Weights and Measures and are not available to the ordinary user of measuring instruments for purposes of comparison or calibration.

The primary standards(or basis standards) represent the fundamental units and some of the derived mechanical and electrical units. One of the main functions of primary standards is the verification and calibration of secondary standards. They are maintained by national standard laboratories or stored in a government vault in different parts of the world.

The secondary standards are the basic reference standards used in industrial measurement laboratories. These standards are maintained by the particular involved industry and are checked locally against other reference standards in the area. The industrial laboratories are entirely responsible for maintenance and calibration of the secondary standards. Secondary standards are normally sent to the national standards laboratories on a regular basis for their calibration and com parison against primary standards after which they are sent back to the industrial user with a certification of their measured value in terms of the primary standard.

The working standards are the principal tools of a measurement laboratory. They are used to check and calibrate general laboratory instruments for accuracy and performance or to perform comparison measurements in industrial application. The working standards may be less accurate and less expensive.

PRESSURE MEASUREMENT

Nearly all industrial processes use liquids, gases or both. Controlling these processes requires the measurement and control of liquid and gas pressures. Thus, pressure measurement is one of the most important of all process measurements.

Pressure is defined as the amount of force applied to a surface or distributed over it and is measured as force per unit area.

The force used to calculate the pressure must act at a right angle to the surface. If force acts at a slant, then only that part of it which acts at right angles is used to calculate the pressure. The part of the force which acts parallel to the surface does not contribute to pressure. Pressure instruments usually refer to those that are used for the measurement of the pressure exerted by a fluid. The essentials of pressure measurement are encompassed in the above definitions and the following observations:

(i) Pressure is strongly influenced by position within a static fluid but, at a given position, it is independent of direction.

(ii) Pressure is unaffected by the shape of the confining boundaries.

Unit of Pressure:

Pressure may be measured in either British (fps), or Metric (also called SI) units. In British units, pressure is measured in pounds (of force) per square inch (of area). In Metric (or SI) units, it is measured in newtons (of force) per square metre (of area).

- In engineering, it is most commonly expressed in terms of pounds per square inch (psi). The atmospheric pressure is approximately 14.696 psi (or 1 kg/cm^3).

Pressure can also be measured in terms of liquid column, in which the atmospheric pressure will be equal to 760 mm (or 29.92 inches) of mercury.

Following relations are commonly used for evaluating high and low pressure:

(a) High Pressure

1 newton per square metre (1 N/m^2)= One pascal (1 Pa)

1 atmospheric pressure (1 atm) = 14.696 psi = 101.325 kPa

(a) Low Pressure

1 millibar = 100 $dyne/cm^2$= 14.5×10^{-3} psi

1 micron = 10^{-6} m Hg = 19.34×10^{-6} psi

1 torr = 1 mm Hg = 1000 microns = 19.34×10^{-3} psi

Different Types of Pressure:

When pressure is measured, it is usually desired to read it in terms of either gauge pressure, absolute pressure or vacuum (or differential) pressure.

Different types of pressures are discussed below:

A. Gauge Pressure

- Most liquid pressure gauges use atmospheric pressure(14.7 psi) as a zero point, i.e. they indicate a pressure of zero psi at the surface of a liquid even though the pressure is actually 14.7 psi (1 kg/cm^3).
- A gauge that indicates zero at atmospheric pressure measures the difference between actual and atmospheric pressure. This difference is called "gauge pressure". It is abbreviated as psig (pounds per square inch gauge).

B. Absolute Pressure

- Absolute pressure is actual total pressure (including atmospheric pressure) acting on a surface. It is abbreviated as psia (pounds per square inch absolute).

C. Vacuum or Differential Pressure

- Gauges that indicate gauge pressure may be designed to indicate pressure below zero. Such a gauge is called a "vacuum gauge". Gauges that indicate absolute pressure cannot indicate pressures below Zero, because zero is a perfect vacuum.
- In a differential pressure measurement, the gauge pressure is the difference between the absolute pressure of the fluid and the atmospheric pressure.

D. Static Pressure and Velocity Pressure

- When the fluid is in equilibrium, the pressure at a particular point is identical in all directions and independent of orientation. This is called "static pressure".
- Velocity pressure is the difference between the total pressure and static pressure.

Velocity pressure = Total pressure - Static pressure

Methods of pressure measurement:

Most pressure instruments measure a difference between two pressures, one usually being that of the atmosphere. The different methods of pressure measurement are listed below.

(i) Manometer method.
(ii) Elastic pressure transducers.
(iii) Pressure measurement by measuring vacuum.
(iv) Pressure measurement by balancing the force produced on a known area by a measured force.
(v) Electrical pressure transducers.

MANOMETERS:

The manometer is the simplest measuring instrument used for gauge pressure (low-range pressure) measurements, by balancing the pressure against the weight of a column of liquid. The action of all manometers depends on the effect of pressure exerted by a fluid at a depth. The different types of manometers are discussed below.

U-tube Manometer:

The U-tube is the simplest form of manometer and is used for experimental work in laboratories. By suitable choice of liquids, a wide range of pressure can be measured.

Construction:

It consists of a transparent (glass) tube constructed in the form of an elongated U and is partially filled with a liquid, most commonly water or mercury. Water and mercury are used because their specific weights for various temperatures are known exactly and they do not stick to the tube. One end of the tube is connected to one pressure tap and the other end is connected to the other pressure tap, or it may be left open to the atmosphere. The U-tube manometer is shown in the

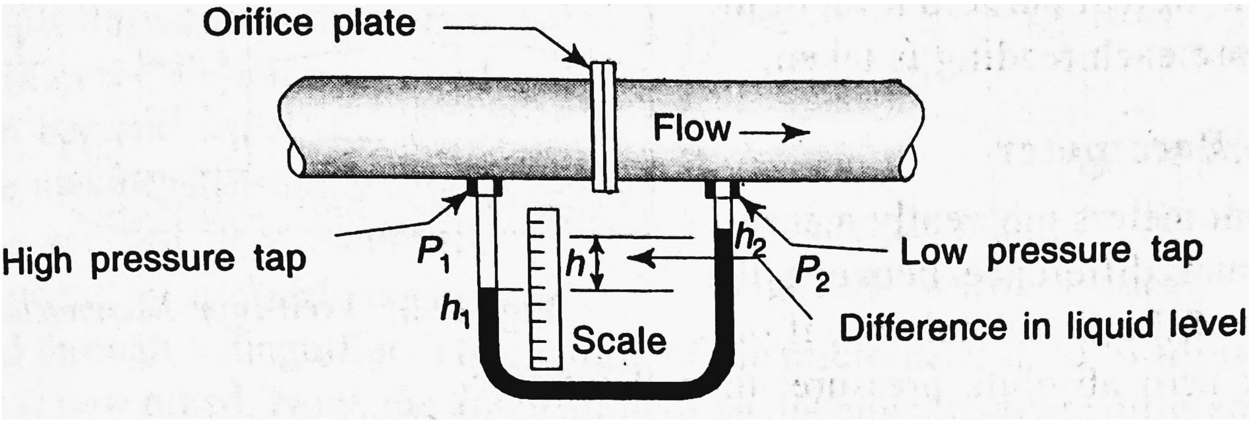


figure.

Working When there is a pressure difference between the two ends of the tube, the liquid level goes down on one side of the tube and up on the other side. The difference in liquid levels from one side to the other indicates the difference in pressure. From the above figure, the differential pressure (P_1 - P_2) is obtained by the relation:

$(P_1 - P_2) = \rho g(h_1 - h_2)$

where ρ= density of fluid in U-tube

P_1 = density of fluid whose pressure is being measured

h= (h_1-h_2), difference in fluid levels of the manometric fluid

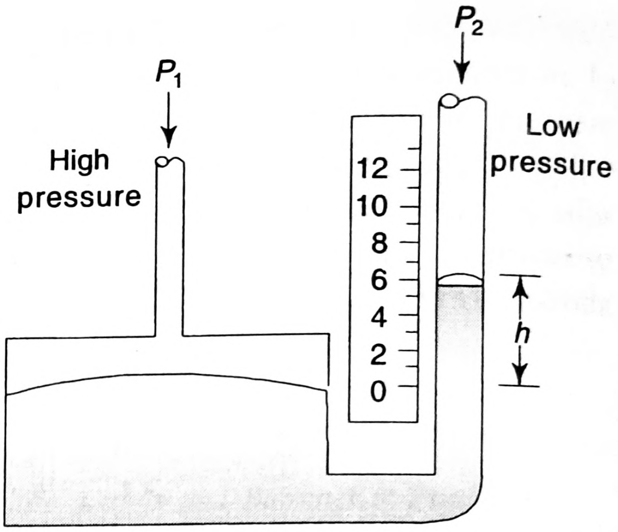
g= acceleration due to gravity

★When a manometer is used to measure low pressure then water is used as the liquid, and when it is used to measure high pressure then mercury is used as the liquid. Mercury is almost 14 times as heavy as water. Therefore, the difference in levels in a mercury-filled manometer is about 1/14 of what it would be if water were in the tube.

Limitations:

In the U-tube manometer, the application of pressure causes the liquid in one leg to go down while that in the other leg goes up, so there is no fixed reference. This tends to make the measurement of the height more difficult than it would be if one surface could be maintained at some fixed level.

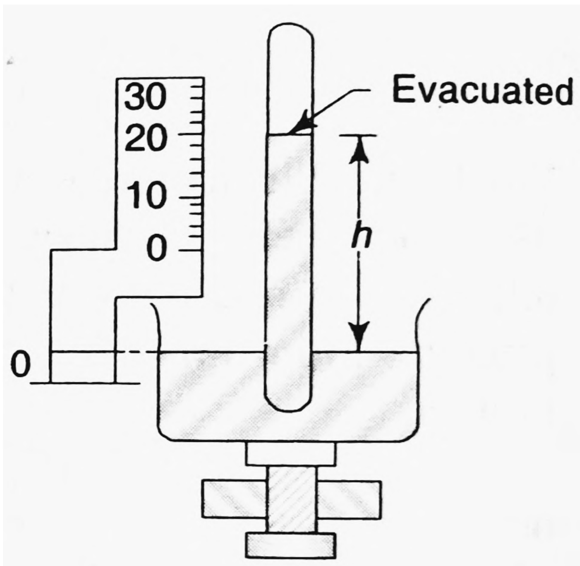
Well-type Manometer:



The well-type manometer is widely used because of convenience; the reading of only a single leg is required in it. It consists of a very large-diameter vessel (well) connected on one side to a very small-sized tube. Thus the zero level moves very little when pressure is applied. Even this small error is compensated by suitably distorting the length of scale. However, such an arrangement is sensitive to non-uniformity of the tube cross-sectional area and is thus considered some what less accurate. Figure shows a well-type manometer.

In a single-leg instrument, high accuracy is achieved by setting the zero level of the well at the zero level of the scale before each reading is taken.

Barometer:



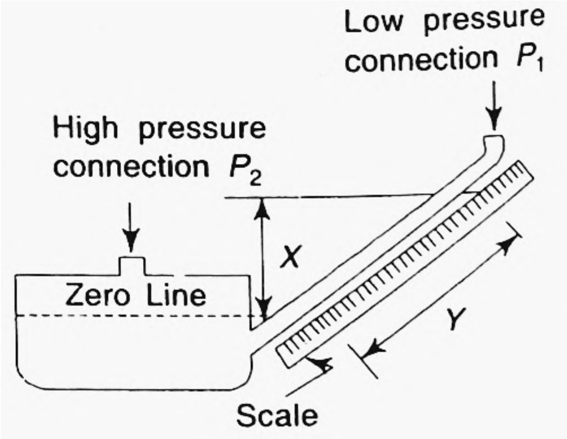
Since manometers inherently measure the pressure difference between the two ends of the liquid column, if one end is at zero absolute pressure, then the difference in height of the liquid from the zero reference indicates the absolute pressure. This is the principle of the barometer, as shown in figure. A barometer is a well-type absolute pressure gauge whose pressure range is from zero absolute to atmospheric pressure. Its readings are generally in millimeters of mercury (mm Hg). With a barometer, high vacuum is not measured.

The pressure in the evacuated portion of the barometer is not really absolute zero but rather the vapour pressure of the filling fluid, mercury, at ambient temperature.

Inclined Manometer:

The inclined tube manometer or slant manometer is an enlarged leg manometer with its measuring leg inclined to the vertical axis by some angle. The angle of inclination is of the order of 10°. The inclination is done to expand the scale and thereby to increase the sensitivity even more.

The inclined manometer is used to mea sure very small pressure differences (in hundredth of an inch of water). The distance y that the liquid moves through the tube is greater than the distance x that the liquid rises.

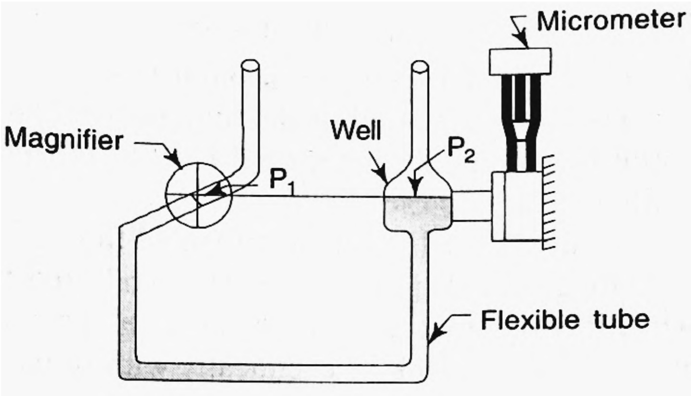


Micromanometer:

A micromanometer is used for the accurate measurement of extremely small pressure differences.

Construction:

A micromanometer consists of a well connected to a flexible tube whose one end is inclined, as shown in the figure. A magnifier is attached to the inclined portion of the tube for observation of the fluid level. A micrometer is connected to the well for observation of reading.



Working:

The micromanometer is initially adjusted so that when pressure in the well and inclined portion become equal, i.e. (P_1 = P_2), the meniscus in the inclined tube is located at a reference point given by a fixed hairline viewed through a magnifier. The reading of the micrometer used to adjust the well height is now noted. Now, the application of an unknown pressure difference causes the meniscus to move off the hairline which can be restored to its initial position by raising or lowering the well with the micrometer. The difference between the initial and final micrometer readings gives the change in height and thus the pressure.

Errors in Manometers:

(i) Effect of Temperature

If there is any variation in temperature, there will be a variation in the reading owing to the reduction of the density of the fluid in the gauge as its temperature rises and the fluid expands.

(b) Capillary Effect:

To reduce the capillary effect itself, the use of large-bore tubes (over 10 mm diameter) is most effective. However, when the same fluid is applied to both legs of the manometer, the capillary effect is often neglected.

(c) Effect of Variable Meniscus:

The crescent-shaped top surface of a liquid column is called the 'meniscus'. The high surface tension of mercury makes the meniscus slightly convex. It is higher in the centre, with the edges depressed. The mercury does not stick to or wet the tube walls. The low surface tension of water makes its meniscus slightly concave. It is lower in the middle, with the edges turned up as it sticks to and wets the tube walls. We should always read the indication of the centre of the meniscus.

Fluids for Manometers:

- The most common fluids for manometers are water, red oil and mercury. Water is the best fluid to use if air is the fluid to be measured and the glass length is within reasonable limits.
- To minimize the effects of freezing and evaporation, kerosene or antifreeze may be used.
- Mercury is used when the measured fluid mixes with the manometer fluid or a very long tube length is necessary.
- Red oil is used as the indicating fluid when it is required to read a manometer from a distant place. It is easier to read and it does not combine chemically with some fluids in a dry system.

Advantages of manometers:

1. They are simple and time proven.
2. They have high accuracy and sensitivity.
3. Wide range of filling fluids of varying specific gravities are available in manometers.
4. Its cost is reasonable.
5. They are suitable for low pressure and low differential pressure applications.

Disadvantages of manometers:

1. They are large and bulky.

2. They need levelling.
3. They are not portable.
4. In a manometer, the measured fluid must be compatible.
5. There is no over-range protection in manometer.
6. Condensation may present problems in manometer.

ELASTIC PRESSURE TRANSDUCERS:

This type of pressure transducers use elastic primary sensing elements such as the Bourdon tube, bellows and diaphragm.

Bourdon Tubes:

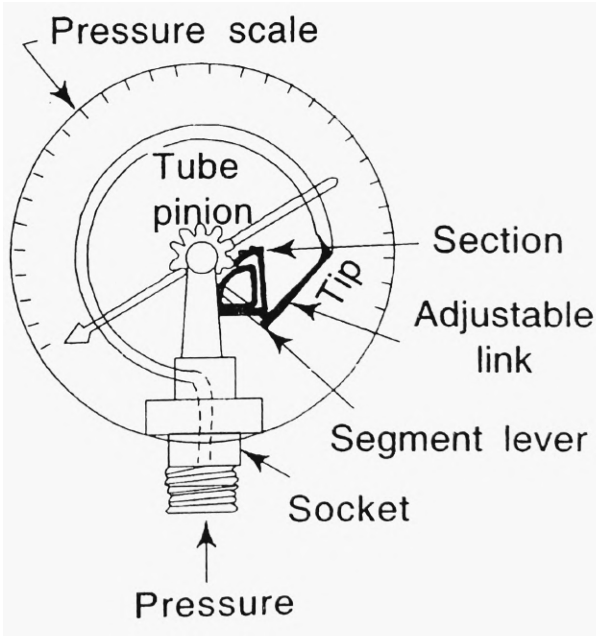
Bourdon tubes are designed to follow the physical law that, within the elastic limit, stress is proportional to strain (Hooke's Law), that is deflection is proportional to the pressure applied.

Types of bourbon tube:
1. C-type bourdon tube
2. Spiral type bourdon tube
3. Helical type bourdon tube

C-type Bourdon Tube Pressure Gauge:

The Bourdon tube is the most frequently used pressure gauge throughout the oil gas industry because of its simplicity and rugged construction. It covers ranges from 0-15 psig to 0-100,000 psig, as well as vacuum from 0 to 30 inches of mercury.

Construction:



- A C-type Bourdon tube consists of a long thin-walled cylinder of non-circular cross-section, sealed at one end.
- It is made from materials such as phosphor bronze, steel and beryllium copper.
- The sealed end is attached to a gear mechanism through adjustable link which operates the pointer.
- The other end of the tube is fixed and is open for the application of the pressure which is to be measured.
- The partially flattened metal tube is usually in a 250^0 arc.
- The tube is soldered or welded to a socket at the base, through which pressure connection is made.

Working:

- As the fluid under pressure enters the Bourdon tube, it tries to change the section of the tube from oval to circular, and this tends to straighten out the tube.
- The tip of the Bourdon tube is connected to a segmental lever through an adjustable length link. The lever length also may be adjustable.
- The segmental lever end on the segment side is provided with a suitable pinion mounted on a spindle.
- The segmental lever is suitably pivoted and the spindle holds the pointer.
- The resulting movement of the free end of the tube causes the pointer to move over the scale.

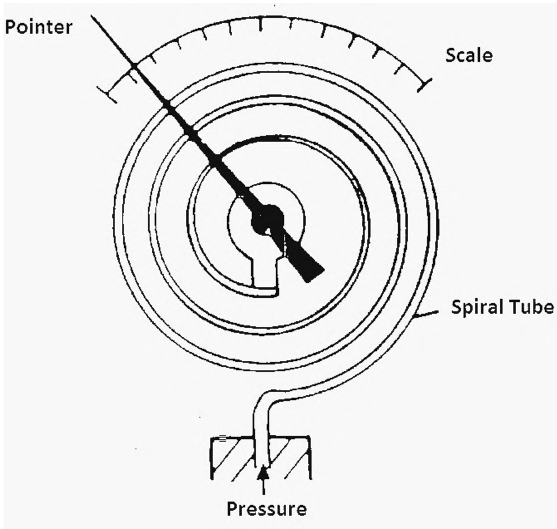
★For adequate reliability, the materials for Bourdon tubes must have good elastic or spring characteristics.

Adjustments:

Basically there are two types of adjustments of the Bourdon tube:

(a) Multiplication Adjustment:

Because of compound stresses developed in the Bourdon tube, actual travel is non-linear in nature. However, for a small travel of the tip this can be considered to be linear and parallel to the axis of the link. The small linear tip movement is matched with a rotational pointer movement. This is known as 'multiplication' and can be adjusted by adjusting the length of the lever. A shorter lever gives larger rotation for the same amount of tip travel.



(b) Angularity:

When the approximately linear motion of the tip is converted to a circular motion with the link lever and pinion attachment, a one to one correspondence between them may not occur and a distortion results. This is known as "angularity". Angularity can be minimized by adjusting the length of the link.

Advantages of Bourdon tubes:

(i) Their cost is low.
(ii) They have simple construction.
(iii) They have been time-tested in applications.
(iv) These tubes are available in a wide variety of ranges, including very high ranges.
(v) They are adaptable to transducer designs for electronic instruments.
(vi) They allow high accuracy, especially in relation to cost.

Disadvantages of Bourdon tubes:

(i) They have low spring gradient at lower pressures.(i.e. below 50 psig).
(ii) They are susceptible to shock and vibration.
(iii) They are susceptible to hysteresis(dead zone).

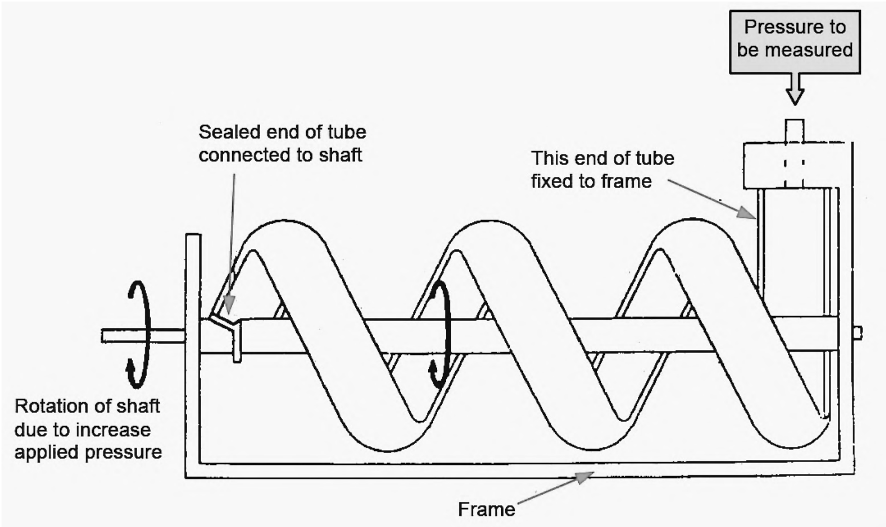
Spiral type Bourdon Tube:

- Spiral Bourdon Tube is made by winding a partially flattened metal tube into a spiral having several turns instead of a single C-bend arc.

- The tip movement of the spiral equals the sum of the tip movements of all its individual C-bend arcs.
- Therefore it produces a greater tip movement with a C-bend bourdon tube.
- It is mainly used in low- pressure application.

Helical type bourdon tube:

- In this case the bourdon tube is wound in the form of helix.
- It allows the tip movement to be converted to a circular motion.
- By installing a central shaft inside the helix along its axis and connecting it to the tip, the tip movement become a circular motion of the shaft.



Advantages of the Spiral and Helical Tubes over the C-Type Bourdon Tube:

1. Both the spiral and helical tubes are more sensitive than the C-Type tube. This means that for a given applied pressure, a spiral or helical tube will show more movement than an equivalent C-Type tube, thus avoiding the need for a magnifying linkage.
2. Spiral and helical tubes can be manufactured in very much smaller sizes than the equivalent C-Type tubes. Hence, they can be fitted into smaller spaces, such as inside recorders or controller cases where a C-Type would be unsuitable because of the size.

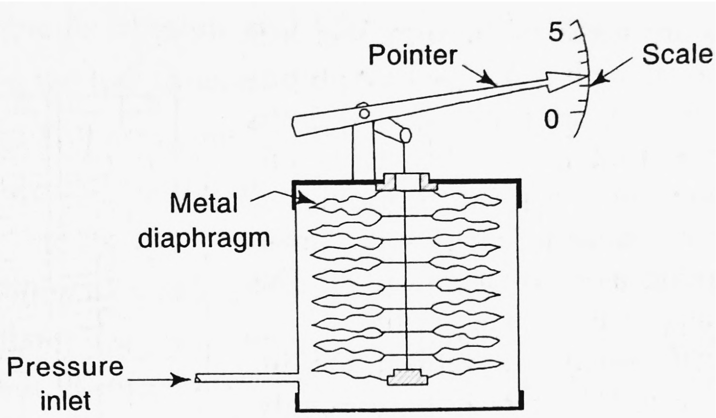
Diaphragm pressure transducers:

- Diaphragms are widely used for pressure (gauge pressure) particularly in very low range. They can detect a pressure differential even in the range of 0 to 4 mm.
- The diaphragm can be in the form of flat, corrugated or dished plates and the choice depends on the strength and amount of deflection desired.

- In high precision instruments the diaphragms are generally used in a pair, back-to-back, to form an elastic capsule.

Metallic Diaphragm Gauge:

- It consists of a thin flexible diaphragm made of materials such as brass or bronze.
- A pointer is attached to the diaphragm.
- The force of pressure against the effective area of the diaphragm causes a deflection of the diaphragm.
- In some cases the deflection of the diaphragm is opposed by the spring qualities of the diaphragm itself and in other cases a spring is added to limit the deflection of the diaphragm.
- The motion of the diaphragm operates an indicating or a recording type of instrument.

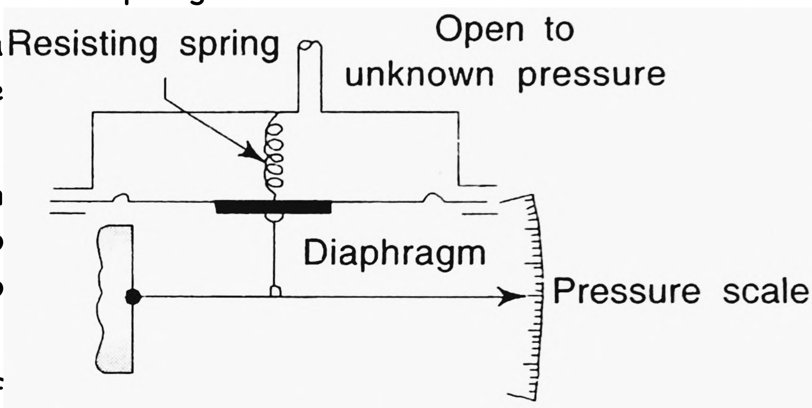


This type of gauge is capable of working in any position and is portable, and therefore well adapted for use or for installation in moving equipments such as aircrafts.

Slack Diaphragm Gauge(non-metallic diaphragm gauge):

It is more difficult to measure pressure below the atmospheric pressure because the changes are small. The full range from atmospheric pressure to a perfect vacuum is
measured with a slight modification of the diaphragm.

- A diaphragm with a large area produces a large change in force from a small change in pressure.
- Similarly, making the diaphragm slack rather than tight allows it to move a large distance in response to a small pressure change.
- A slack diaphragm can be made of rubber or other flexible materials.



- A slack diaphragm gauge with a weak spring and a large area can be used over pressure ranges as low as 0.01−0.40 mm Hg (torr).
- It is possible to achieve accuracies of 1-2%.

Advantages of diaphragm elements:

(i) Their cost is moderate.
(ii) They possess high over-range characteristics.
(iii) They are adaptable to absolute and differential pressure measurement.
(iv) They have good linearity.
(v) They are available in several materials for good corrosion resistance.
(vi) They are small in size.
(vii) They are adaptable to slurry services. Disadvantages Following are the

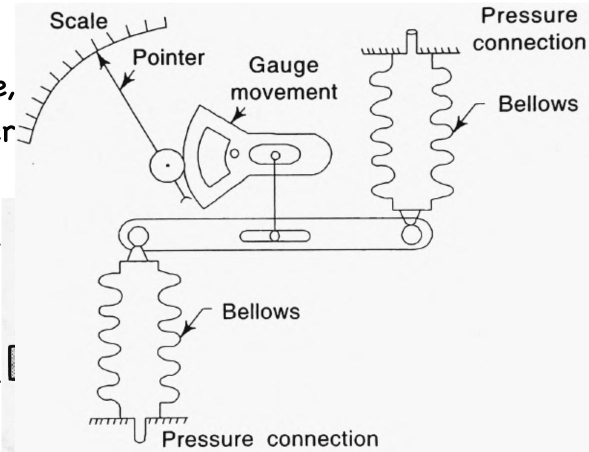
Disadvantages of diaphragm elements:

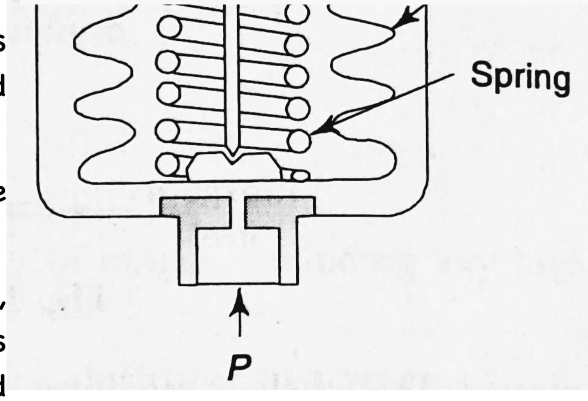
(i) They lack good vibration and shock resistance.
(ii) They are difficult to repair.
(iii) They are limited to relatively low pressures.

Bellows:

- The bellows-type gauges are used for the measurement of absolute pressure (normal as well as low pressure).
- It is somewhat more sensitive than Bourdon tube gauge. Spring-opposed bellow elements are very sensitive and are quite useful because of the considerable amount of movement for a given change in pressure.
- It is generally used for the range down to 155.1 mm Hg (3 psi).
- It may be used for even lower pressures upto 40 mm Hg by making the bellows large enough.

Construction and working:





- The bellows are made of an alloy which is ductile, has high strength and retains its properties over long use, i.e. has very little hysteresis effect.
- It is made of a metallic bellows enclosed in a shell which is connected to a pressure source.
- Phosphor bronze is the commonly used material for bellows and the springs are of carefully heat treated metal.
- Pressure acting on the outside of the bellows compresses the bellows and moves its free end against the opposing force of the spring.
- A rod resting on the bellows transmits the motion to a pointer.
- They are used in two forms. In one arrangement, pressure is applied to one side of the bellows and the resulting deflection is counter balanced by a spring.

- In another differential arrangement, the differential pressure is also indicated.
- In this device, one pressure is applied to the inside of one sealed bellow while the other pressure is applied to the inside of another sealed bellow.
- By suitable linkage and calibration of the scale, the pressure difference is indicated by a pointer on the scale.

For larger static pressure (upto 2000 psig) and larger differential pressures(upto 50 psi), bellows of differential gauges are extensively used.

Advantages of bellows:

(i) Its cost is moderate.
(ii) It is able to deliver high force.
(iii) It is adaptable for absolute and differential pressure.
(iv) It is good in the low-to-moderate pressure range.

Disadvantages of bellows:

(i) It needs ambient temperature compensation.
(ii) It is unsuitable for high pressure.
(iii) The availability of metals and work-hardening of some of them is limited.

(iv) It is unsuitable for zero and the stiffness (Therefore, it is used only in conjunction with (in parallel with) a reliable spring of appreciably higher stiffness for accurate characterization.

MEASUREMENT OF VACUUM:

Vacuum pressure are those which are below atmospheric.

There is no single transducer available which covers the full range.

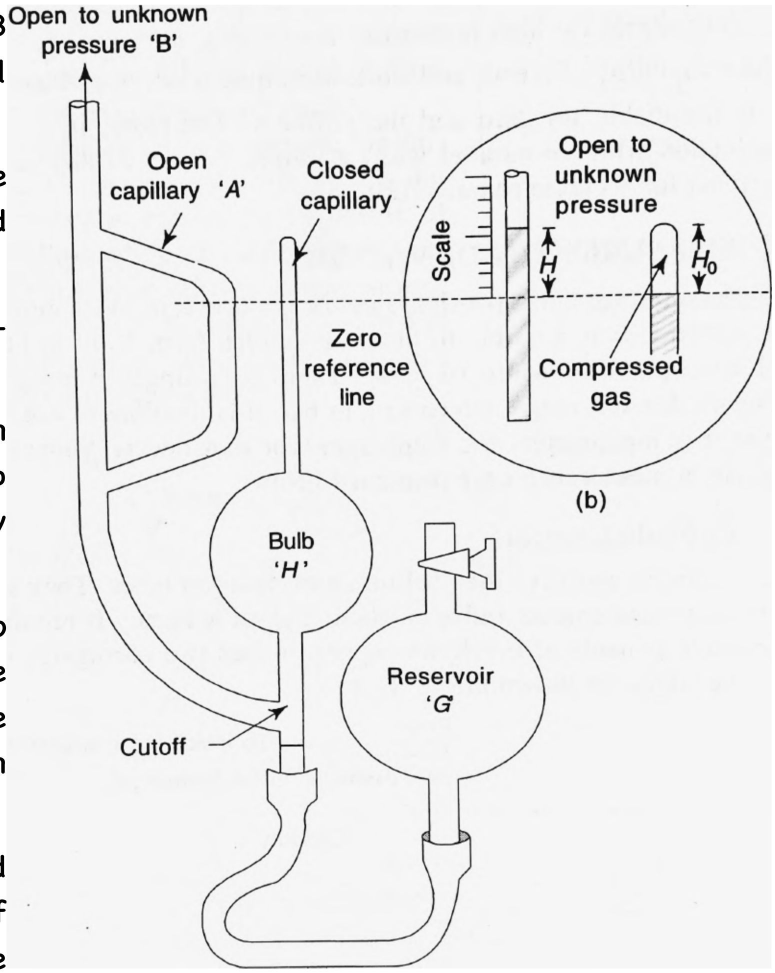
Down to 1 m bar, it is possible to use some of the techniques, e.g. manometers and diaphragm-type transducers.

McLeod Gauge:

- The McLeod gauge is used for measuring very low pressure down to one hundred-thousandth of an inch of mercury (or 10 m bar down to 10^{-3} m bar).
- The McLeod gauge amplifies pressure by compressing a gas into a small volume. The pressure of the compressed gas is then measured with a mercury manometer.

Construction and Working:

- A McLeod gauge is connected to the unknown gas whose pressure measurement is required.
- The gas enters the gauge through B and fills the tubes down to the level of the mercury reservoir.
- The pressure is equal throughout the tubes and the bulb mercury is pumped up from the reservoir G.
- As the mercury, rises above the cut-off, it traps gas inside the bulb.
- The mercury is then pumped higher in the gauge until all the gas in the bulb is compressed into the closed capillary tube.
- The operator allows the mercury to rise until it reaches a zero reference line on the closed capillary tube. The mercury rises faster in the open capillary tube A.
- The compression of gas in the closed capillary tube makes the pressure of the trapped gas higher than the measured pressure.



- This pressure difference causes a difference in the mercury levels in the two tubes. The difference in height is used to calculate the pressure.
- The volume of the bulb can be made quite large and the zero reference line on the closed capillary tube can be placed near the top of the tube.Thus, a large volume of gas can be compressed into a very small volume.
- This compression multiplies the pressure many times.

The pressure can be calculated by using the following equation:

$P= KHH_0(1-KH)$

where, P = measured pressure

K = a constant, determined by the geometry of the gauge

H = difference in heights of the two mercury columns

H_0= height of the top of the closed capillary tube above the line marked on the tube.

★The McLeod gauge is a very accurate pressure-measuring device and often serves as a standard for calibrating other low-pressure gauges.

It can be designed to measure pressure as low as 0.05 microns (0.00005 torr).

Thermal-conductivity Gauge:

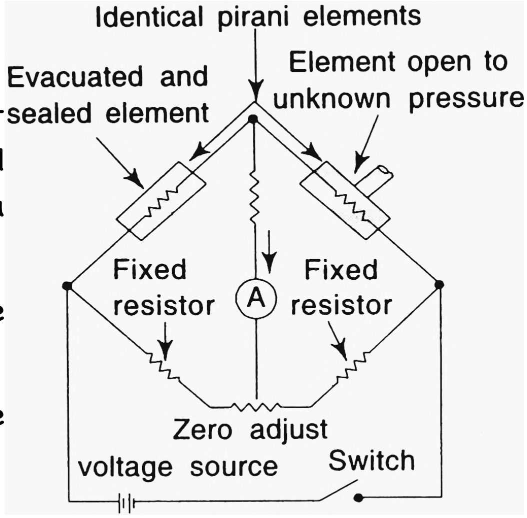
- Thermal-conductivity gauges measure pressure by measuring the changes in the ability of a gas to conduct heat.
- The conductivity of a gas does not change when the pressure changes, until the pressure drops below about one torr.
- As the pressure continues to drop, the conductivity of the gas decreases and the gas loses its ability to conduct heat. Thus, at low pressure, the conductivity of a gas has a direct relationship to its pressure.
- The relationship between changes in conductivity and changes in pressure work over a pressure range from about 10^{-4} torr upto about 10^{-2} torr.
- It is used for the absolute pressure (very low pressure) measurement.

Basic Operating Principles:

- A pressure gauge based on changes in thermal conductivity is made by enclosing a wire filament in a chamber connected to the pressure source.
- When voltage is applied to the filament, electricity flows, making it hot.
- The rising temperature increases the resistance of the filament. The filament then reaches an equilibrium temperature, after heat is removed by both radiation and conduction to the gas inside the chamber. Convection is so light that it can be ignored.
- The voltage applied to the filament is held constant and any change in pressure causes a change in conductivity of the gas surrounding the filament.
- The change in conductivity changes the equilibrium temperature of the filament, which in turn causes the change in the resistance. Therefore, the change in resistance is used to indicate the pressure change.
- An increase in conductivity (due to an increase in pressure) increases the flow of heat away from the filament, decreasing the temperature of the filaments. A decrease in conductivity (due to decrease in pressure) increases the filament temperature.

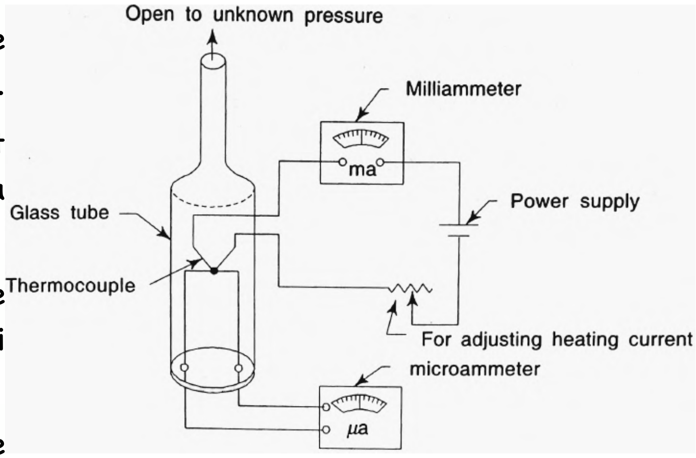
There are two types of thermal conductivity gauge generally used to measure pressure, which are discussed below:

Pirani Gauge:



- It consists of two wire filaments. One filament serves as a reference and is sealed in an evacuated glass, while the other filament is kept in a container connected to the source of pressure.
- These two filaments are connected in a bridge circuit.
- If the resistance of the two pirani elements are equal, no current flows through the ammeter.
- If the resistance of one pirani element changes, current will flow through the ammeter. This current flow indicates a change in pressure of the gas being measured.
- Pirani gauges are used for the pressure range about 10 to 1 torr.
- Gases significantly differ in heat conductivity. So, the gauge must be calibrated for the gas being measured. Users must follow the manufacturers calibrating procedure carefully for accurate pressure readings.

Thermocouple Gauge:



- The thermocouple gauge works on the same basic principle as the pirani gauge.
- The only difference is that the filament temperature is measured by a thermocouple.
- It requires careful calibration, but once calibrated it is as accurate as the pirani gauge.
- Thermocouple gauges are used for the pressure range from about 10 to 1 torr.

Disadvantages of Thermal Conductivity Gauges:

Both the pirani gauge and thermocouple gauge are easily damaged by organic vapours. The filaments get coated with a deposit of decomposed vapours, which alters the way the filament transfers heat.

Ionization Gauges:

An ionization gauge measures the density of a gas. The operating principle of the ionization gauge follows Boyle's law, i.e. at constant temperature, the ratio of pressure of two gases is equal to the ratio of their two densities, i.e.

$$\frac{P}{P_1} = \frac{\rho}{\rho_1}$$

where P = measured pressure

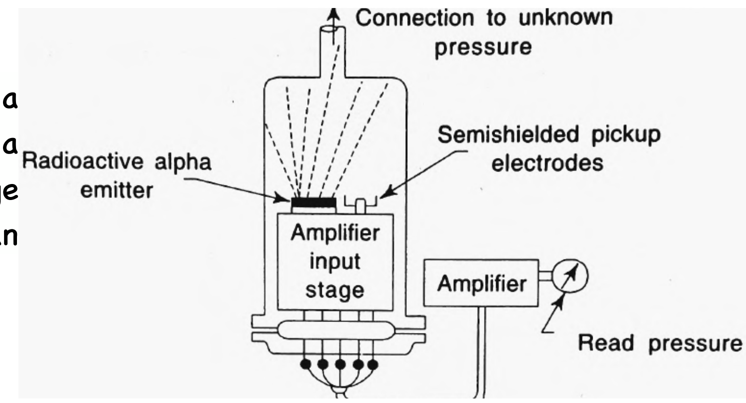
P_1 = initial pressure

ρ = measured density

ρ_1 = initial density

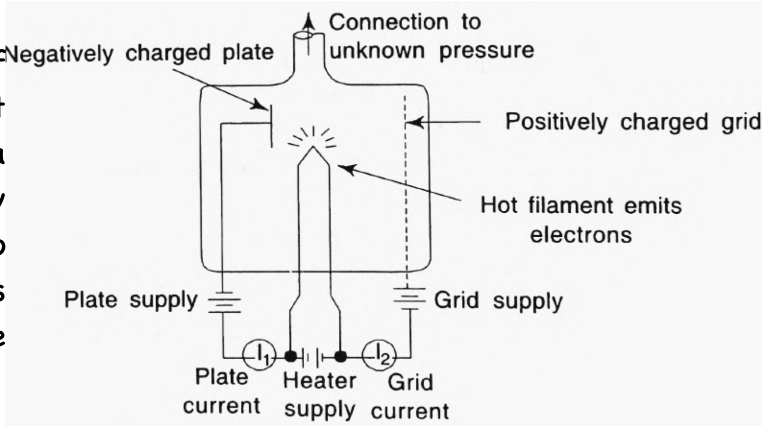
- This instrument consists of a chamber in which some of the gas molecules are changed to positively charged ions. These ions are attracted towards a negatively charged plate and deliver their charge, which creates an electric current.
- The current increases in proportion to the number of ions arriving in a given period of time.
- The number of ions increases in proportion to the density of the gas inside the chamber. Thus, the pressure is measured proportional to the relative density.
- There are two methods used to produce gas ions.

In the first method, a stream of alpha (α) particles are produced from a radioactive source. An ionization gauge using alpha radiation is known as an Alphatron gauge.



Alphatron ionization gauge

In the second method, a stream of electrons, produced from a red-hot filament, are attracted towards a positively charged grid of wire. Any positively charged ions produced due to collision of electrons with gas molecules are attracted to wards the negatively charged plate.



Hot filament ionization gauge