TOPICS :

1. Measurement of Non-Electrical quantity
2. Flow Measurement
3. Ultrasonic Flow Meters.
4. Hot Wire Anemometers.
5. Electromagnetic Flow meters.

Flow meter

- Accurate measurement of flow rate of liquids and gases is an essential requirement for maintaining the quality of industrial processes.
- In fact, most of the industrial control loops control the flow rates of incoming liquids or gases in order to achieve the control objective. As a result, accurate measurement of flow rate is very important. Needless to say that there could be diverse requirements of flow measurement, depending upon the situation.
- It could be volumetric or mass flow rate, the medium could be gas or liquid, the measurement could be intrusive or nonintrusive, and so on. As a result there are different types of flow measuring techniques that are used in industries. The common types of flowmeters that find industrial applications can be listed as below:

Types of Flow meters

(a) Obstruction type (differential pressure or variable area)

(b) Inferential (turbine type)

(c) Electromagnetic

(d) Positive displacement (integrating)

(e) fluid dynamic (vortex shedding)

(f) Anemometer

(g) ultrasonic and

(h) Mass flowmeter (Coriolis).

Obstruction type flowmeter

Obstruction or head type flowmeters are of two types:

(i)differential pressure type and

(ii)variable area type.

Orifice meter, Venturimeter, Pitot tube fall under the first category, while rotameter is of the second category.

In all the cases, an obstruction is created in the flow passage and the pressure drop across the obstruction is related with the flow rate.

- It is well known that flow can be of two types: viscous and turbulent. Whether a flow is viscous or turbulent can be decided by the Reynold’s number RD.
- If RD > 2000, the flow is turbulent. In the present case we will assume that the flow is turbulent, that is the normal case for practical situations.
- We consider the fluid flow through a closed channel of variable cross section, as shown in fig. 1. The channel is of varying cross section and we consider two cross sections of the channel, 1 and 2.
- Let the pressure, velocity, cross sectional area and height above the datum be expressed as p1, v1, A1 and z1 for section 1 and the corresponding values for section 2 be p2, v2, A2 and z2 respectively. We also assume that the fluid flowing is incompressible.

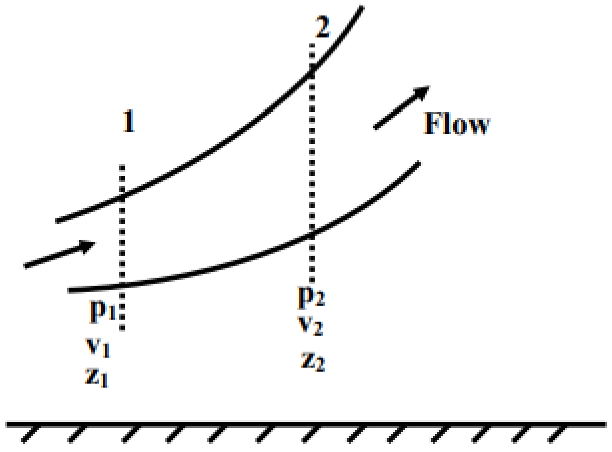


Fig. 1 Flow through a varying cross section

Now from Bernloulli's equation:

$$\frac{p_1}{\gamma}+\frac{v_1^2}{2g}+z_1=\frac{p_2}{\gamma}+\frac{v_2^2}{2g}+z_2 \qquad (1)$$

where γ is the specific weight of the fluid

If z1=z2, then

$$\frac{p_1}{\gamma}+\frac{v_1^2}{2g}=\frac{p_2}{\gamma}+\frac{v_2^2}{2g} \qquad (2)$$

If the fluid is incompressible, then $v_1 A_1 = v_2 A_2$. Therefore,

$$v_2^2 - v_1^2 = \frac{2g}{\gamma}(p_1 - p_2)$$

or,

$$v_2^2(1 - \frac{A_2^2}{A_1^2}) = \frac{2g}{\gamma}(p_1 - p_2)$$

Therefore,

$$v_2 = \frac{1}{\sqrt{(1 - \frac{A_2^2}{A_1^2})}}\sqrt{\frac{2g}{\gamma}(p_1 - p_2)} = \frac{1}{\sqrt{1 - \beta^4}}\sqrt{\frac{2g}{\gamma}(p_1 - p_2)}$$

Considering circular cross section, we define β as the ratio of the two diameters, i.e.

$$\beta = \frac{d_2}{d_1}, \text{ and so, } \frac{A_2}{A_1} = \beta^2 .$$

Therefore, the volumetric flow rate through the channel can be expressed as:

$$Q = v_2 A_2 = \frac{A_2}{\sqrt{1-\beta^4}} \sqrt{\frac{2g}{\gamma}(p_1 - p_2)} \qquad (3)$$

- From the above expression, we can infer that if there is an obstruction in the flow path that causes the variation of the cross sectional area inside the closed flow channel, there would be difference in static pressures at two points and by measuring the pressure difference, one can obtain the flow rate using eqn. However, this expression is valid for incompressible fluids (i.e. liquids) only and the relationship between the volumetric flow rate and pressure difference is nonlinear. A special signal conditioning circuit, called square rooting circuit is to be used for getting a linear relationship.

Orifice meter

- Depending on the type of obstruction, we can have different types of flow meters.
- Most common among them is the orifice type flowmeter, where an orifice plate is placed in the pipe line, as shown in fig.2. If d_1 and d_2 are the diameters of the pipe line and the orifice opening, then the flow rate can be obtained using eqn. (3) by measuring the pressure difference (p_1-p_2).

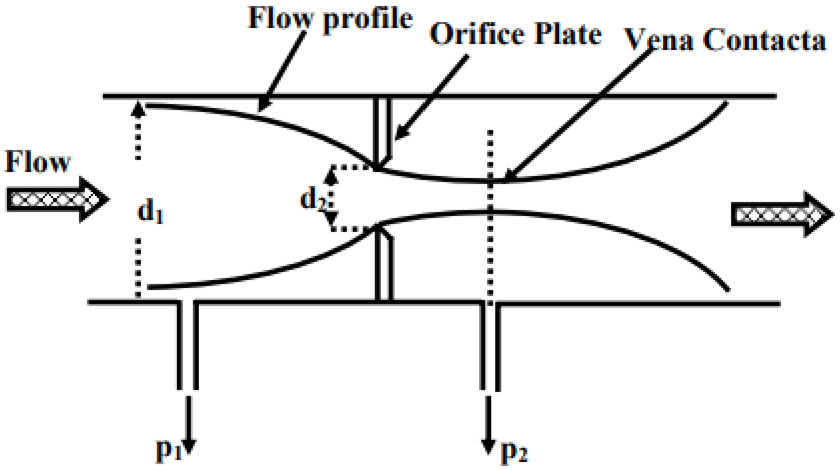


Fig. 2 Orifice type flowmeter

- The flow expression obtained from eqn.(3) is not an accurate expression in the actual case, and some correction factor, named as discharge co-efficient (Cd) has to be incorporated in (3), as

$$Q = v_2 A_2 = \frac{C_d A_2}{\sqrt{1-\beta^4}} \sqrt{\frac{2g}{\gamma}(p_1 - p_2)} \qquad (4)$$

Cd is defined as the ratio of the actual flow and the ideal flow and is always less than one. There are in fact two main reasons due to which the actual flow rate is less than the ideal one (obtained from eqn. (3)). The first is that the assumption of frictionless flow is not always valid. The amount of friction depends on the Reynold’s number (RD).

- The more important point is that, the minimum flow area is not the orifice area A2, but is somewhat less and it occurs at a distance from the orifice plate, known as the Vena Contracta, and we are taking a pressure tapping around that point in order to obtain the maximum pressure drop. As a result, the correction factor Cd <1 has to be incorporated
- In fact Cd depends on β, as well as on RD. But it has been observed that for $RD>10^4$, the flow is totally turbulent and Cd is independent on RD. In this range, the typical value of Cd for orifice plate varies between 0.6 and 0.7.

Orifice Plate, Venturimeter and Flow nozzle

- The major advantages of orifice plate are that it is low cost device, simple in construction and easy to install in the pipeline as shown in fig.3.
- The orifice plate is a circular plate with a hole in the center. Pressure tappings are normally taken distances D and 0.5D upstream and downstream the orifice respectively (D is the internal diameter of the pipe). But there are many more types of pressure tappings those are in use.

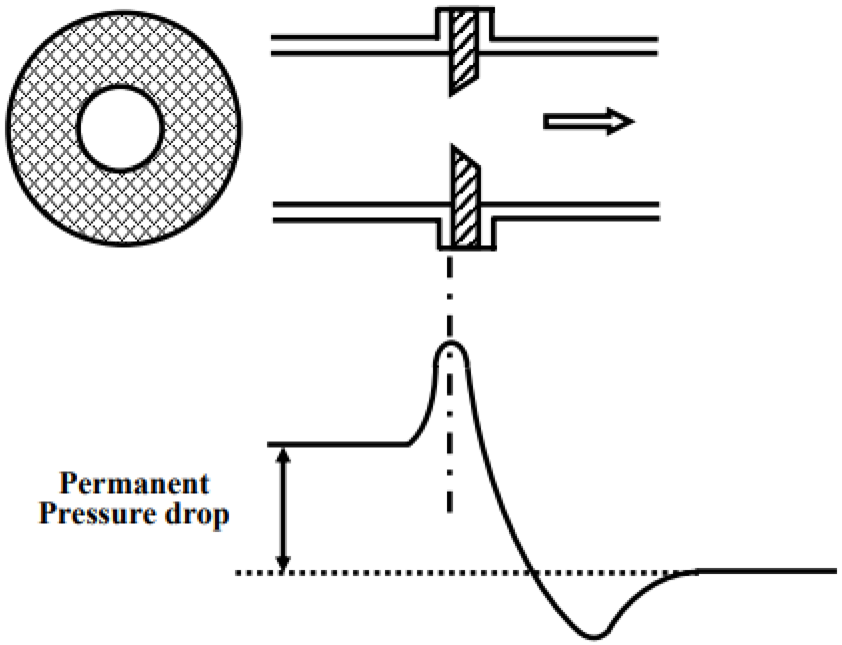


Fig. 3 Orifice plate and permanent pressure drop

- The major disadvantage of using orifice plate is the permanent pressure drop that is normally experienced in the orifice plate as shown in fig.3. The pressure drops significantly after the orifice and can be recovered only partially. The magnitude of the permanent pressure drop is around 40%, which is sometimes objectionable. It requires more pressure to pump the liquid. This problem can be overcome by improving the design of the restrictions. Venturimeters and flow nozzles are two such devices.

venturimeter

- The construction of a venturimeter is shown in fig.4. Here it is so designed that the change in the flow path is gradual.
- As a result, there is no permanent pressure drop in the flow path. The discharge coefficient Cd varies between 0.95 and 0.98. The construction also provides high mechanical strength for the meter.
- However, the major disadvantage is the high cost of the meter.

Flow nozzle

- Flow nozzle is a compromise between orifice plate and venturimeter. The typical construction is shown in fig. 5.

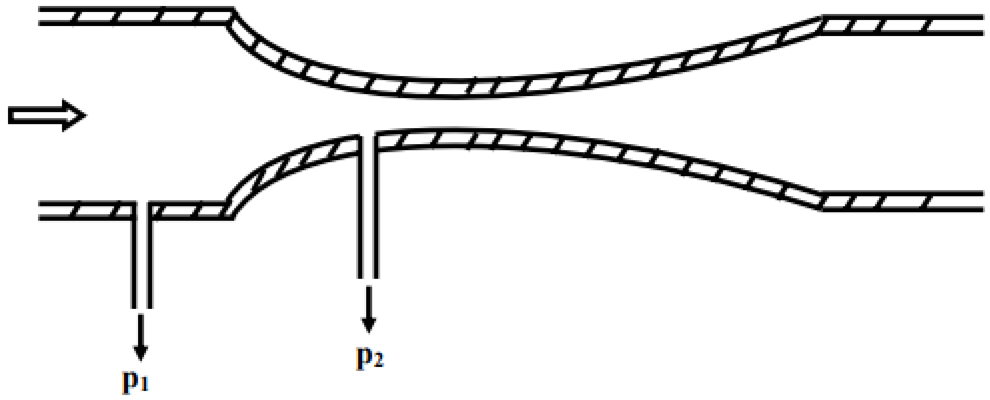


Fig. 4 Venturimeter

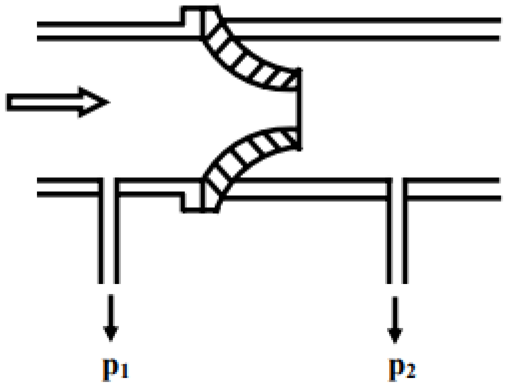


Fig. 5 Flow nozzle

- In general, few guidelines are to be followed for installation of obstruction type flowmeters.
- Most important among them is that, no other obstruction or bending of the pipe line is not allowed near the meter. Though this type of flowmeters are most popular in industries, their accuracy is low for low flow rates. As a result, they are not recommended for low flow rate measurement.

Flow measurement of compressible fluids

- Compressible fluids, i.e. gases, the flow rates are normally expressed in terms of mass flow rates. The same obstruction type flowmeters can be used, but an additional correction factor needs to be introduced to take in to account the compressibility of the gas used. The mass flow rate gases can be expressed as :

$$W = Y\left[\frac{C_d A_2}{\sqrt{1-\beta^4}}\sqrt{\frac{2g(p_1 - p_2)}{v_1}}\right] \qquad (5)$$

where,

v_1= specific volume of the gas in m^3/kgf

$$Y = 1-(0.41+0.35\beta^4)\frac{p_1 - p_2}{p_1}\frac{1}{K}$$

K= Specific heat ratio C_p/C_v of the gas at state 1

And all other terms are as defined in (1).

Pitot Tube

Pitot tube is widely used for velocity measurement in aircraft. Its basic principle can be understood from fig. 6(a). If a blunt object is placed in the flow channel, the velocity of fluid at the point just before it, will be zero. Then considering the fluid to be incompressible, from eqn. (2), we have,

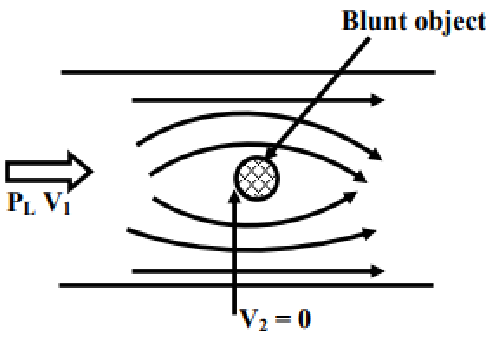


Fig. 6(a) Pitot Tube: Basic Principle

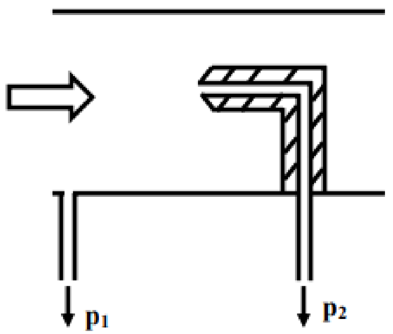


Fig. 6(b) Pitot Tube: Construction

$$\frac{p_1}{\gamma}+\frac{v_1^2}{2g}=\frac{p_2}{\gamma}+\frac{v_2^2}{2g}$$

Now $v_2 = 0$.

Therefore,

$$\frac{v_1^2}{2g}=\frac{p_2-p_1}{\gamma}$$

or,

$$v_1=\sqrt{\frac{2g}{\gamma}(p_2-p_1)} \qquad (6)$$

Rotameter

- The orificemeter, Venturimeter and flow nozzle work on the principle of constant area variable pressure drop. Here the area of obstruction is constant, and the pressure drop changes with flow rate.
- On the other hand Rotameter works as a constant pressure drop variable area meter. It can be only be used in a vertical pipeline. Its accuracy is also less (2%) compared to other types of flow meters.
- But the major advantages of rotameter are, it is simple in construction, ready to install and the flow rate can be directly seen on a calibrated scale, without the help of any other device, e.g. differential pressure sensor etc. Moreover, it is useful for a wide range of variation of flow rates (10:1).

- The basic construction of a rotameter is shown in fig. 7. It consists of a vertical pipe, tapered downward. The flow passes from the bottom to the top. There is cylindrical type metallic float inside the tube. The fluid flows upward through the gap between the tube and the float. As the float moves up or down there is a change in the gap, as a result changing the area of the orifice. In fact, the float settles down at a position, where the pressure drop across the orifice will create an upward thrust that will balance the downward force due to the gravity. The position of the float is calibrated with the flow rate.

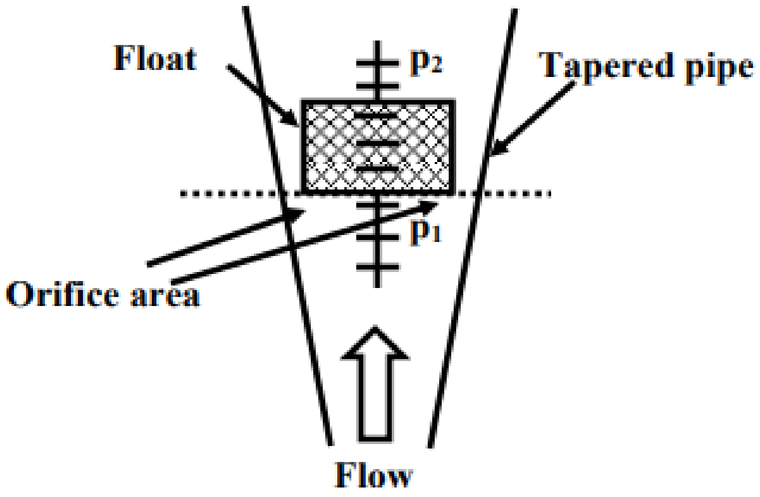


Fig. 7 Basic construction of a rotameter.

Let us consider,

γ_1 = Specific weight of the float

γ_2 = specific weight of the fluid

v_f = volume of the float

A_f = Area of the float.

A_t = Area of the tube at equilibrium (corresponding to the dotted line)

From equation (4), for incompressible fluid, we have, for the orifice,

$$Q = \frac{C_d A_2}{\sqrt{1-\left(\frac{A_2}{A_1}\right)^2}} \sqrt{\frac{2g}{\gamma_2}(p_1 - p_2)} \qquad (7)$$

- Now consider the free body diagram of the float, shown in fig. 8. Let,

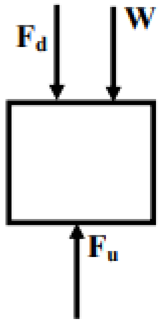


Fig. 8 Forces acting on the float

- Fd = Downward thrust on the float Fu = Upward thrust on the float
- W = Apparent weight of the float At balance,

$$W = F_u - F_d$$

or, $V_f(\gamma_1 - \gamma_2) = p_1 A_f - p_2 A_f$

Therefore,

$$p_1 - p_2 = \frac{v_f}{A_f}(\gamma_1 - \gamma_2)$$

Substituting the above expression in (7), we obtain:

$$Q = \frac{C_d(A_t - A_f)}{\sqrt{1 - \left\{\frac{A_t - A_f}{A_t}\right\}^2}}\left[\sqrt{\frac{2g}{\gamma_2}\frac{v_f}{A_f}(\gamma_1 - \gamma_2)}\right] \quad (8)$$

- The term within the third bracket in the above expression is constant.

$$\text{If } \left\{ \frac{A_t - A_f}{A_t} \right\}^2 << 1 \text{, then,}$$

We can have, $Q = K(A_t - A_f)$

If the tube is made in such a way that At varies linearly with the displacement, one have a linear relationship in the form $Q = K_1 + K_2 x$

- that is, the scale of the tube can be graduated linearly in terms of flow rate.
- Otherwise, the displacement of the float can be converted to electrical signal by using a LVDT or similar type of displacement sensor.
- For large flow rate measurement, the rotameter is normally place in a bypass line.
- The major source of error in rotameter is due to the variation of density of the fluid. Besides, the presence of viscous force may also provide an additional force to the float.

Construction of the float

- The construction of the float decides heavily, the performance of the rotameter.
- In general, a float should be designed such that: (a) it must be held vertical (b) it should create uniform turbulence so as to make it insensitive to viscosity (c) it should make the rotameter least sensitive to the variation of the fluid density.
- A typical construction of the float is shown in fig. 9. The top section of the float has a sharp edge and several angular grooves. The fluid passing through these grooves, causes the rotation of the float. The turbulence created in this process reduces the viscous force considerably.

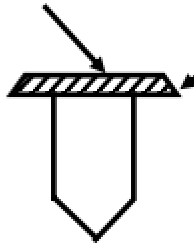


Fig. 9 Construction of a float

From (8) the expression for volumetric flowrate can be written as:

$$Q = K\sqrt{\frac{2g}{\gamma_2}\frac{v_f}{A_f}(\gamma_1 - \gamma_2)} \qquad (10)$$

The performance of the flowmeter can be made almost independent of the variation of fluid density, if we select the material of the float, such that, $\gamma_1 >> \gamma_2$.

For measurement of mass flow rate (W), we can write,

$$W = \gamma_2 Q = K\sqrt{K_1(\gamma_1 - \gamma_2)\gamma_2} \qquad (11)$$

The condition, $\frac{dW}{d\gamma_2} = 0$, can be satisfied, if we select $\gamma_1 = \gamma_2$. This can be achieved by using a hollow float, or a plastic float.

Electromagnetic Flowmeter

- Electromagnetic flowmeter is different from all other flowmeters due to its uniqueness on several accounts.
- The advantages of this type of flowmeter can be summarized as:

1. It causes no obstruction to flow path.
2. It gives complete linear output in form of voltage.
3. The output is unaffected by changes in pressure, temperature and viscosity of the fluid.
4. Reverse flow can also be measured.
5. Flow velocity as low as 10-6m/sec can be measured.

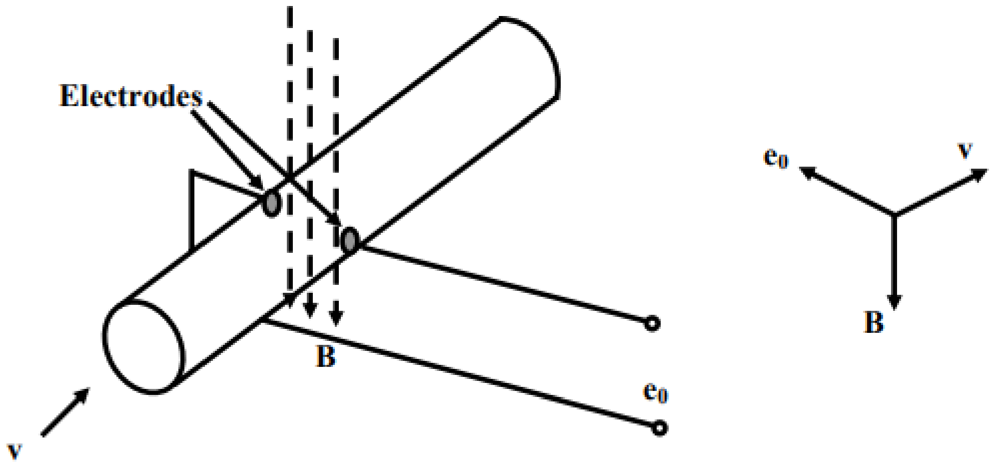


Fig. 10 Electromagnetic Flowmeter

- Electromagnetic flowmeters are suitable for measurement of velocity of conducting (Mercury) and weakly conducting (water) liquid.
- The basic principle of operation can be understood from fig. 10.
- It works on the principle of basic electromagnetic induction; i.e. when a conductor moves along a magnetic field perpendicular to the direction of flow, a voltage would be induced perpendicular to the direction of movement as also to the magnetic filed. The flowing liquid acts like a conductor. External magnetic field is applied perpendicular to the direction of the flow and two electrodes are flushed on the wall of the pipeline as shown.
- The expression for the voltage induced is given by: $e_o = B\,l\,v$

- where l is the length of the conductor (diameter d in this case) and v is the velocity of the liquid.
- The above expression shows the complete relationship between the voltage induced and the velocity. However, the magnetic field applied is not d.c. if the liquid medium is water or any other polarizable liquid. This is because, if the magnetic field is d.d. the voltage induced will also be d.c. and a small amount of d.c. current will flow if a measuring circuit is connected to the terminals.
- This small d.c. current will cause electrolysis; oxygen and hydrogen bubbles will be formed and they will stick to the electrodes surfaces for some time. This will provide an insulating layer on the electrodes surfaces that will disrupt the voltage generation process. As a result, the magnetic field applied for these cases is a.c., or pulsed d.c. excitation. The meter can only be used for liquids having moderate conductivities (more than 10 μmho cm /). As a result, it is not suitable for gases or liquid hydrocarbons. The accuracy is around±1%.

Turbine type Flowmeter

- Turbine type flowmeter is a simple way for measuring flow velocity.
- A rotating shaft with turbine type angular blades is placed inside the flow pipe. The fluid flowing through the pipeline will cause rotation of the turbine whose speed of rotation can be a measure of the flowrate. Referring fig.11, let blades make an angle α with the body. Then,

$$\frac{\omega_r R}{\bar{v}} = \tan\alpha$$

where,

$\bar{v}$ = Average velocity of the fluid $= \frac{Q}{A}$

Q = Volumetric flowrate

A = Effective flow area of the pipe

R = Radius of the blade

ω_r = Angular speed of the blade.

From the above expression, the volumetric flow rate can be related with the angular speed, as:

$$\omega_r = kQ \tag{13}$$

where,

$$k = \frac{\tan\alpha}{RA}$$

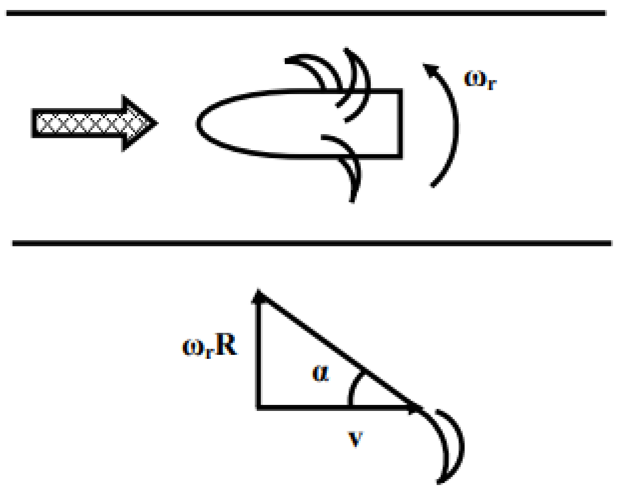


Fig. 11 Turbine type flowmeter

The speed of rotation of the turbine can be measured using several ways, such as, optical method, inductive pick up etc.

Vortex type Flowmeter

- Formation of vortex on a flowing stream by an obstruction like straw or stone is a common observation. But what is probably not commonly known is the fact that, the frequency of vortex formation is proportional to flow velocity.

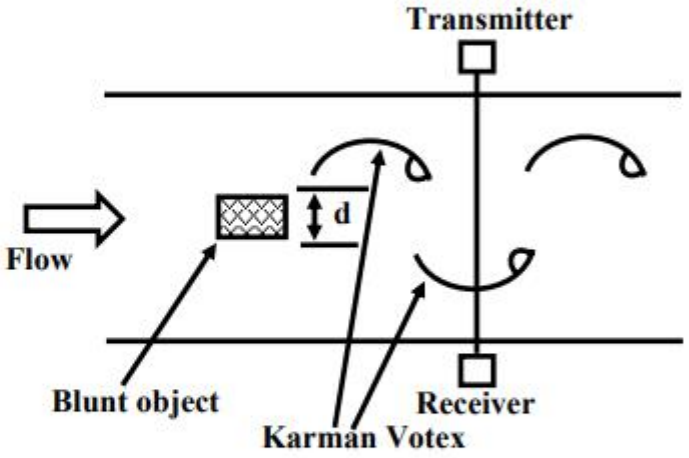


Fig. 12 Vortex type flowmeter

- Fig.12 shows the basic principle of vortex type flowmeter. It is based on the principle of vertex shading. When a blunt object is placed on the passage of a flowing stream, vortices are formed. A vortes of this sort is called Karman Vortex. If the flow is turbulent and the Reynold's number is $R_D > 10^4$, then the frequency of vortex formation is given by:

$$f = \frac{N_{st}}{d} v$$

Where, d= width of the blunt object.
v= velocity of the fluid
Nst = A constant, called Strouhal Number.

- The fig. 12 shows a typical arrangement of measurement of frequency of vorticex formation using ultrasonic technique. Formation of a vortex will modulate the intensity of ultrasound received by the receiver, and the frequency of modulation can be measured easily.

What is Ultrasonic Flow Meter ?

Ultrasonic flow meter measure fluid velocity by passing high-frequency sound waves along the fluid flow path.

Fluid motion influences the propagation of these sound waves, which may then be measured to infer fluid velocity.

Two major sub-types of ultrasonic flow meters exist:

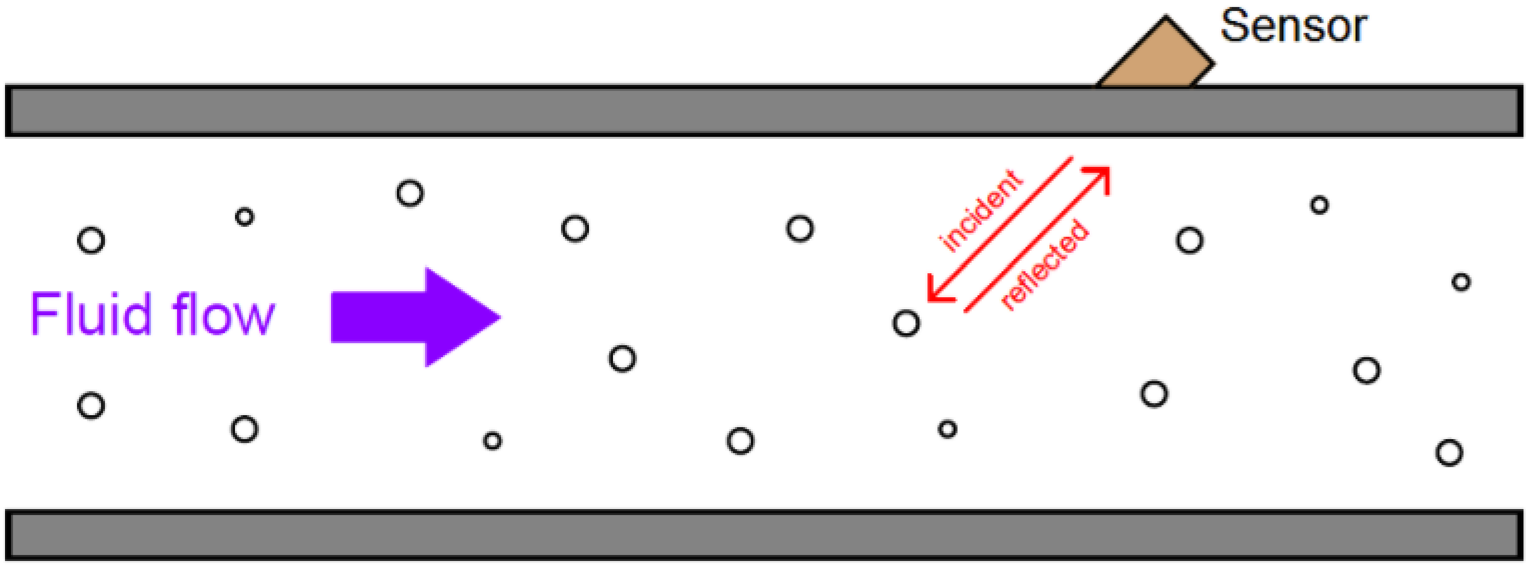
Doppler and transit-time.

Both types of ultrasonic flowmeter work by transmitting a high-frequency sound wave into the fluid stream (the incident pulse) and analyzing the received pulse.

- Doppler flowmeters exploit the Doppler effect, which is the shifting of frequency resulting from waves emitted by or reflected by a moving object.
- A common realization of the Doppler effect is the perceived shift in frequency of a horn’s report from a moving vehicle: as the vehicle approaches the listener, the pitch of the horn seems higher than normal; when the vehicle passes the listener and begins to move away, the horn’s pitch appears to suddenly “shift down” to a lower frequency.
- In reality, the horn’s frequency never changes, but the velocity of the approaching vehicle relative to the stationary listener acts to “compress” the sonic vibrations in the air. When the vehicle moves away, the sound waves are “stretched” from the perspective of the listener.

- The same effect takes place if a sound wave is aimed at a moving object, and the echo’s frequency is compared to the transmitted (incident) frequency. If the reflected wave returns from a bubble advancing toward the ultrasonic transducer, the reflected frequency will be greater than the incident frequency.
- If the flow reverses direction and the reflected wave returns from a bubble traveling away from the transducer, the reflected frequency will be less than the incident frequency.
- This matches the phenomenon of a vehicle’s horn pitch seemingly increasing as the vehicle approaches a listener and seemingly decreasing as the vehicle moves away from a listener.
- A Doppler flowmeter bounces sound waves off of bubbles or particulate material in the flow stream, measuring the frequency shift and inferring fluid velocity from the magnitude of that shift.

Ultrasonic Flow Meter – Doppler Flow meter



- The requirement for there to be objects in the flow stream large enough to reflect sound waves limits Doppler ultrasonic flow meters to liquid applications.
- Dirty liquids such as slurries and wastewater, or liquids carrying a substantial number of gas bubbles (e.g. carbonated beverages) are good candidate fluids for this technology.
- It is unrealistic to expect that any gas stream will be carrying liquid droplets or solid matter large enough to reflect strong echoes, and so Doppler flow meters cannot be used to measure gas flow.
- The mathematical relationship between fluid velocity (v) and the Doppler frequency shift (Δf) is as follows, for fluid velocities much less than the speed of sound through that fluid (v << c):

$$\Delta f = \frac{2vf\cos\theta}{c}$$

$$\Delta f = \frac{2vf\cos\theta}{c}$$

Where,

Δf = Doppler frequency shift

v = Velocity of fluid (actually, of the particle reflecting the sound wave)

f = Frequency of incident sound wave

θ = Angle between transducer and pipe centerlines

c = Speed of sound in the process fluid

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- Note how the Doppler effect yields a direct measurement of fluid velocity from each echo received by the transducer.
- This stands in marked contrast to measurements of distance based on time-off light (time domain reflectometry – where the amount of time between the incident pulse and the returned echo is proportional to distance between the transducer and the reflecting surface)
- such as in the application of ultrasonic liquid level measurement. In a Doppler flowmeter, the time delay between the incident and reflected pulses is irrelevant. Only the frequency shift between the incident and reflected signals matters.
- This frequency shift is also directly proportional to the velocity of flow, making the Doppler ultrasonic flowmeter a linear measurement device.
- Re-arranging the Doppler frequency shift equation to solve for velocity (again, assuming $v << c$),

$$v = \frac{c\Delta f}{2f\cos\theta}$$

Knowing that volumetric flow rate is equal to the product of pipe area and the average velocity of the fluid (Q = Av), we may re-write the equation to directly solve for calculated flow rate (Q):

$$Q = \frac{Ac\Delta f}{2f\cos\theta}$$

- A very important consideration for Doppler ultrasonic flow measurement is that the calibration of the flow meter varies with the speed of sound through the fluid (c).
- This is readily apparent by the presence of c in the above equation: as c increases, Δf must proportionately decrease for any fixed volumetric flow rate Q.
- Since the flowmeter is designed to directly interpret flow rate in terms of Δf, an increase in c causing a decrease in Δf will thus register as a decrease in Q.
- This means the speed of sound for a fluid must be precisely known in order for a Doppler ultrasonic flowmeter to accurately measure flow.

- The speed of sound through any fluid is a function of that medium's density and bulk modulus (how easily it compresses):

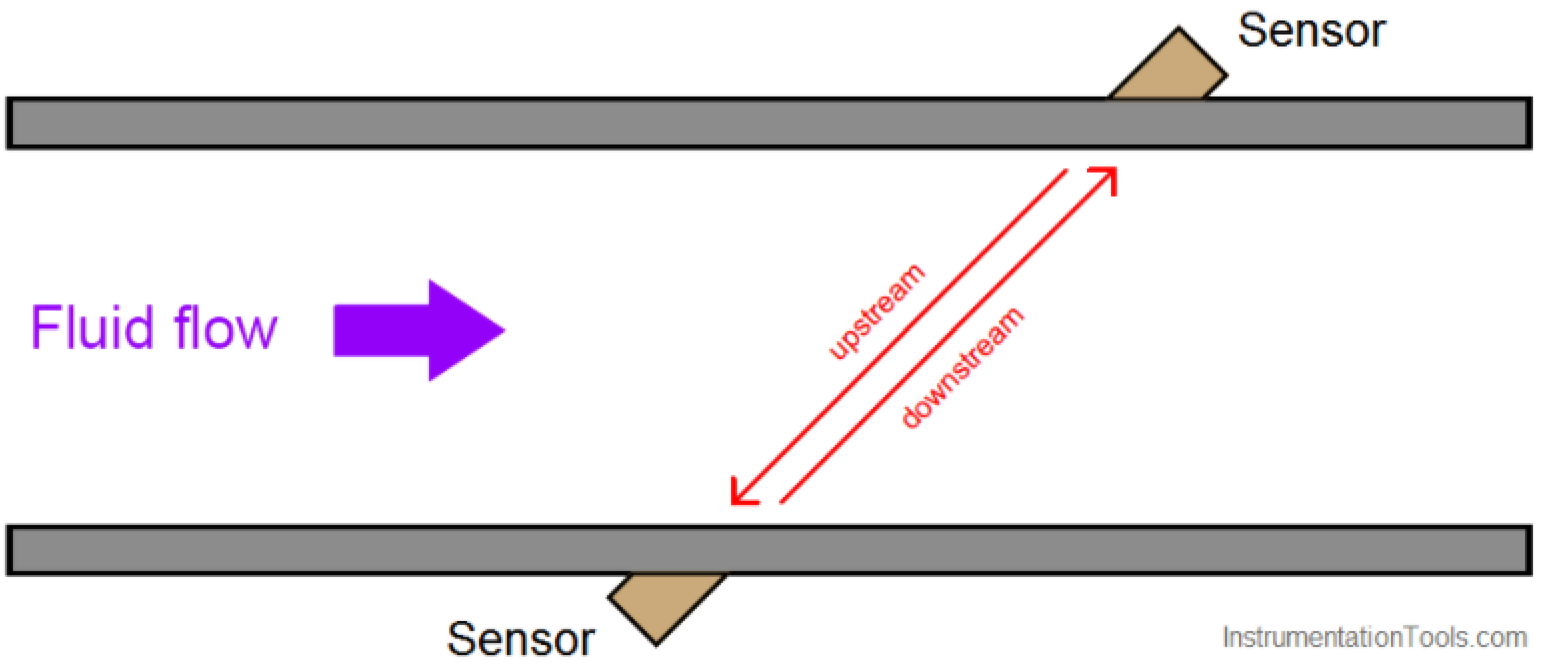
$$c = \sqrt{\frac{B}{\rho}}$$

Where,
c = speed of sound in a material (meters per second)
B = Bulk modulus (pascals, or newtons per square meter)
ρ = Mass density of fluid (kilograms per cubic meter)

- Temperature affects liquid density, and composition (the chemical constituency of the liquid) affects bulk modulus. Thus, temperature and composition both are influencing factors for Doppler ultrasonic flowmeter calibration.
- Pressure is not a concern here, since pressure only affects the density of gases, and we already know Doppler flowmeters only function with liquids.
- Following on the theme of requiring bubbles or particles of sufficient size, another limitation of Doppler ultrasonic flowmeters is their inability to measure flow rates of liquids that are too clean and too homogeneous. In such applications, the sound-wave reflections will be too weak to reliably measure.
- Such is also the case when the solid particles have a speed of sound too close to the that of the liquid, since reflection happens only when a sound wave encounters a material with a markedly different speed of sound.
- Doppler-type ultrasonic flowmeters are useless in applications where we cannot obtain strong sound-wave reflections.

Transit-time flowmeters

- Transit-time flowmeters, sometimes called counterpropagation flowmeters, are an alternative to Doppler ultrasonic flowmeters.
- A transit-time ultrasonic flowmeter uses a pair of opposed sensors to measure the time difference between a sound pulse traveling with the fluid flow versus a sound pulse traveling against the fluid flow.
- Since the motion of fluid tends to carry a sound wave along, the sound pulse transmitted downstream will make the journey faster than a sound pulse transmitted upstream:


Sensor
Fluid flow
upstream
downstream
Sensor
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Ultrasonic flow meter working principle

- **Ultrasonic flow meters** operate using the transit-time differential method. The **Transit-time** differential measurement is based on a simple physical fact.
- Imagine two canoes crossing a river on the same diagonal line, one with the flow and the other against the flow. The canoe moving with the flow needs much less time to reach the opposite bank

Ultrasonic waves behave exactly the same way. A sound wave travelling in the direction of flow of the product is propagated at a faster rate than one travelling against the flow ($v_{down} > v_{up}$).

Transit times t_{down} and t_{up} are measured continuously. The difference ($t_{up} - t_{down}$) in time travelled by the two ultrasonic waves is directly proportional to the mean flow velocity (vm).

Where,

t_{down} is Time required for ultrasonic wave to travel from top Sensor A to bottom B sensor

t_{up} is Time required for ultrasonic wave to travel from Sensor B to A sensor

- The rate of volumetric flow through a transit-time flowmeter is a simple function of the upstream and downstream propagation times:

$$Q = k\frac{t_{up} - t_{down}}{(t_{up})(t_{down})}$$

Where,
Q = Calculated volumetric flow rate
k = Constant of proportionality
t_{up} = Time for sound pulse to travel from downstream location to upstream location (upstream, against the flow)
t_{down} = Time for sound pulse to travel from upstream location to downstream location (downstream, with the flow)

- An interesting characteristic of transit-time velocity measurement is that the ratio of transit time difference over transit time product remains constant with changes in the speed of sound through the fluid.
- If you would like to prove this to yourself, you may do so by substituting path length (L), fluid velocity (v), and sound velocity (c) for the times in the flow formula. Use tup = L/(c−v) and tdown = L/(c+v) as your substitutions, then algebraically reduce the flow formula until you find that all the c terms cancel. Your final result should be Q = 2kv/L .
- When this equation is cast into terms of path length (L), fluid velocity (v), and sound velocity (c), the equation simplifies to Q = 2kv/L , proving that the transit-time flow meter is linear just like the Doppler flowmeter, with the advantage of being immune to changes in the fluid’s speed of sound.
- Changes in bulk modulus resulting from changes in fluid composition, or changes in density resulting from compositional, temperature, or pressure variations therefore have little effect on a transit-time flow meter’s accuracy.
- Not only are transit-time ultrasonic flow meters immune to changes in the speed of sound, but they are also able to measure that sonic velocity independent of the flow rate.

$$c = \frac{L}{2}\left(\frac{t_{up} + t_{down}}{(t_{up})(t_{down})}\right)$$

- Where,
  c = Calculated speed of sound in fluid
  L = Path length
  t_{up} = Time for sound pulse to travel from downstream location to upstream location (upstream, against the flow)
  t_{down} = Time for sound pulse to travel from upstream location to downstream location (downstream, with the flow)

- A requirement for reliable operation of a transit-time ultrasonic flow meter is that the process fluid be free from gas bubbles or solid particles which might scatter or obstruct the sound waves.
- Note that this is precisely the opposite requirement of Doppler ultrasonic flow meters, which require bubbles or particles to reflect sound waves.
- These opposing requirements neatly distinguish applications suitable for transit-time flow meters from applications suitable for Doppler flow meters, and also raise the possibility of using transit-time ultrasonic flow meters on gas flow streams as well as on liquid flow streams.

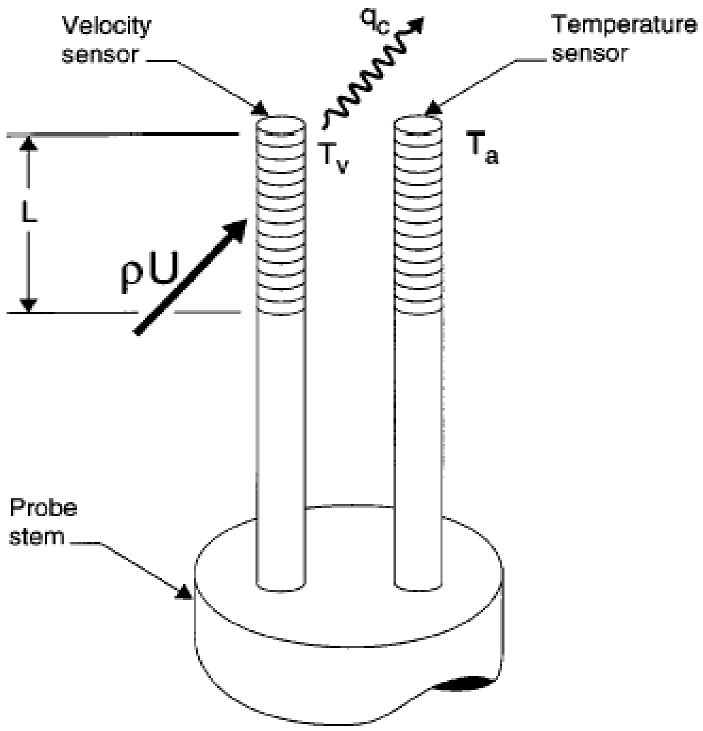
Pros and Cons of ultrasonic flow meter

PROS	・There is no pressure loss ・A type that can perform detection from the outside of piping is available
CONS	・A long section of straight pipe is required ・Liquids that have a large solid content will cause malfunctions ・Measurement is not possible when there are many air bubbles

Hot wire Anemometer

- A thermal anemometer measures the velocity at a point in a flowing fluid — a liquid or a gas.
- A typical industrial thermal anemometer used to monitor velocity in gas flows has two sensors — a velocity sensor and a temperature sensor
- That automatically correct for changes in gas temperature.
- Both sensors are reference-grade platinum resistance temperature detectors (RTDs).
- The electric resistance of RTDs increases as temperature increases.
- For this reason, they are one of the most commonly used sensors for accurate temperature measurements.

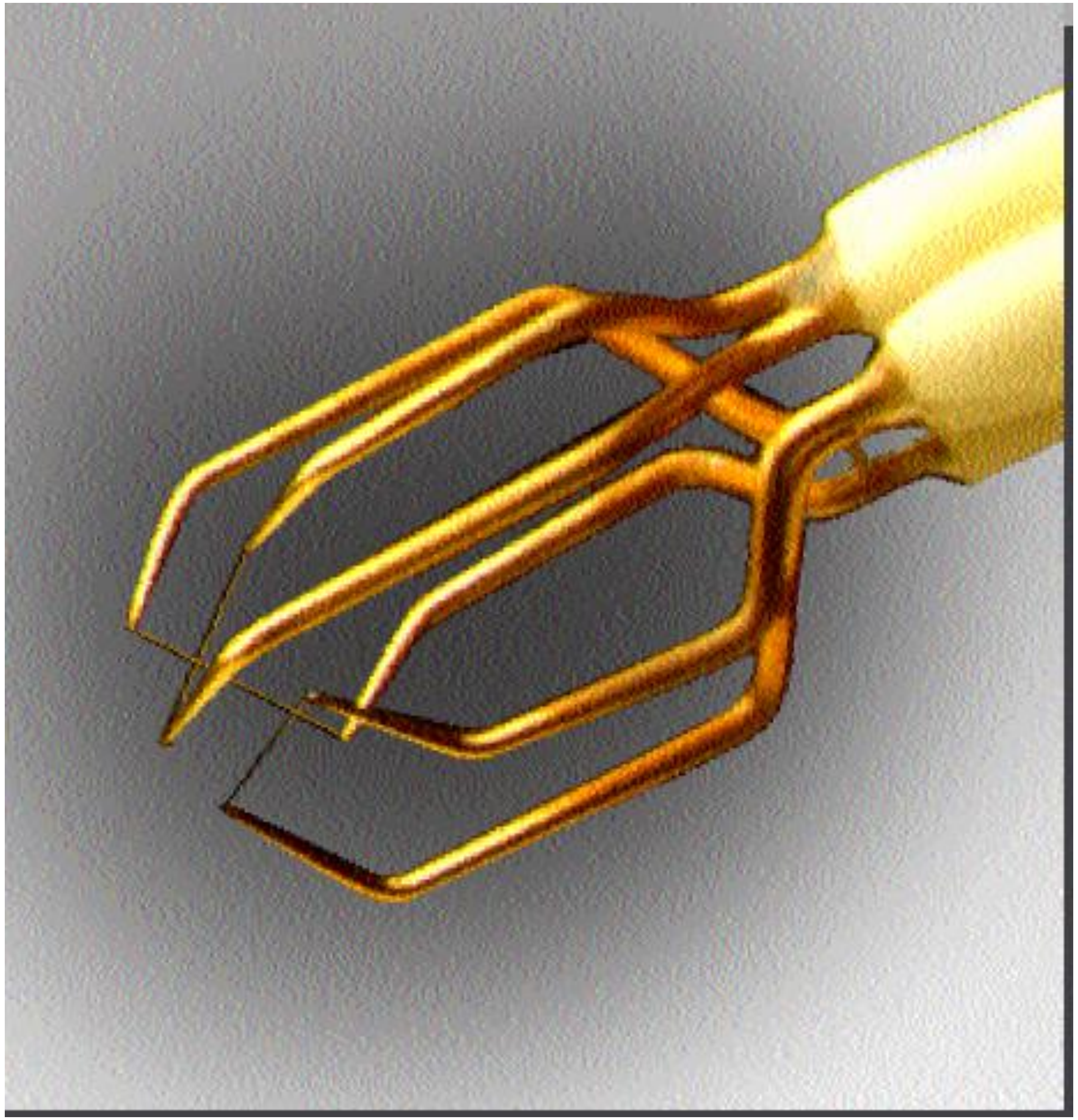
Continued…



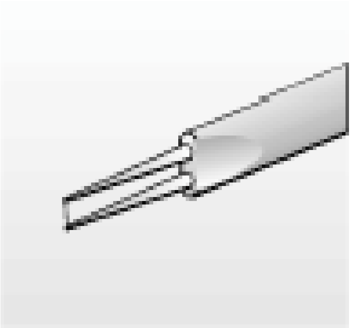
The electronics circuit passes current through the velocity sensor, thereby heating it to a constant temperature differential (T_v – T_a) above the gas temperature T_a and measures the heat q_c carried away by the cooler gas as it flows past the sensor.

Hence, it is called a “constant-temperature thermal anemometer.”

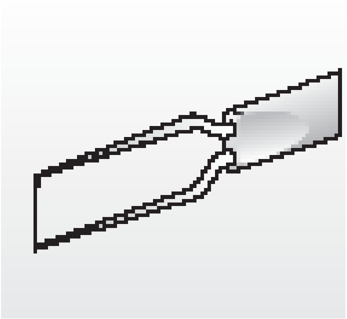
Three Wire Anemometer



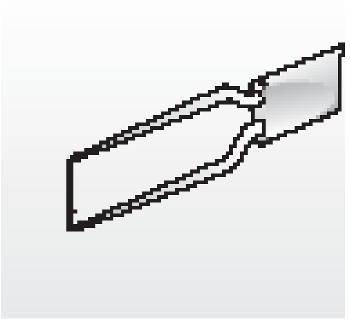
Sensor Types



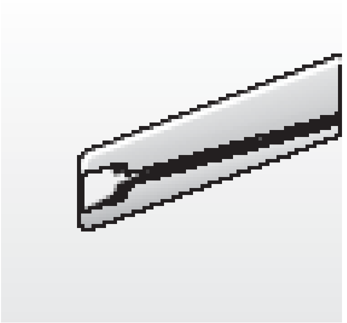
Miniature wires



Gold-plated wires



Fibre-film



Film-sensors

- Wires are normally 5 μm in diameter and 1.2 mm long suspended between two needle-shaped prongs.
- Gold-plated wires have the same active length but are copper- and gold-plated at the ends to a total length of 3 mm long in order to minimise prong interference.

- Fibre-sensors are quartz-fibers, normally 70 µm in diameter and with 1.2 mm active length, covered by a nickel thin-film, which again is protected by a quartz coating.
- Fibre-sensors are mounted on prongs in the same arrays as are wires.
- Film sensors consist of nickel thin-films deposited on the tip of aerodynamically shaped bodies, wedges or cones.

What is an Anemometer?

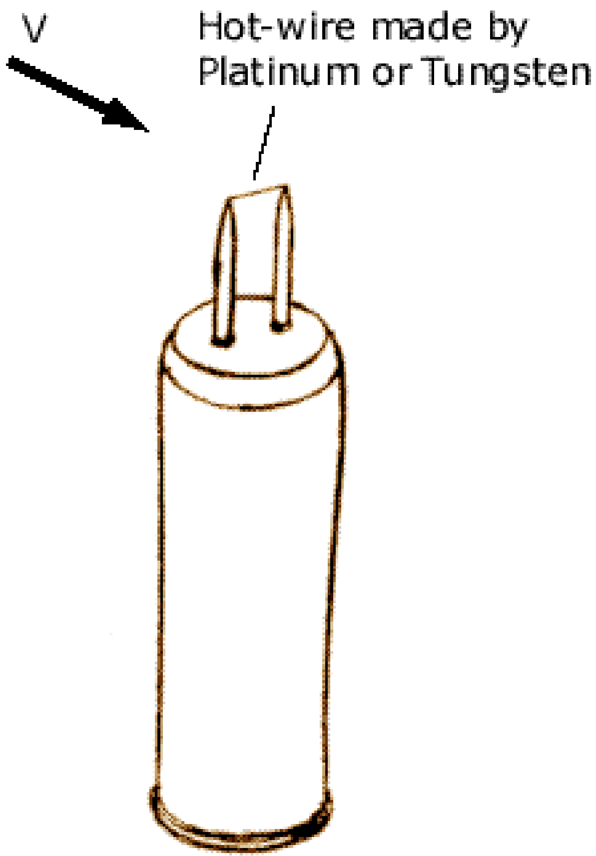
- Anemometer – measures gas speed
- Types
  - rotating cup
  - pitot static tube
  - thermal (hot wire)
    - also performs temperature measurement

Theory of Operation

- Energy Balance
- Constant temperature or constant current operation
- Measure change in current or change in temperature
- Correlate I or T_{wire} to gas velocity based on convective H.T. and fluid dynamics

Probe

- Tungsten or Platinum filament
  - ~1 mm long
  - 4-10 μm diameter
- Benefits
  - Good spatial resolution
  - Flat frequency response
- Limitations
  - Fragile
  - Requires clean flow
  - Cost (start at $300-400)



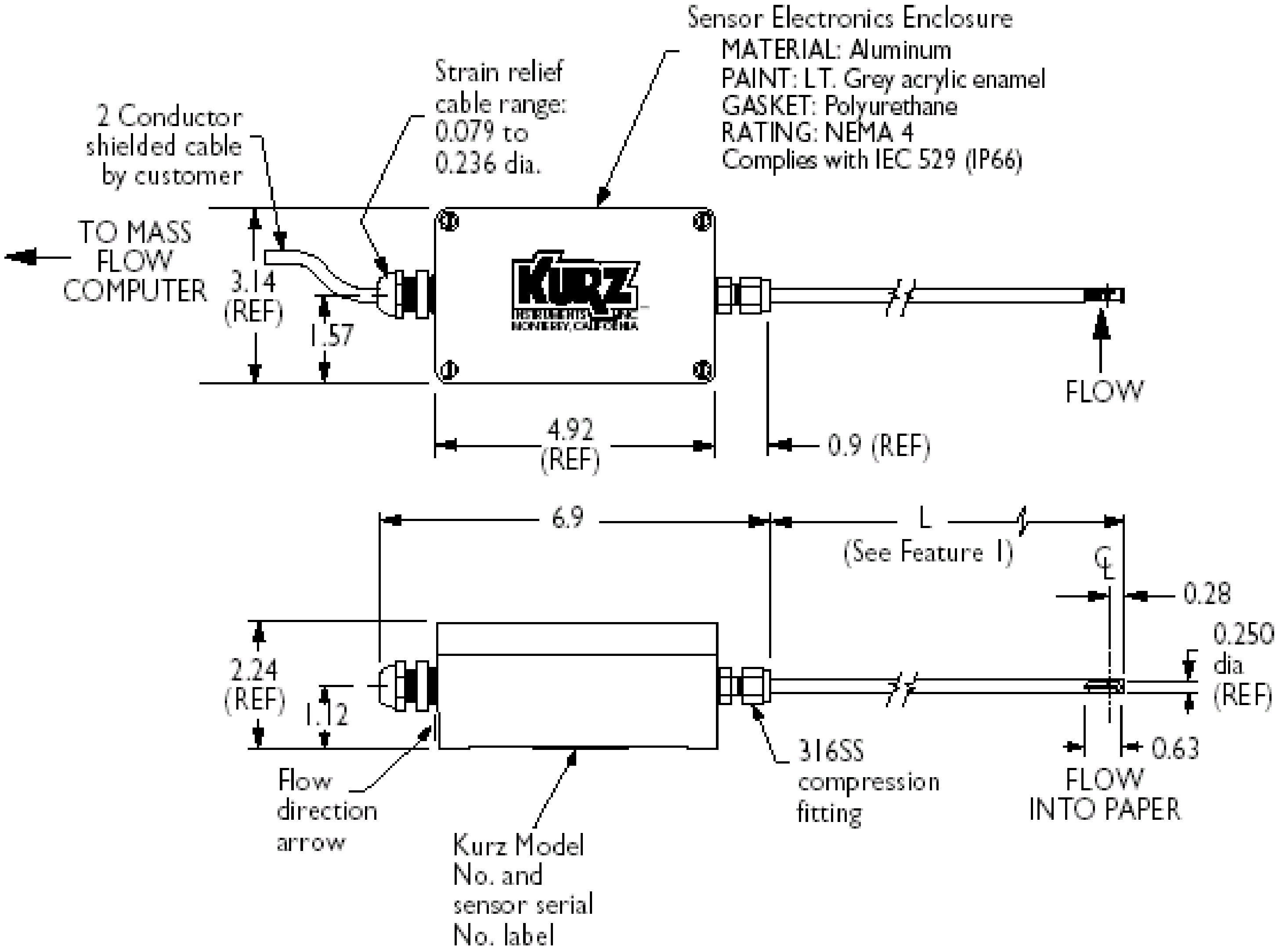
Interfacing

- Wide variety of options
  - Devices typically come with some sort of μ-controller
  - Depends on application
  - Handheld vs. in-situ
- Most common
  - Serial RS232 – for sampled data collection and control
- Larger selection for industrial sensors
  - Serial RS232, RS485
  - Analog 4-20 mA, 0-10V
  - Profibus, Modbus, etc.

Typical Specifications

	Handheld/Economy	**Industrial Grade**
Measurable velocities	0.2-20 m/s	0.2-90 m/s
Operating temp ranges	0-50 °C	-40-200 °C
Velocity Accuracy	± 3% reading	± 1% reading
Time constant	200 ms	100 ms
Interfacing options	Handheld reader, RS232	RS232, RS485, voltage, 4-20 mA, Modbus, Profibus, etc.

83
76.1
POWER
HOLD
RECORD
RECALL
UNIT
Hot Wire
Thermo-Anemometer
EXTECH
PC Interface



Sensor Electronics Enclosure
MATERIAL: Aluminum
PAINT: LT. Grey acrylic enamel
GASKET: Polyurethane
RATING: NEMA 4
Complies with IEC 529 (IP66)
Strain relief cable range: 0.079 to 0.236 dia.
2 Conductor shielded cable by customer
TO MASS FLOW COMPUTER
3.14 (REF)
1.57
KURZ
INSTRUMENTS INC
MONTEREY, CALIFORNIA
FLOW
4.92 (REF)
0.9 (REF)
6.9
L
(See Feature 1)
0.28
0.250 dia (REF)
2.24 (REF)
1.12
0.63
Flow direction arrow
Kurz Model No. and sensor serial No. label
316SS compression fitting
FLOW INTO PAPER

UNIT –V

1.Measurement of Displacement-Introduction and types
2. Measurement of speed-Introduction and types
3. Measurement of liquid level-Introduction and types
4.Measurement of Pressure-Introduction and types

Displacement Measurement

- A displacement sensor (displacement gauge) is primarily **used to measure the range of where an object has to travel** and in relation to a reference position.
- Displacement sensors have multiple uses.
- Its primary use is for dimension measurement to figure out an object's width, height, and thickness.

Types

- **Potentiometer.**
- **Control Position Transducer (CPT)**
- **Linear variable differential Transformer(LVDT)**
- **Accelerometers**

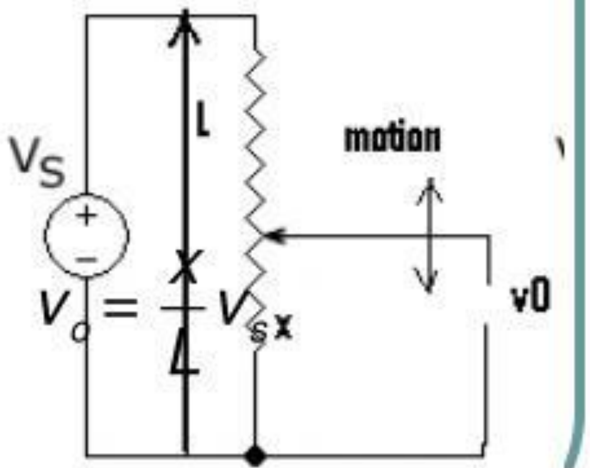
Longitudinal Displacement

Potentiometer or longitudinal displacement

Theory of Operation:

The sensor consists of a length "L" of resistance wire attached across a voltage source "V_s". The wiper is pushed up or down by moving target, for which displacement "x" is required to be measured. V_o is the output voltage representing displacement in terms of volts and is given by:

$$V_o = \frac{x}{L} V_s$$

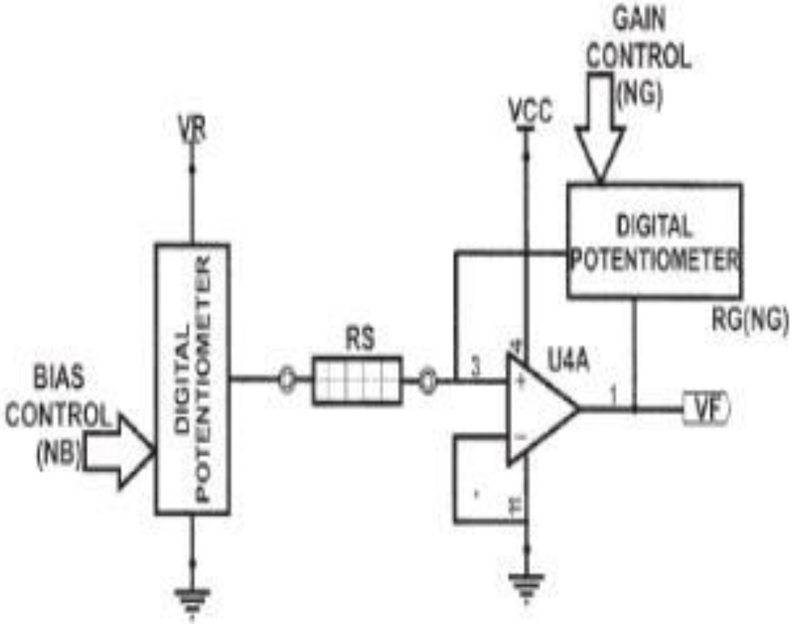


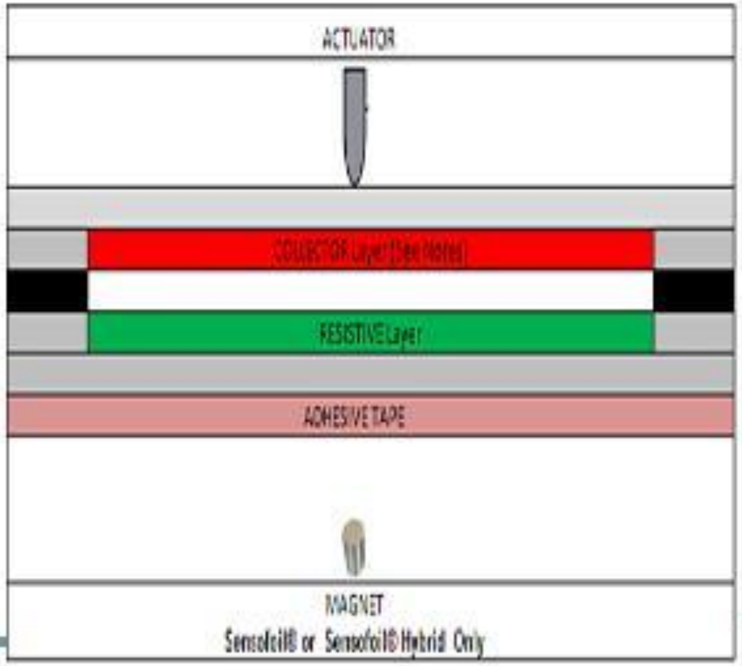
Wire-Wound Potentiometer

The resistance of the wire wound potentiometer increases in step manner as the wiper moves from one position to the adjacent turn. This step change in resistance limits the resolution of the potentiometer to L/n, where n is the numbers of turns. The resolution ranges from 0.05 to 1 percent are common. Therefore such potentiometer are not suitable for precise and finer movements.

Thin film potentiometer

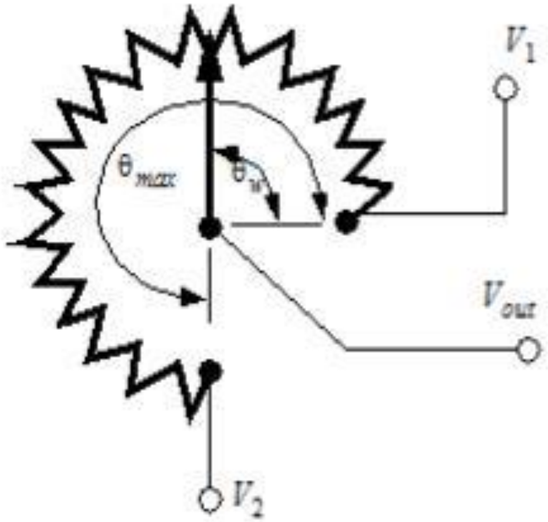
The film resistance on an insulating substrate exhibits high resolution, lower noise, and longer life. For example a resistance of 50 to 100 Ohm/mm can be obtained with the conductive plastic film





Thin Film Potentiometer

Thin Film potentiometer are introduced to improve resolution. Movement can be nearly continuous rather than in steps.



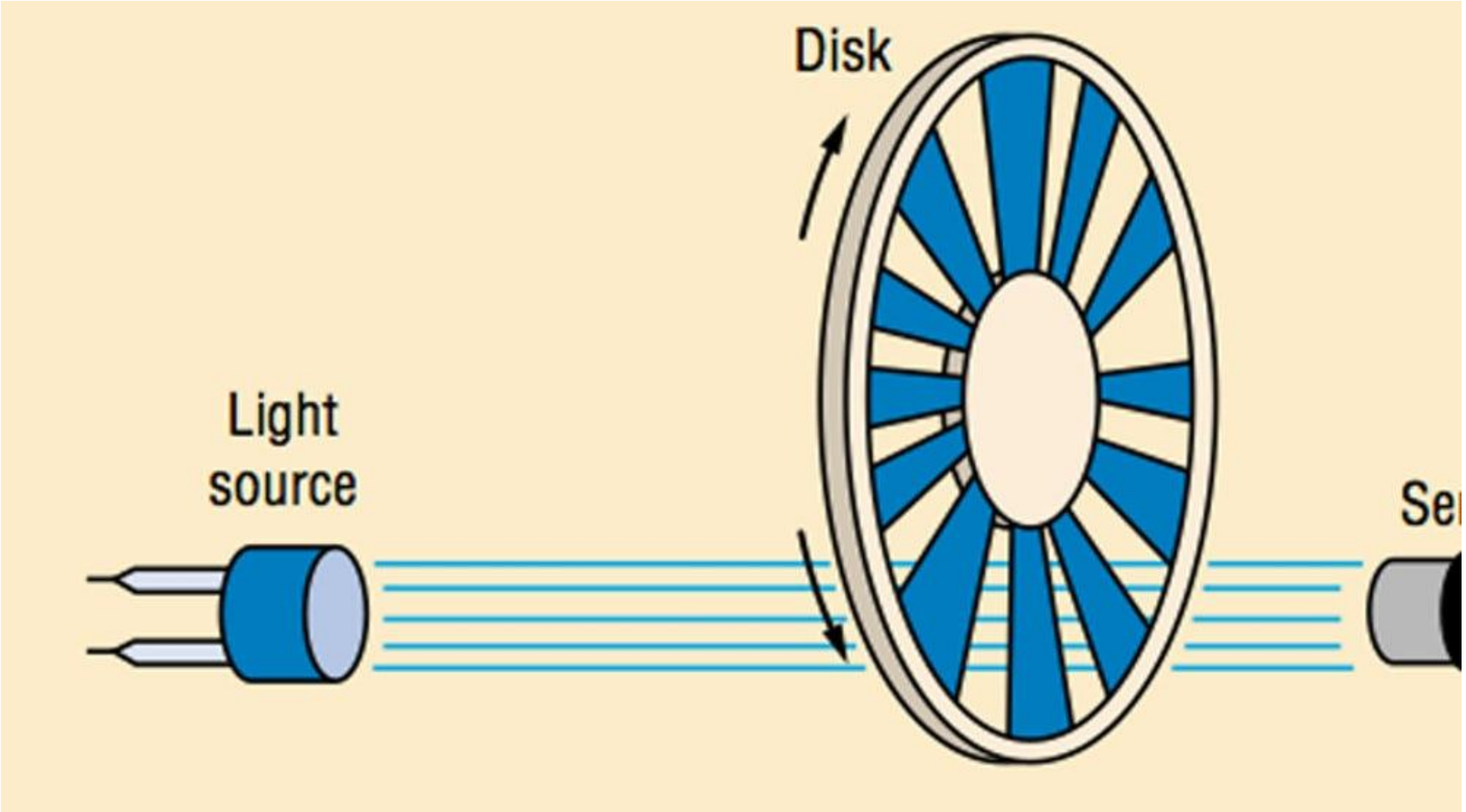
$$V_{out} = (V_2 - V_1)\left(\frac{\theta_w}{\theta_{max}}\right) + V_1$$

Thin Film Potentiometer

For angular Movements

Position Transducer

- A position transducer typically consists of two fundamental parts.
- One part remains fixed in position while the other part moves with the mechanism whose displacement is being measured.
- The exact nature, and therefore the size, of the fixed and moving portions depend on the sensing technology being used.
- Some transducers are intended to be mounted integrally to the mechanism, while others are designed to be mounted externally.


Disk
Light
source

Accelerometer

- An accelerometer is a device that measures the vibration, or acceleration of motion of a structure.
- The force caused by vibration or a change in motion (acceleration) causes the mass to "squeeze" the piezoelectric material which produces an electrical charge that is proportional to the force exerted upon it.

PRINCIPLE

The working principle of an accelerometer is based on PIEZO-ELECTRIC EFFECT (due to accelerative forces) and on the DISPLACEMENT SENSING (based on displacement of mass).

HOW IT WORKS

In most of the cases working of an ACCELEROMETER is based on voltage generation and its further calculations which leads to the determination of acceleration where as some other involve the measurement of displacement of mass.

TYPES OF ACCELEROMETER

There are basically two types of accelerometer frequently used for measurement of acceleration:-

- PIEZO ELECTRIC ACCELEROMETER
- DISPLACEMENT SENSING OR SEISMIC TYPE ACCELEROMETER

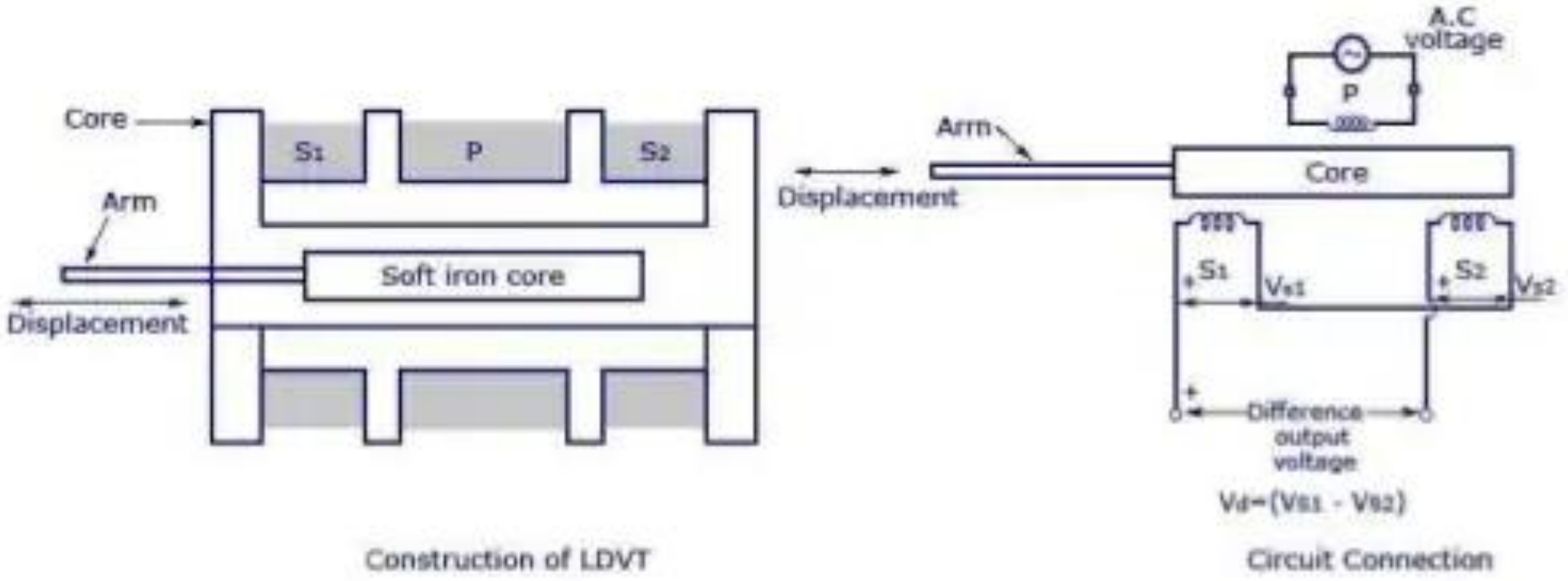
1. Linear Variable Differential Transformer

- The device consists of a primary winding (P) and two secondary windings named S1 and S2.
- Both of them are wound on one cylindrical former, side by side, and they have equal number of turns.
- Their arrangement is such that they maintain symmetry with either side of the primary winding (P).
- A movable soft iron core is placed parallel to the axis of the cylindrical former.
- An arm is connected to the other end of the soft iron core and it moves according to the displacement produced.
- The pressure range is 250 Pa - 70 MPa with a sensitivity of 0.35 MPa.

Working Principle of LVDT

- AC voltage with a frequency of (50-400) Hz is supplied to the primary winding. Thus, two voltages VS1 and VS2 are obtained at the two secondary windings S1 and S2 respectively.
- The output voltage will be the difference between the two voltages (VS1-VS2) as they are combined in series.
- Null Position – This is also called the central position as the soft iron core will remain in the exact centre of the former. Thus the linking magnetic flux produced in the two secondary windings will be equal. The voltage induced because of them will also be equal. Thus the resulting voltage VS1-VS2 = 0.
- Right of Null Position – In this position, the linking flux at the winding S2 has a value more than the linking flux at the winding S1. Thus, the resulting voltage VS1-VS2 will be in phase with VS2.

- Left of Null Position – In this position, the linking flux at the winding S2 has a value less than the linking flux at the winding S1. Thus, the resulting voltage VS1-VS2 will be in phase with VS1.
- VS1-VS2 will depend on the right or left shift of the core from the null position.
- The resulting voltage is in phase with the primary winding voltage for the change of the arm in one direction, and is 180 ° out of phase for the change of the arm position in the other direction.
- The magnitude and displacement can be easily calculated or plotted by calculating the magnitude and phase of the resulting voltage.
- The LVDT is connected to a diaphragm or bellow and with changes of pressure, the position of the LVDT changes, producing current output from where the pressure difference can be evaluated.



Construction and Circuit Connection of LVDT

Advantages of LVDT:

- It possesses high sensitivity
- Very rugged in construction and therefore tolerant towards shock and vibration
- Stable and easy to align
- Offers infinite resolution
- Low hysteresis, hence repeatable

Disadvantages of LVDT:

- Relatively large core displacement
- Sensitive to stray magnetic fields
- Affected by temperature

Measurement of Speed

Tachometer, What's That?

- Tachometer is used for measuring rotational speed
- Can be used to measure speed of a rotating shaft
- Can also be used to measure flow of liquid by attaching a wheel with inclined vanes
- Tachometers can be classified

  1.On the basis of data acquisition
    - Contact
    - Non contact types

  2. Classified as data type
    - Analog
    - Digital

  3. On the basis of power .
    - Mechanical
    - Electrical

What Are the Different Types of Tachometers?

- Classification of tachometers:
  - Mechanical Tachometers
    - Revolution counter
    - Hand speed indicator
    - Tachoscope
    - Centrifugal tachometer
    - Resonance (vibrating read) tachometer
  - Electrical Tachometers
    - Eddy current or drag cup tachometer
    - Tachogenerator (DC and AC)
  - Contactless electrical Tachometers
    - Magnetic pickup tachometer
    - Photo-electric tachometer
    - Stroboscope

Mechanical Tachometers

Hand speed indicator

Tachoscope

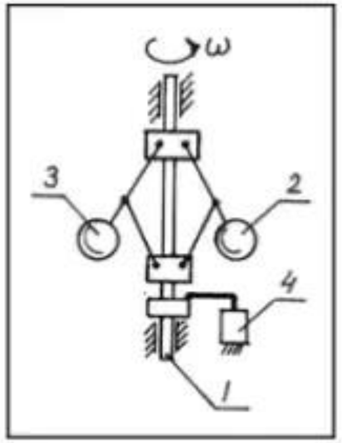
- Tachoscope consists of revolution counter for timing device.
- The two components are integrally mounted and start simultaneously when contact point is pressed against rotating shaft.
- The rotational speed is computed from reading of counter and timer.
- Tachometer can be used to measure speeds up to 5000r.p.m.

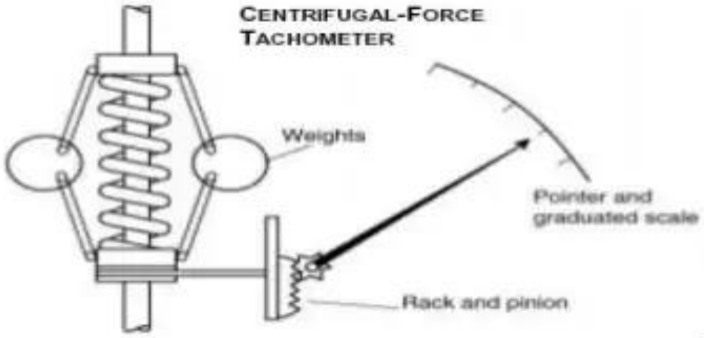
Tachoscope

Centrifugal tachometer

- Centrifugal Tachometer operates on principle that centrifugal force is proportional to speed of rotation.
- It consists two balls arranged about spindle. Centrifugal force developed by these balls compress spring as function of speed positions pointer.
- They are suitable for 4000r.p.m.

Centrifugal tachometer





w = angular speed, 1 = shaft,
2 and 3 = masses, 4 = displacement-sensitive element.

Resonance (vibrating read) tachometer

- In Vibrating Read Tachometers a series of consecutively timed steel rods are used to determine speed on basis of vibrations created by machine.
- One end of rod is fixed to a base which is kept in contact with any non-moving part of machine and other is attached to calibrated scale.
- These can be used in speed range of 600-10000 rpm .

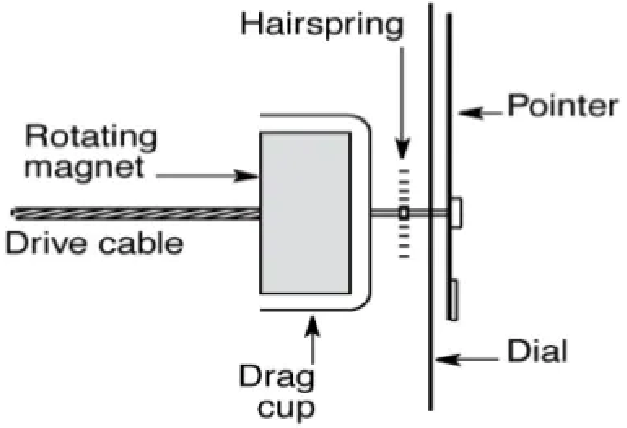
Resonance (vibrating read) tachometer

Electrical Tachometers

Eddy current or drag cup tachometer

- An eddy-current tachometer uses the interaction of the magnetic fields generated by a permanent magnet and a rotor, whose speed of rotation is proportional to the eddy currents generated.
- The currents tend to deflect a disk, which is mounted on the shaft and restrained by a spring, through a certain angle.
- The deflection of the disk, which is rigidly connected to a pointer, is indicated on a dial.

Eddy current or drag cup tachometer



magnetic-drag tachometer

D.C. Tachogenerator

- In a D.C. generator the e.m.f generated depends upon the following two factors:
  - (i) Field excitation
  - (ii) Speed
- If for the field system permanent magnet pole pieces are used, the generated voltage depends only on the speed. Hence the s **can be computed by measuring the generated e.m.f.**
- The shaft whose speed is to be measured is coupled to the armature.
- A moving coil voltmeter is connected across the brushes to me the generated voltage. The variable resistance R is incorporate limit the current through the voltmeter.
- Since voltage is proportional to speed, the voltmeter may be calibrated in terms of speed (r.p.m.).

D.C. Tachogenerator

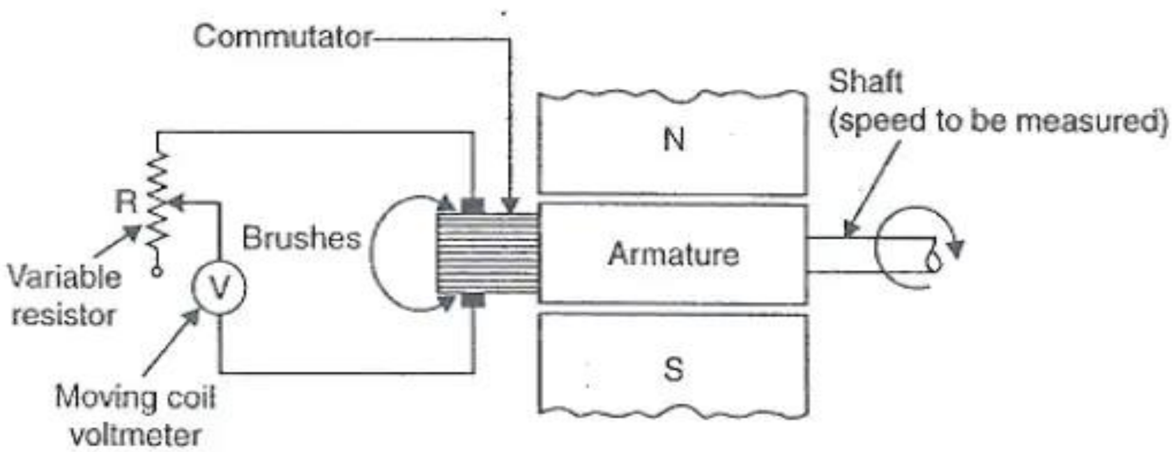


Fig. 32. D.C. tachometer generator.

A.C. Tachogenerator

- The inherent demerits associated with D.C. tachometer generator, due to the provision of commuter and brushes, are eliminated in A.C. tachometer generator.
- It consists of, like an alternator, a stationary armature (stator) and a rotating field system (rotor). Owing to the generation of e.m.f in a stationary coil on a stator, commutation problems no longer exist.
- The alternating e.m.f. induced in the stationary coil is rectified, and the output D.C. voltage is measured with the help of a moving coil voltmeter (V).
- The ripple content of the rectified voltage is smoothened by the capacitor filter (C).

A.C. Tachogenerator

- As the speed depends on both the amplitude of the voltage and frequency, anyone of them can be used as a measure of the speed. In an A.C. tachometer, it is the induced voltage that is considered as the required parameter.

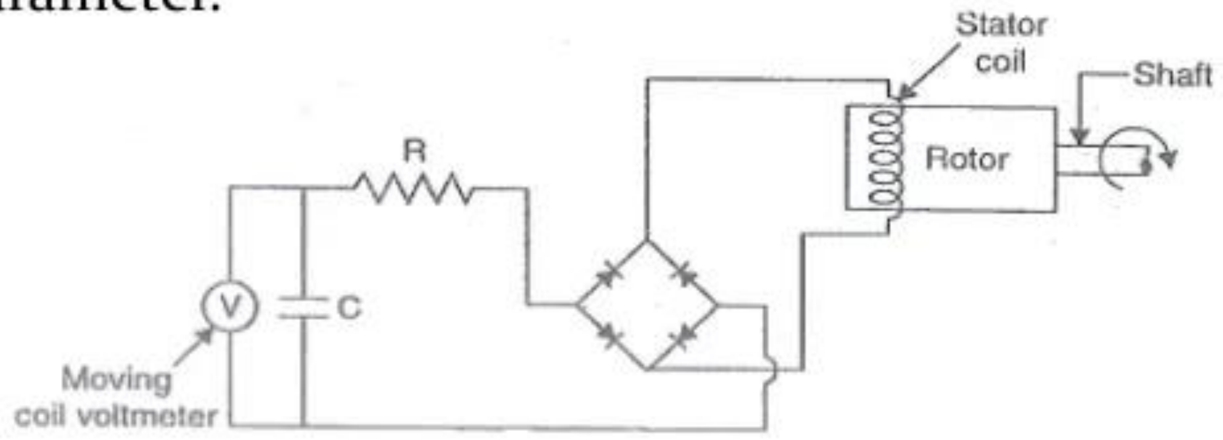


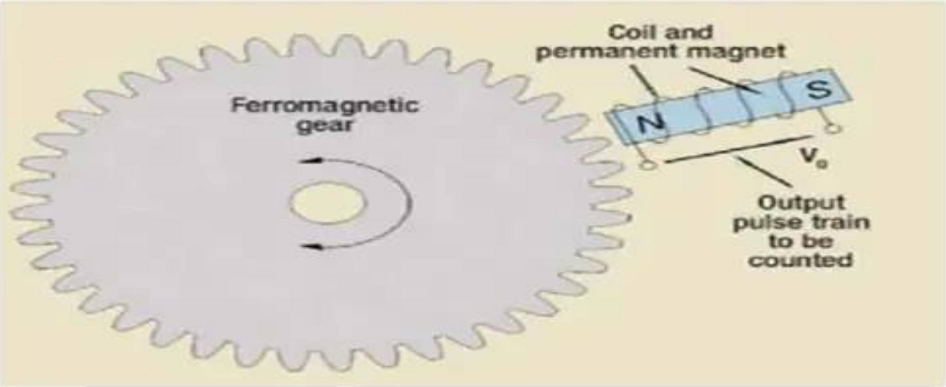
Fig. 33. A.C. tachometer generator.

Contactless electrical Tachometers

Magnetic pickup tachometer

- A coil wounded on permanent magnet not on iron core, this configuration enable us to measure rotational speed of the systems.
- In the construction of variable reluctance sensor, we use ferromagnetic gearwheel. As the gearwheel rotates, change in magnetic flux take place in the pickup coil which further induces voltage. This change in magnitude is proportional to the voltage induced in the sensor.

Magnetic pickup tachometer



Pickup tachometer

- Various pick-up devices can be used in conjunction with a digital counter to give a direct reading of speed.
- An inductive pick-up tachometer is shown in Figure (a).
- As the individual teeth pass the coil they induce an e.m.f. pulse which is appropriately modified and then fed to a di counter.
- A capacitive pick-up tachometer is shown in Figure (b). As rotating vane passes between the plates a capacitance ch occurs in the form of a pulse.
- This is modified and then fed to the digital counter.

Pickup tachometer

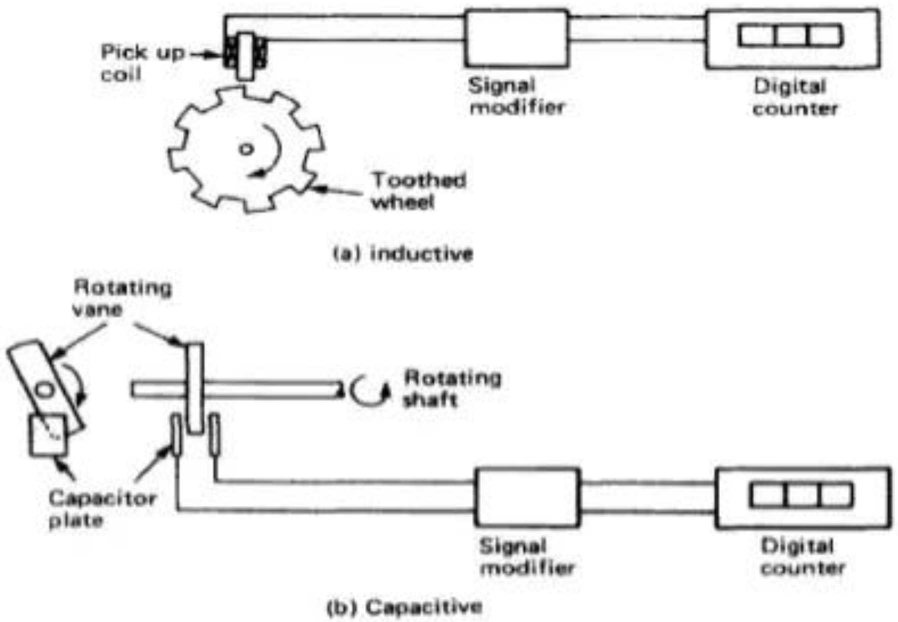


Figure Pick-up tachometers, (a) inductive; (b) capacitive

Photo-electric tachometer

- It consists of a opaque disc mounted on the shaft whose speed is to be measured. The disc has a number of equivalent holes around the periphery. On one side of the disc there is a source of light (L) while on the other side there is a light sensor (may be a photosensitive device or photo-tube) in line with it (light-source).
- On the rotation of the disc, holes and opaque portions of the disc come alternatory in between the light source and the light sensor. When a hole comes in between the two, light passes through the holes and falls on the light sensor, with the result that an output pulse is generated. But when the opaque portion of the disc comes in between, the light from the source is blocked and hence there is no pulse output.
- Thus whenever a hole comes in line with the light source and sensor, a pulse is generated. These pulses are counted/measured through an electronic counter.

Photo-electric tachometer

- The number of pulses generated depends upon the foliowing factors:
  i. The number of holes in the disc;
  ii. The shaft speed.
- Since the number of holes are fixed, therefore, the number of pulses generated depends on thespeed of the shaft only. The electronic counter may therefore be calibrated in terms of speed (r.p.m.)

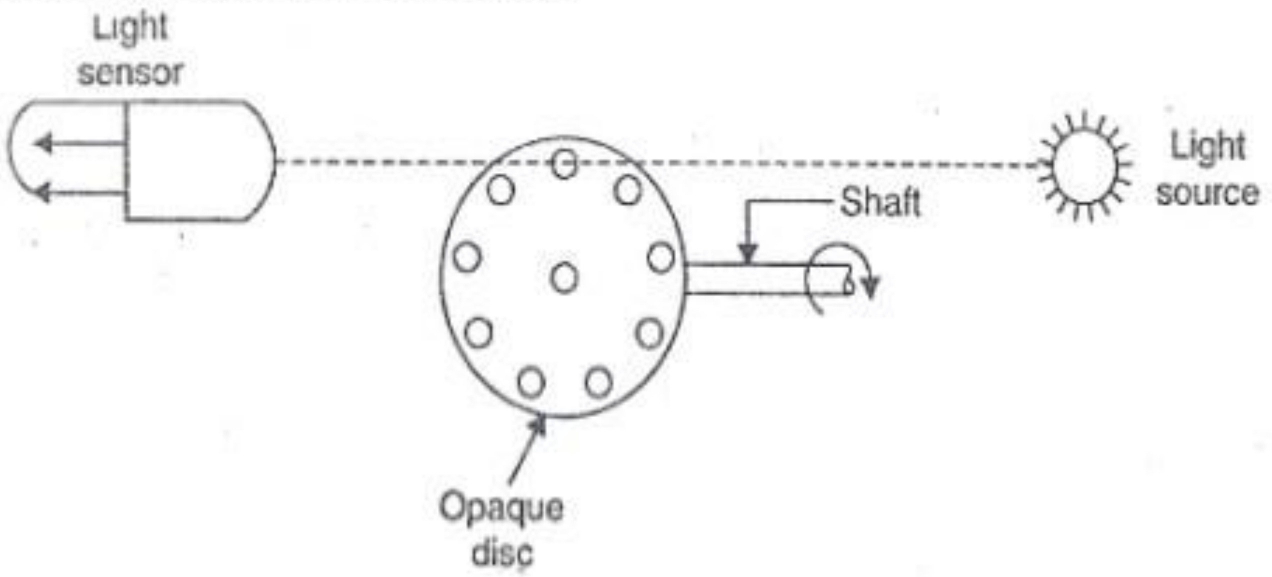
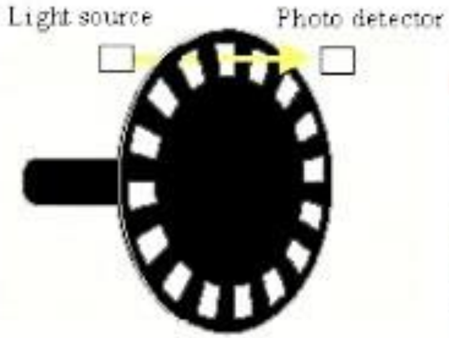
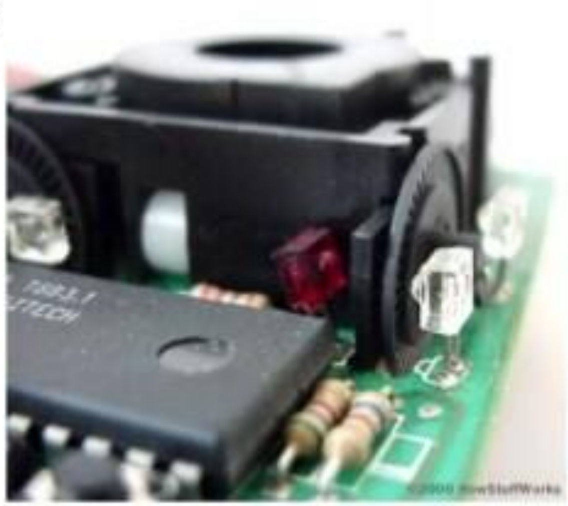
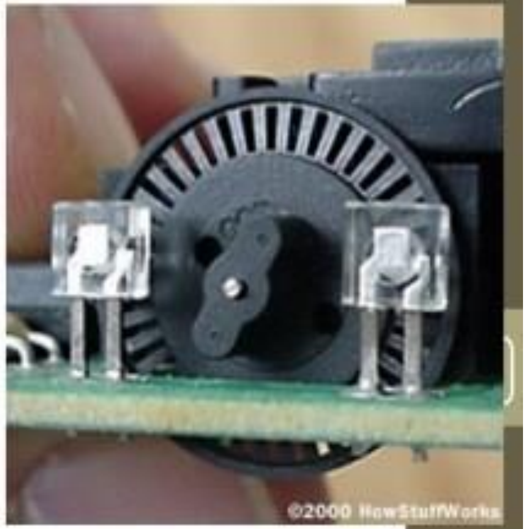


Photo-electric tachometer

- Computer mouse with a ball





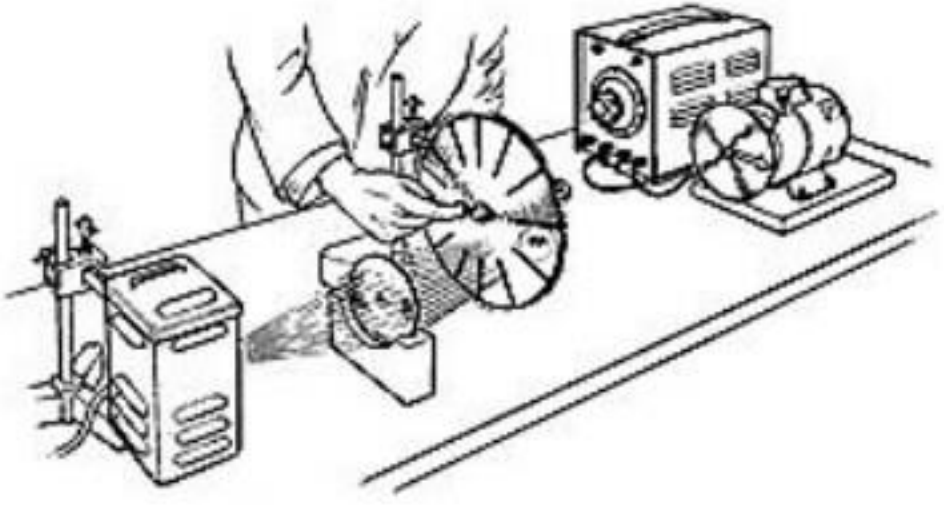


Stroboscope

- The instrument operates on the principle that if a repeating event is only viewed when at one particular point in it's cycle it appears to be stationary. A mark is made on rotating shaft, and a flashing light is subjected on the shaft. The frequency of the flashing is one very short flash per revolution.
- To determine the shaft speed we increases the frequency of flashing gradually from small value until the rotating shaft appears to be stationary, then note the frequency. The frequency then doubled, if there is still one apparent stationary image, the frequency is again doubled. This continued until two images appear 180 degrees apart. When first appear for these two images the flash frequency is twice the speed of rotation.

Stroboscope

- Stroboscopes are used to measure angular speed between 600 to 20000 rpm .
- It’s advantage is that it doesn’t need to make contact with the rotating shaft.



Comparison Between Analog and Digital Tachometers

Analog Tachometer

- Has a needle and dial type of interface
- No provision for storage of readings
- Cannot compute average, deviation, etc

Digital Tachometer

- Has a LCD or LED readout
- Memory is provided for storage
- Can perform statistical functions like averaging, etc

LIQUID LEVEL MEASUREMENT

LIQUID LEVEL MEASUREMENT

- Generally, there are two methods used in industries for measuring liquid level.

These are

1. Direct Method
2. Indirect Method

- Direct method use the varying level of the liquid as a mean of obtaining the measurement and the indirect method use a variable that changes with the liquid level to accurate the measuring mechanism.

1. DIRECT METHOD

This is the simplest method of measuring liquid level. In this method, the level of the liquid is measured directly by means of the following level indicators

i. Sight Glass / Gauge Glass

ii. Float Type / Float - Operated Level Gauges

iii. Torque Tube Displacer / Float Displacement Type Level Gauges

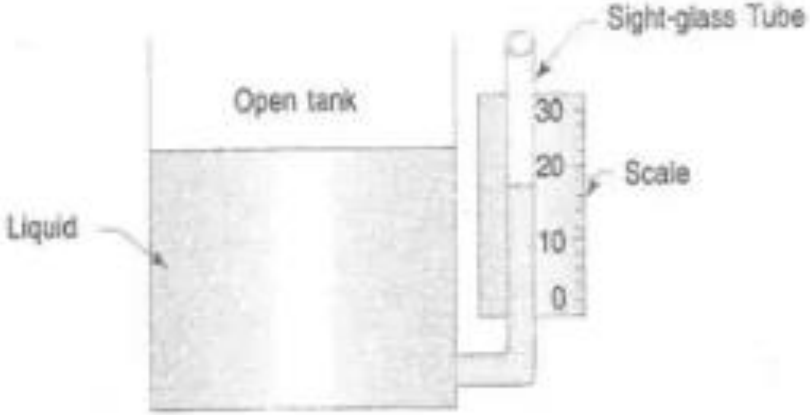
2. INDIRECT METHODS

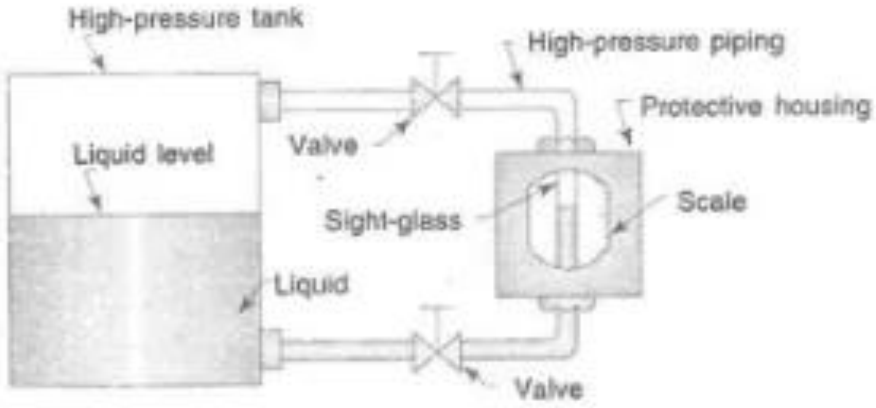
Following are the indirect methods of liquid level measurement generally used in industries.

i. Hydrostatic pressure type
ii. Electrical methods
iii. Ultrasonic level sensor

SIGHT GLASS / GAUGE GLASS

•Sight glass is used for the continuous indication of liquid level within a tank or vessel. A sight glass instrument consists of a graduated tube of toughened glass which is connected to the interior of the tank at the bottom in which the water level is required.





- Fig.1 shows a simple sight glass for an open tank in which the liquid level in the sight glass matches the level of liquid in the tank. As the level of liquid in the tank rises and falls, the level in the sight glass also rises and falls accordingly. Thus, by measuring the level in the sight glass, the level of liquid in the tank is measured. In sight glass, it is not necessary to use the same liquid as in the tank. Any other desired liquid also can be used.

- Fig.2 shows a high pressure sight glass in which measurement is made by reading the position of the liquid level on the calibrated scale. This type of sight glass in high pressure tanks is used with appropriate safety precautions. The glass tube must have a small inside diameter and a thick wall.

Advantages

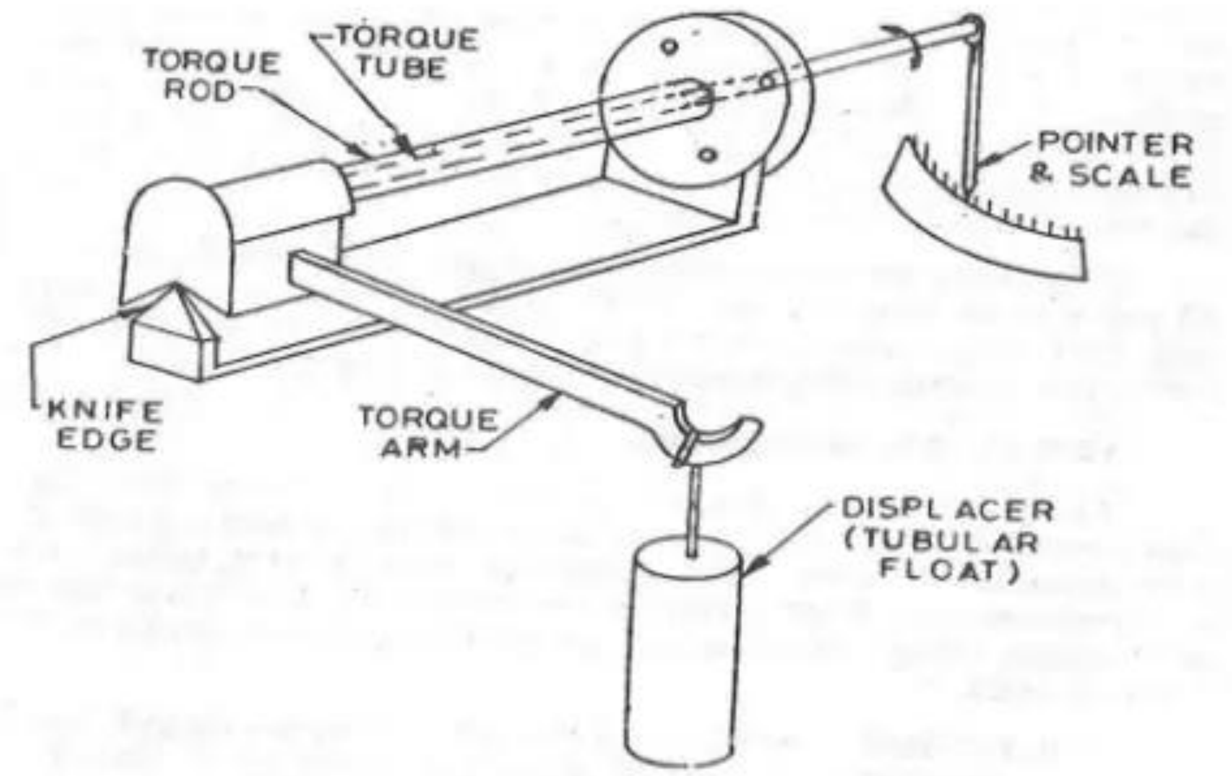
- Direct reading is possible –
- Special designs are available for use up to 316°C and 10000 psi.
- Glassless designs are available in numerous materials for corrosion resistance.

Disadvantages

- It is read only where the tank is located, which is not always convenient.
- Overlapping gauges are needed for long level spans
- Accuracy and readability depend on the cleanliness of glass and fluid

FLOAT DISPLACEMENT TYPE LEVEL MEASUREMENT

- These instruments work on the Archimedes principle according to which a body when placed in a liquid is buoyed up by a force equal to the weight of the displaced liquid, and the apparent change in weight of the body is directly proportional to the level of liquid in which it is placed.
- Torque tube is the most commonly used device for this purpose.
- The displacer is attached to a torque tube assembly whose rotary motion is used for read out/control.
- Otherwise, this instrument is rugged and simple in construction and reliable in operation. With selection of suitable material for float, float cage, and torque tube, it’s possible to use this instrument over a wide range of pressure and for many liquids.



Float Displacement Type Level Measurement

Advantages

- High accuracy
- Reliable in clean liquids
- Can be mounted internally or externally (external mounted unit can be disconnected for maintenance)
- Adaptable to liquid interface measurement

Disadvantages

- Limited range, devices exceeding 1.2m in length are bulky and difficult to balance
- Cost increases appreciably for externally mounted units as pressure ratings increase
- External units may require stilling chambers

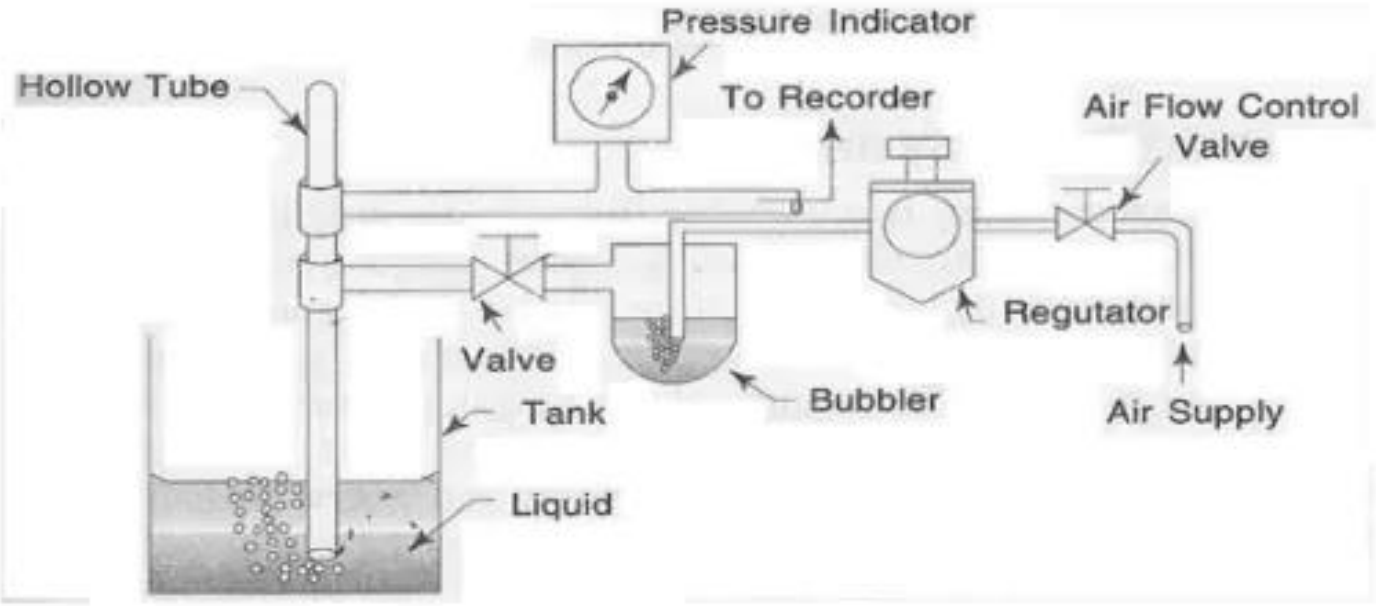
i. HYDROSTATIC PRESSURE TYPE

Hydrostatic pressure methods used for liquid level measurement are listed below.

a. Pressure gauge method
b. Air purge system
c. Diaphragm box type
d. Torque balance type

a. Air purge system

Air purge (bubbler tube) is one of the most popular hydrostatic pressure types of liquid measuring system which is suitable for any liquid as shown in fig.

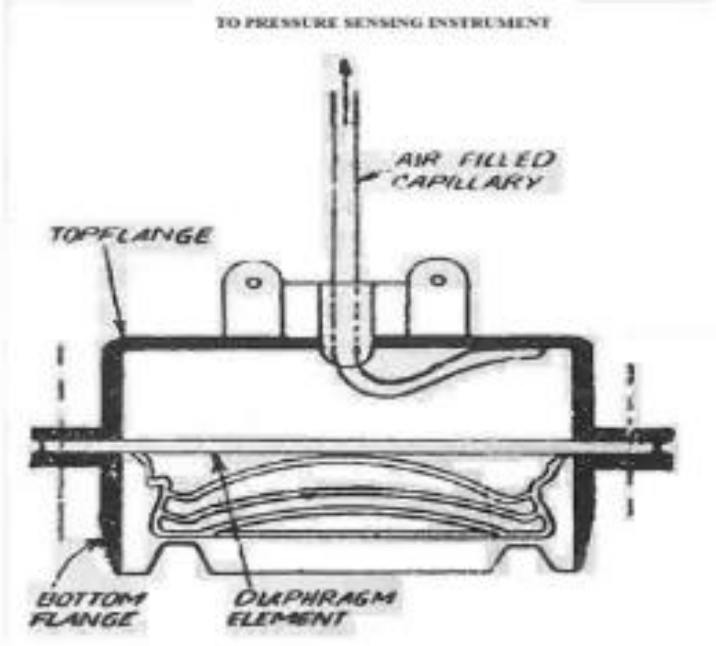


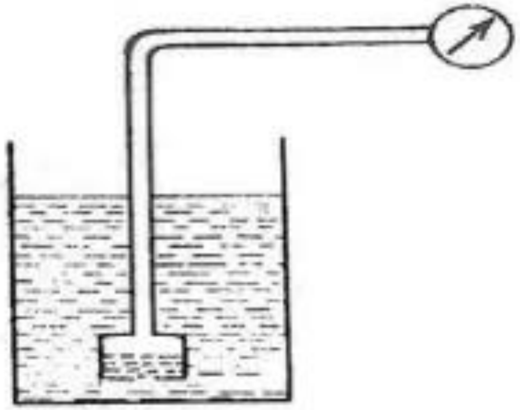
Advantages

- Pressure gauge can be placed above or below the tank level and can be kept as far away as 500 ft (12.7m) from the tank with the help of piping.
- Well - suited for measuring the corrosive/abrasive liquid.

b. DIAPHRAGM BOX METHOD

The diaphragm box liquid level meter is shown in fig. and consist of two flanges in between which is contained a diaphragm element made of rubber or oil resistant synthetic composition.





Advantage

- Where it is necessary to prevent contact b/w liquid and diaphragm, the box may be installed in a well outside the tank and the well is communicated to the tank with an impulse piping. The impulse piping and the well are filled with an inert liquid.

Disadvantage

- The main disadvantage is that the head developed is not sufficient to meet up the line losses as well as for a satisfactory indication. Hence ranges are quite limited.

Method of Pressure Measurement

- Manometer method.
- Elastic pressure transducers.
- Pressure measurement by measuring vacuum.
- Pressure measurement by balancing the force produced on a known area by a measured force.
- Electrical pressure transducers.

➢ Monometers

- A manometer is an instrument that uses a column of liquid to measure pressure.
- The manometer utilizes the hydrostatic (standing liquid) balance principle where in a pressure is measured by the height of the liquid it will support.
- Manometer depends on 3 factors;
    1. the Height of the column of the fluid [H]
    2. The density of the fluid [ρ]
    3. The gravitational constant [g] which equal 9.81m/s2

So the pressure in manometer = **H x g**

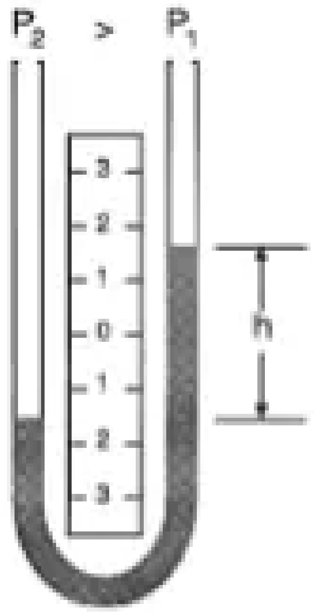
- Manometers measure the unknown pressure by balancing against the gravitational force of liquid heads

- There are many types of manometers, some of which are as follows:

  - U tube manometer.
  - Well type manometer.
  - Barometer.
  - Inclined tube manometer.
  - Micromanometer.

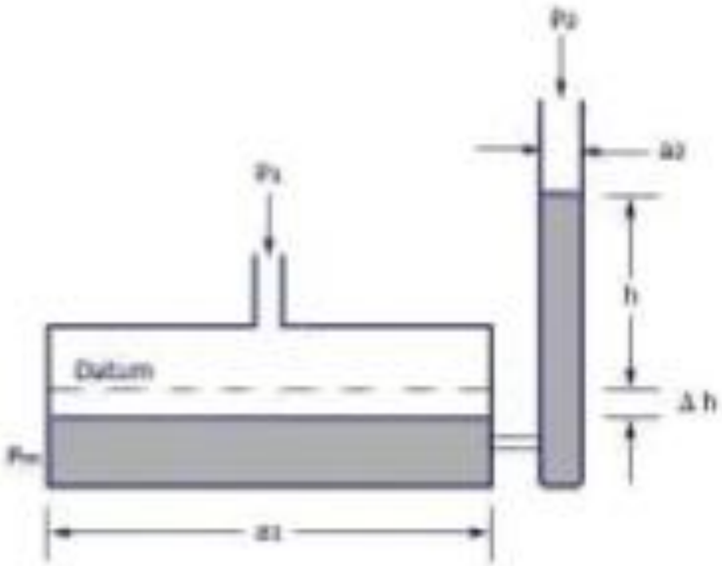
❖ U tube manometer.

- Simplest manometer.
- Used in the measurement of liquid or gas pressure.
- Both legs have same area.
- Manometric fluid of known specific gravity is used.
- Water and mercury are used as a manometric fluid.
- Advantage of using these fluid is that mass density of these fluid can be obtained easily and they do not stick to the tube.



❖ Well type manometer.

- One leg is a simple tube, other leg is a large well.
- For small displacement of liquid level in the well there will be a large change in the height of simple tube.
- The well type manometer is widely used because of inconvenience; the reading of only a single leg is required in it.

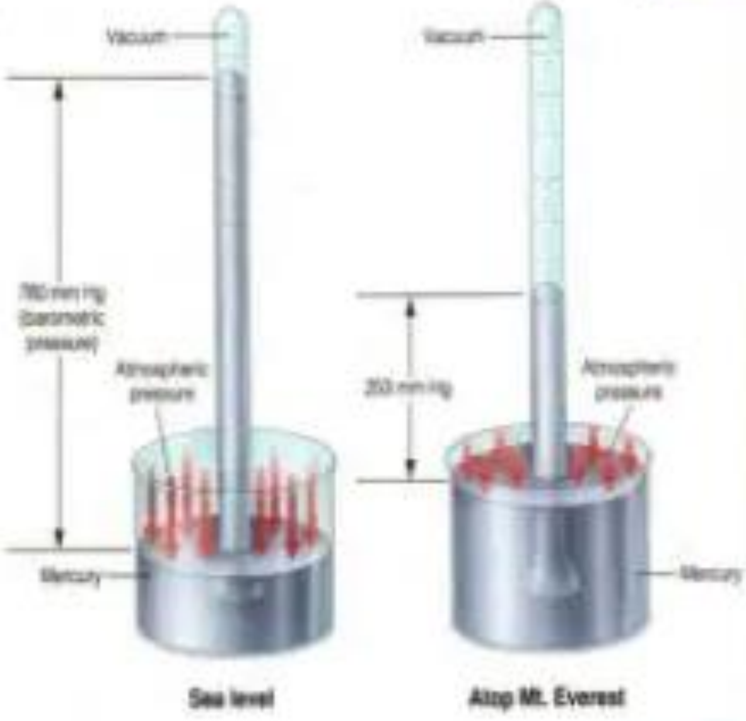


Well Type Manometer

- It consist 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.

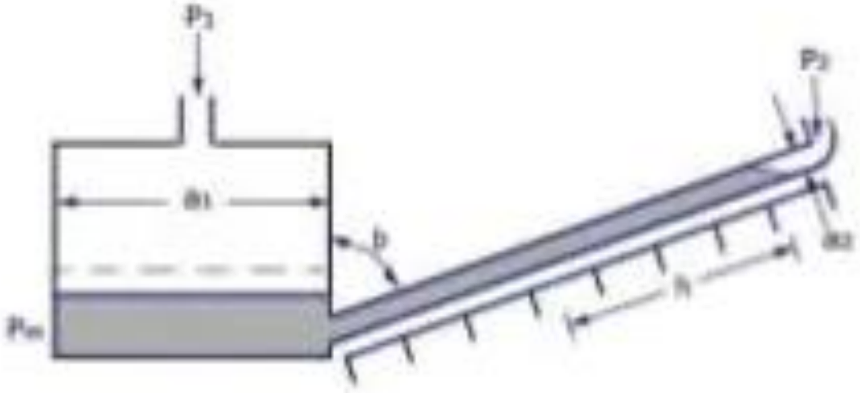
❖ Barometer.

- Principle of working: If one end is at zero absolute pressure then “h” indicates the absolute pressure.
- Well type absolute pressure gauge.
- Its range is from zero absolute to atmospheric pressure.
- High vacuum are not measured.



❖ Inclined tube manometer.

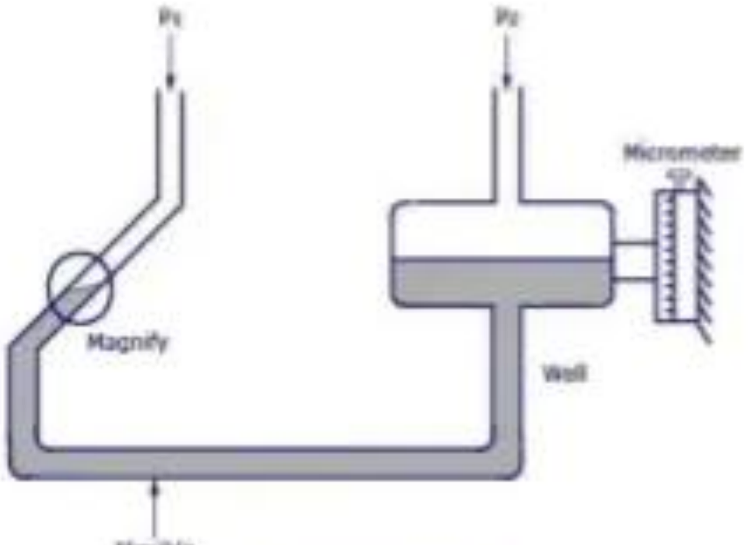
- It is slant manometer.
- The angle of measuring leg is about 10^0.
- Inclination is done to improve the sensitivity.
- This manometer is used to measure very small pressure difference



Inclined Tube manometer

❖ Micromanometer.

- One leg is well type and other leg is inclined tube.
- Inclined leg consist magnifier.
- Initially both well and inclined legs are at same pressure.
- Application of unknown pressure causes meniscus to move towards the reference point.
- The difference between initial & final reading gives change in height.



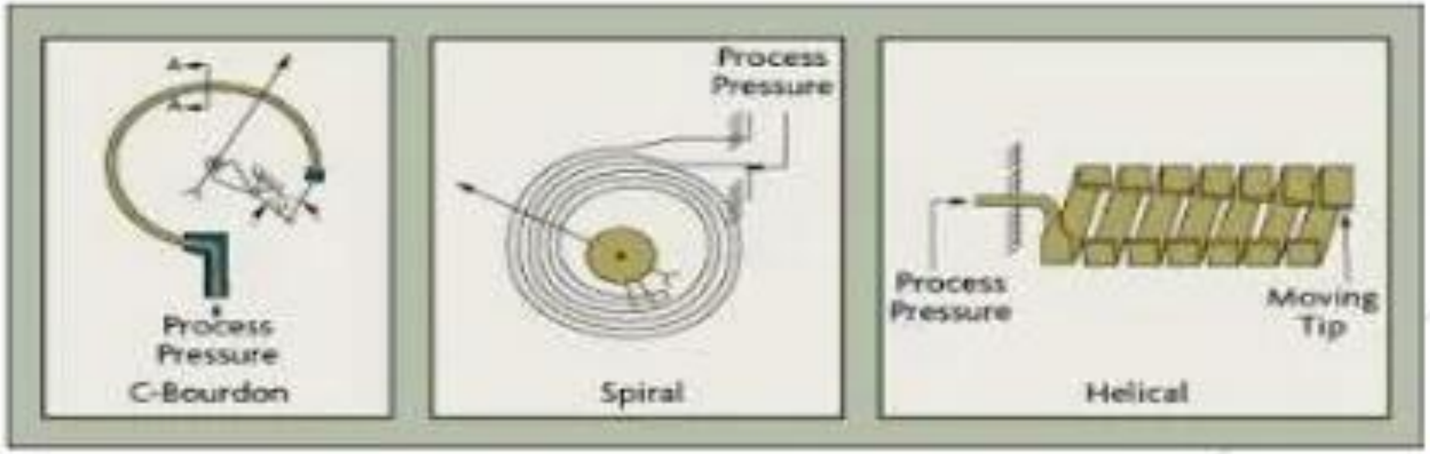
Micromanometer

Elastic Pressure Transducers

- The elastic pressure transducers are the mechanical elements that are used for converting one form of energy into the other form of energy that can be measured easily.
- There are number of mechanical transducers, some of the commonly used ones are described below:
  1) Bourdon tube pressure transducers
  2) Diaphragm pressure transducers
  3) Bellows pressure transducers

➢ Bourdon tube pressure transducers

- A Bourdon gauge uses a coiled tube, which, as it expands due to pressure increase causes a rotation of an arm connected to the tube. In 1849 the Bourdon tube pressure gauge was patented in France by Eugene Bourdon



Advantages:

- Low cost
- Simple construction
- Time-tested in applications
- Availability in a wide variety of ranges, including very high ranges
- Adaptability to transducer designs for electronic instruments
- High accuracy, especially in relation to cos

Disadvantages:

- Low spring gradient (i.e. below 50 psig)
- Susceptibility to shock and vibrations
  Susceptibility to hysteresis

➢ Diaphragm pressure transducers

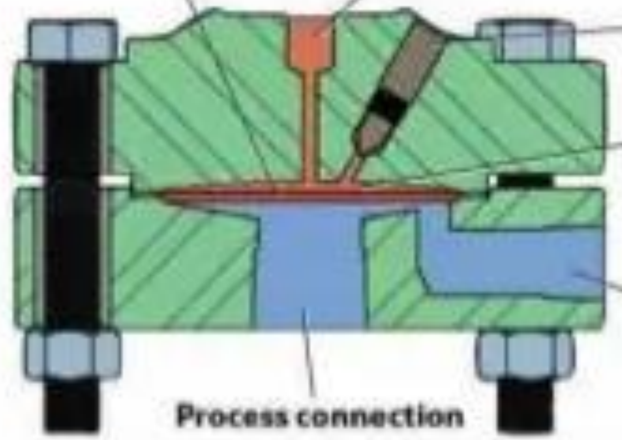
- A second type of aneroid gauge uses the deflection of a flexible membrane that separates regions of different pressure.
- The amount of deflection is repeatable for known pressures so the pressure can be determined by using calibration.
- The deformation of a thin diaphragm is dependent on the difference in pressure between its two faces.
- The reference face can be open to atmosphere to measure gauge pressure, open to a second port to measure differential pressure, or can be sealed against a vacuum or other fixed reference pressure to measure absolute pressure. The deformation can be measured using mechanical, optical or capacitive techniques.
- Ceramic and metallic diaphragms are used.

- Diaphragm are widely used for pressure (gauge pressure), particularly in very low ranges. They can detect a pressure differential even in the range of 0 to 4mm.
- The diaphragm can be in the form of Flat, Corrugated and Capsules the choice depends on the strength and amount of deflection required.

  - Two types of diaphragm are generally used:
    1) Metallic diaphragm gauge
    2) Slack diaphragm gauge

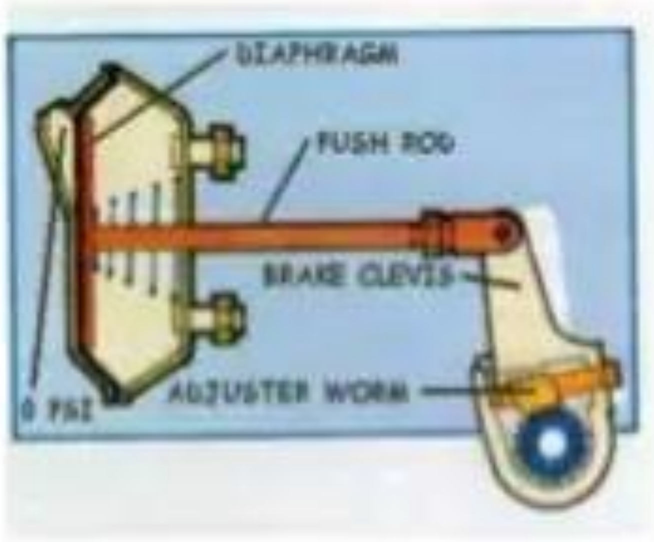
❖ Metallic diaphragm gauge

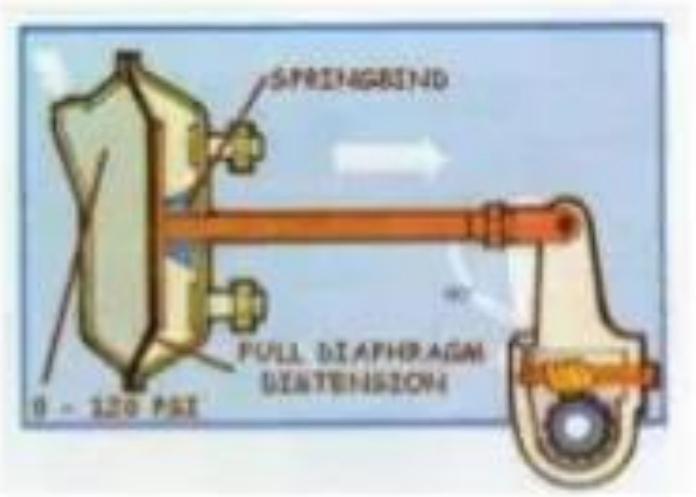
Metallica Diaphragm gauge



❖ Slack diaphragm gauge

Slack Diaphragm gauge





Advantages:

- Diaphragm Pressure Transducer cost is moderate.
- Diaphragm Pressure Transducer possesses high over range characteristics.
- Diaphragm Pressure Transducers are adaptable to absolute and differential pressure measurement.
- Diaphragm Pressure Transducer has good linearity.
- Diaphragm Pressure Transducer is small in size.

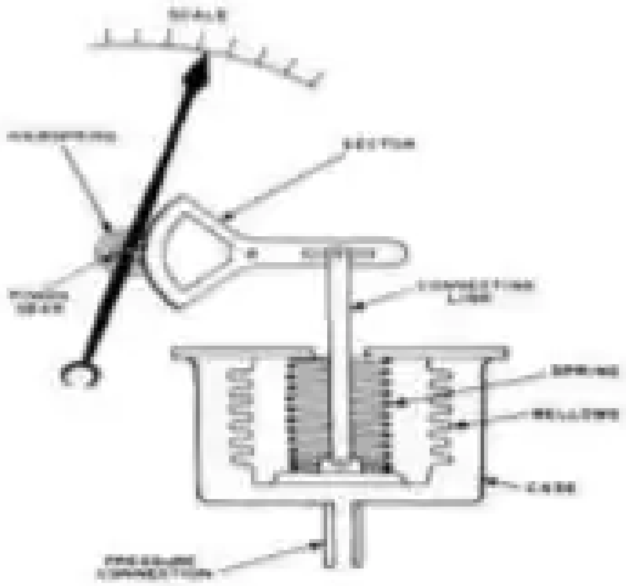
Disadvantages:

- Diaphragm Pressure Transducer lack good vibration and shock resistance
- Diaphragm Pressure Transducers are difficult to repair.
- Diaphragm Pressure Transducer is limited to relatively low pressures

➢ Bellows pressure transducers

- A bellows gauge contains an elastic element that is a convoluted unit that expands and contracts axially with change in pressure.
- The pressure to be measured can be applied to the outside or inside of the bellows however, in practice, most bellows measuring devices have the pressure applied to the outside of the bellows.

Bellows Pressure Transducers



Advantages:

- Moderate cost
- Delivery of high force
- Adaptability for absolute and differential pressure
- Good in the low to moderate pressure range

Disadvantages:

- Ambient temperature compensation neede
- Unsuitable for high pressure
- Limited availability of metals and work hardening of some of them
- Unsuitability of its zero and the stiffness (therefore it is used in conjunction with (in parallel with) a reliable spring of appreciably higher stiffness for accurate characterization

Measurement of Vacuum

- “Pressures below atmosphere are generally termed as low pressures or vacuum pressures.”
- “When the term vacuum is mentioned it means that the gauge pressure is negative.”
- “However, atmospheric pressure serves as a reference and absolute pressure is positive. Low pressures are more difficult to measure than medium pressures.”
- “Pressures above 1 Torr can easily be measured by the direct measurement method, wherein the force applied causes a displacement.”

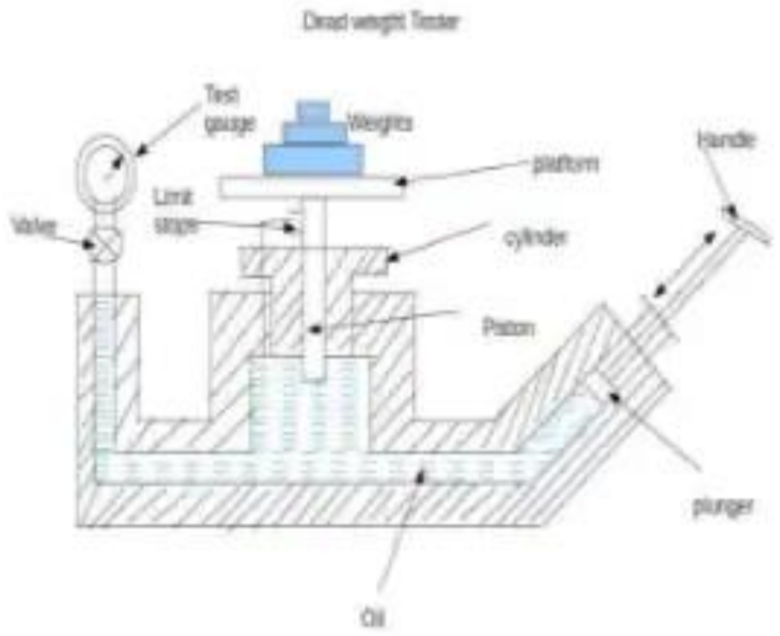
- “Manometers, diaphragms, bellows, and Bourdon tubes are some examples of the instruments used in direct measurement of pressure.”
- “These devices are generally employed to measure a pressure value of about 10 mmHg.”
- “For measuring pressures below 1 Torr, indirect or inferential methods are often employed.”
- “In these methods, pressure is determined by drawing indirect references to pressure-controlling properties such as volume, thermal conductivity, and ionization of gas.”
- “Some of the devices that fall under this category include McLeod gauge, Pirani gauge, and ionization gauge.

Force-Balance Pressure Gauges

- This kind of system is mostly linear.
- It is a continuous balancing system.
- They find application in calibration purposes.
- Pressure easily converted to force with introduction of surface area.
- Dead weight piston gauge, ring balance and bell type pressure gauge are its commonly used devices.

➢ Dead Weight Piston Gauge

- It is used in higher steady pressure measurement.
- Also find usage in calibration of bellows and diaphragms.
- The units of measurement are force and area
- Accuracy < 0.1 %
- Range up to 300 psig.
- It consists of a very accurately machined, bored and finished piston which is inserted into a close-fitting cylinder.

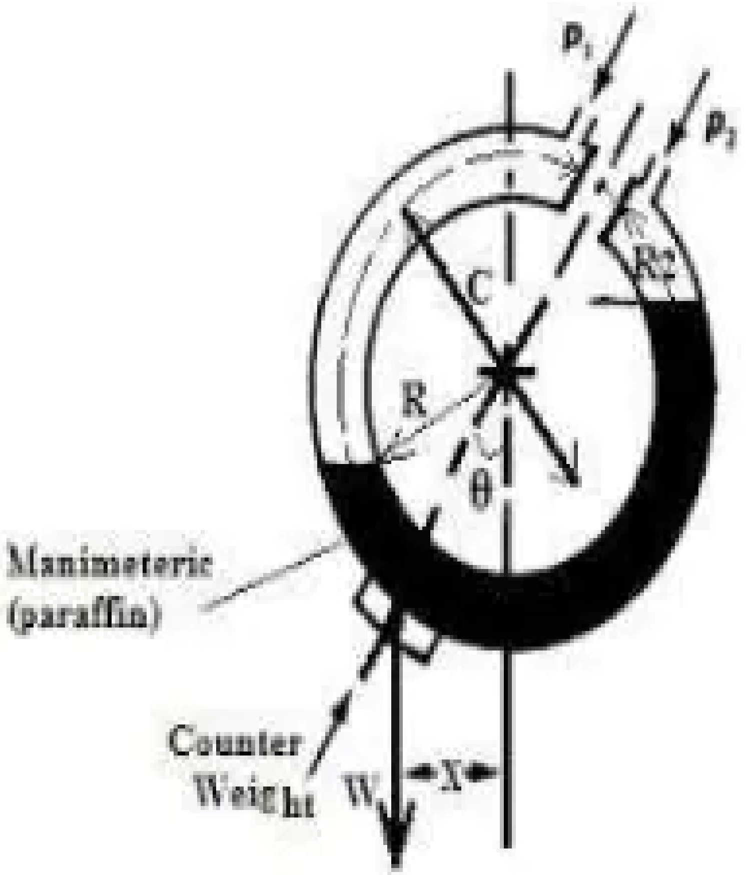


- The area of cross section of both the piston and cylinder are known.
- A platform is provided at the top of the piston where standard and accurate weights are placed.
- An oil reservoir with check valve is provided at the bottom.
- The oil can be sucked by displacement pumps on its upward stroke.
- For calibration, a known weight is first placed on the platform and fluid pressure is applied on the other end of the piston until enough force is developed to lift the piston weight combination and the piston floats freely within the cylinder between limit stops.

➢ Ring Balance Gauge

- For measurement of low differential pressure.
- It consists of a hollow ring of circular section, partitioned at the upper part and partially filled with liquid to form two pressure chambers.
- The ring is supported at the centre of a knife edge.
- Made up of aluminium alloy or plastic moulding.
- Force operating the instrument is generated by the difference between the pressure on two sides of partition.
- Cross section is large in case differential pressure is large.

- The fluid under test are led into the ring through flexible connections.
- Placed such that length and movement are minimum.
- The ring balance is controlled by a weight which is at its lowest point with same pressure on both sides.
- It is the rotation of the ring that indicates the pressure difference.



Ring Balance manometer

➢ Bell Type Pressure Gauge

- Range for differential pressure is between 0.06 Pa and 4 KPa.
- For static pressure, it is as high as 4 to 6 MPa.
- Force produced inside and outside the bell is balanced against a weight by compression of the spring.
- Types: Two : - Thick Wall and Thin Wall.

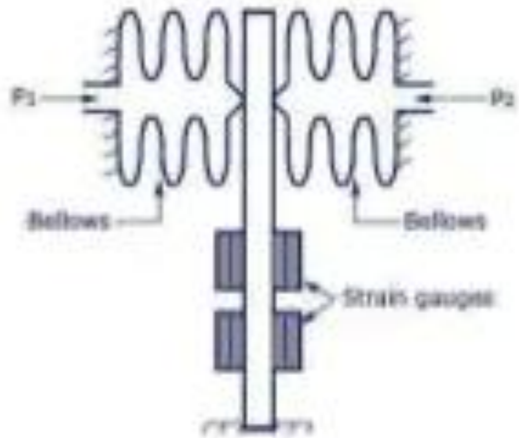
Electrical Pressure Transducers

- The electrical transducers is one which converts the nonelectrical quantity into the equivalent electrical quantity.
- Non-electrical quantity such as force, displacement, stress, temperature.
- Electrical quantity such as current , voltage
- This is four type
  - Strain Gauge Pressure Transducer
  - Potentiometric Pressure Transducer
  - Capacitive Pressure Transducer
  - Reluctance Pressure Transducer
    1. Linear Variable Differential Transformer
    2. Servo Pressure Transducer
    3. Piezoelectric Pressure Transducer

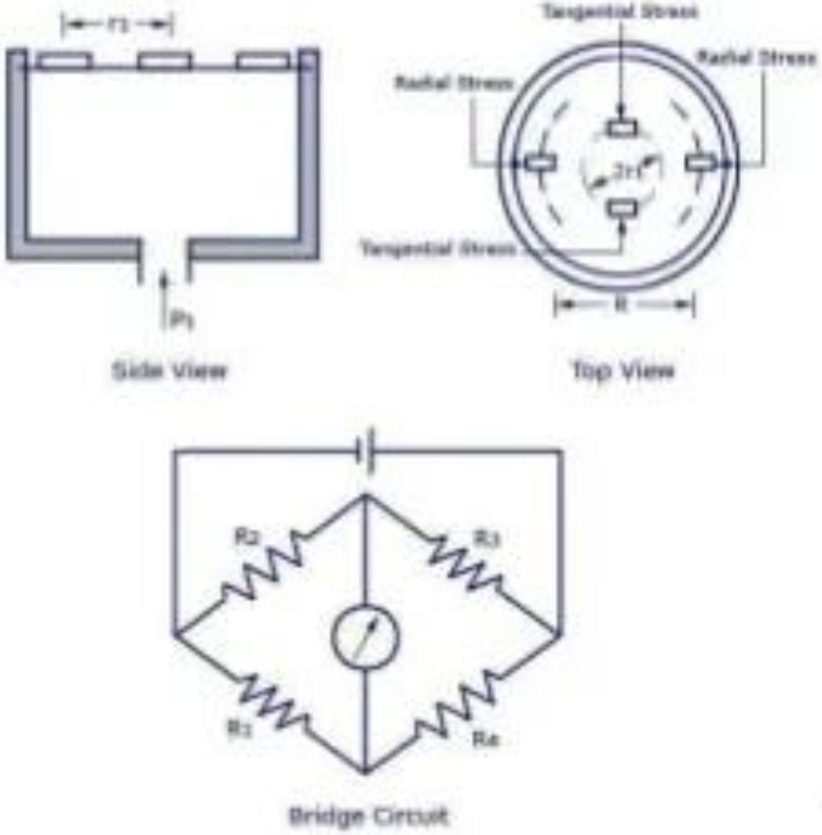
➤ Strain Gauge Pressure Transducer

- Passive resistance transducer.
- Resistance changes when compressed or stretched.
- Attached to pressure sensing device.
- There are four strain gauges connected to a bridge circuit, for two resistance increases with increase of pressure and for the remaining two, resistance decreases with increase of pressure.
- Under no load condition, bridge remains at balance and therefor no current flows in the galvanometer.
- With application of pressure the strain gauges stretch or compress and the bridge becomes unbalanced, resulting a current flow.
- The measuring the current, pressure may be calculated.

Pressure Measurement With Strain Gauge on Bellows



Pressure Measurement With Strain Gauges on Diaphragm



Advantages of Strain Gauge Pressure Transducer:

- Small and easy to install
- Considerably accurate
- Offers wide range of measurement (vacuum to 20000 psig)
- Good stability
- High output signal strength
- High over range capacity
- No moving parts
- Good stability against shock and vibration
- Fast speed of response

Disadvantages of Strain Gauge Pressure Transducer:

- Cost is high
- Electrical readout is necessary
- Require constant voltage supply
- Require temperature compensation

➢ Potentiometric Pressure Transducer

- Here a potentiometer is involved.
- A movable electrical contact, called wiper, slides along the cylinder, touching the wire at one point on each turn.
- The wiper position determines the resistance value between wiper and wire end.
- A mechanical linkage from a bellow or a diaphragm controls the position of the wiper.
- The wiper position determines the resistance which eventually determines the value of pressure.

Measurement of vibration

WHAT IS VIBRATION SENSOR?

- Vibration sensor is a device that serves to detect the presence of vibration then it will be converted into electrical signals, the electric signals are processed in the measuring instrument then we can read the information in the measuring instrument. The selection of vibration sensors for vibration signal monitoring purposes is based on the following considerations:

- Vibration signal type
- Measurement frequency range
- The size and weight of the vibration object.
- Sensitivity of the sensor

TYPES

- Generally there are two types of vibration sensor :

□Contact Vibration Sensors The following sensors require mounting the transducer to the vibrating test piece. This has the advantage of moving with the test article to measure absolute motion.

□Non-Contact Vibration Sensors For non-contact sensors, probes and machines or media are not in direct contact.

TYPES

Contact Vibration Sensors

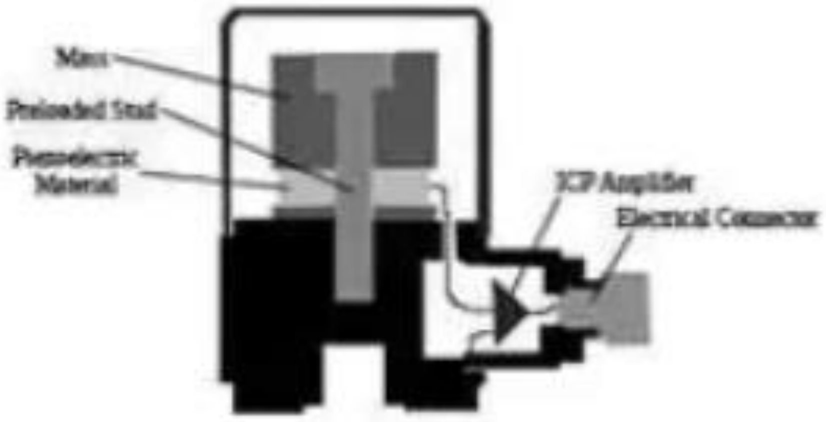
- ❑Acceleration Sensor
  - Piezoelectric Accelerometer
  - Piezoresistive Accelerometer
  - Capacitive MEMS
- ❑Strain Gauges
- ❑Velocity Sensor

Non-Contact Vibration Sensors

- ❖Microphones or Acoustic Pressure Sensors
- ❖Laser Displacement Sensor
- ❖Eddy Current and Capacitive Displacement Sensors

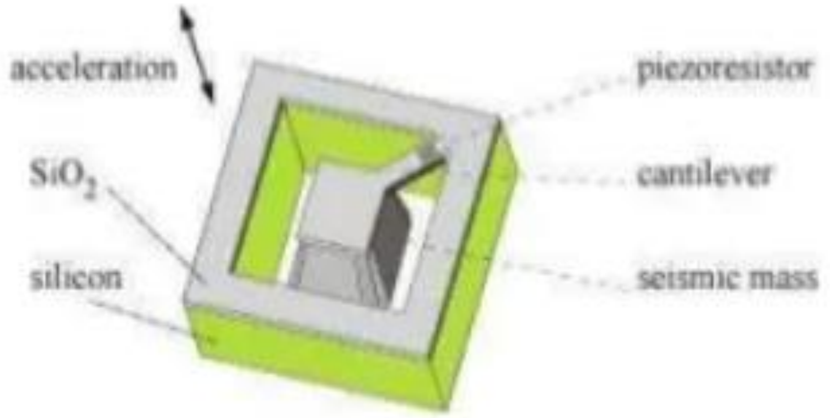
Piezoelectric Accelerometer

- Piezoelectric accelerometers are the most popular for their wide availability and high signal-to-noise ratio. They are AC coupled though so they can't measure static accelerations like gravity. They can also experience issues when excited at their internal resonance.



Piezoresistive Accelerometer

- Piezoresistive accelerometers are becoming increasingly popular because they overcome the issues a piezoelectric accelerometer experiences at high (internal damping and don't magnify resonance issues) and low frequencies (measure down to 0 Hz).

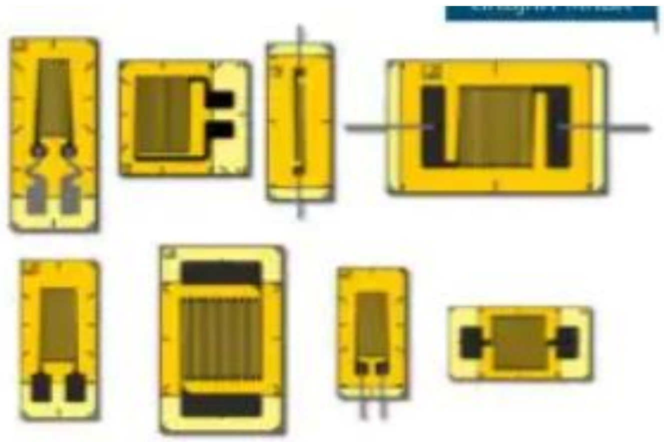


Capacitive MEMS

- These are the type you'll find in your phone. Capacitive MEMS accelerometers are the most cost- effective accelerometers and are typically PCB board mounted. Their data quality is typically much noisier than piezoelectric accelerometers and limited to bandwidths below a few hundred Hertz.

Strain Gauges

- A strain gauge is a foil with an electrically conductive grid. As a strain gauge is stretched or compressed, the electrical resistance of the grid increases or decreases proportionally. The reason being that as the grid is stretched, the current has to travel a greater distance in a thinner conductor which both lead to increased resistance.



Electromagnetic Velocity

- They operate by using the current generated from a magnet traveling within a coil. The advantage of these is that they measure velocity directly and they have a very high-temperature range.

Microphones or Acoustic Pressure Sensor

- Sound is not often thought of as a way to measure vibration, but it should be. After all sound, by definition, is a vibration that travels through the air in the form of pressure waves. Microphones offer a cost-effective means of measuring high-frequency vibration and is especially useful to determine how a system's vibration changes with time

Laser Displacement Sensor

- A laser displacement sensor uses triangulation with a transmitting and receiving lens.
- A laser beam is emitted down towards the target through a transmitting lens. The light then reflects back towards the sensor and is directed by a receiver lens to a receiving element.
- As the target moves closer and farther away, the angle of the reflected light changes

Current and Capacitive Displacement Sensors

- These sensors have similar benefits and drawbacks as lasers for vibration testing.
- But they only measure relative motion, they need to remain fixed and measure the difference in motion of a nearby structure.
- So they typically are used only in the lab especially considering the fragility of the system

Vibration Sensing Systems

- All the previous vibration sensor options discussed require the user to handle wiring, provide power, signal conditioning, and electronics to acquire the data.
- The next two options do all that for you in one, self-contained system. These make it much easier to do vibration testing for the general purpose user, but they often come in handy for advanced vibration measurement and analysis experts for initial testing.

Vibration Meters

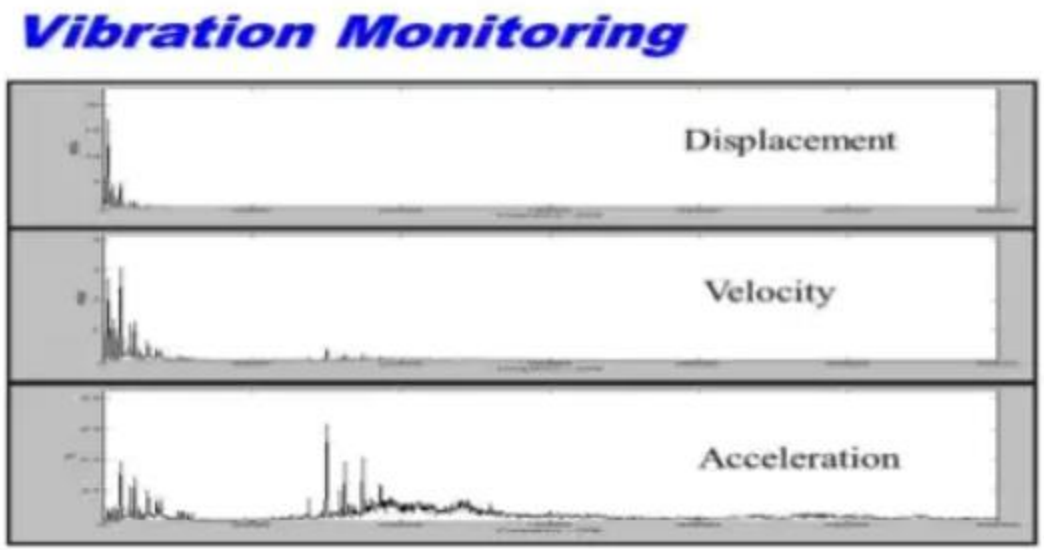
- Vibration meters offer real-time vibration analysis in a handheld unit so that maintenance decisions can be made quickly in the field.
- They either wire to a traditional accelerometer or some even incorporate the accelerometer into the unit cutting down on wiring requirements and complexity.
- Vibration meters give RMS and peak-to- peak levels in real time, sometimes include the resonant frequency of the vibration.
- They also will typically have an algorithm to rate the overall vibration of your bearing or machine.

Vibration Data Loggers

- To put it simply - vibration data loggers are when you grimace at the complexity and cost of setting up a "traditional" accelerometer-based vibration measurement system.
- Vibration data loggers are best for applications that need to do some testing quickly.
- They are very easy to set up so that an engineer is able to acquire vibration data quickly and easily.

Spectrum

- Spectrum or frequency analyzers can be used for signal analysis. These devices analyze a signal in the frequency domain by separating the energy of the signal into various frequency bands. The separation of signal energy into frequency bands is accomplished through a set of filters.



Application of sensors in home appliances

Introduction

- Appliances create their own unique challenges based on the environment they are creating.
- Sensors in many cases are put into a position to measure in the challenging environment.
- For example, a sensor can be used to measure humidity and temperature in a **dishwasher**. While our dishes and forks are cleaned with water jets spraying, elevated temperatures and high humidity, it creates unique challenges for sensors to survive humidity while producing an electrical output signal.
- In similar cases, we cook food in **ovens** to ensure our meals are safe to eat. Building a temperature sensor to ensure the meat is cooked completely requires the survival of the sensor and cabling at elevated oven temperatures.

Force Sensors

- The compact force sensor elements for load imbalance detection in washing machines and microwave ovens. Our FX29 compression load cell features a compact design with millivolt, analog, and digital output signal options.

Washing Machine / Clothes Dryer

- Temperature sensor measures water temperature and controls heating elements
- Pressure sensor monitors water level
- Vibration sensor detects out-of balance conditions during spin
- Proximity sensor verifies door closed and latched before start-up
- Force sensors measure payload weight at the beginning of the wash cycle
- Humidity sensor monitors process humidity and stops the dryer when clothes are dry
- Thermopile measures clothing temperature to prevent overheating and fabric damage
- Force sensors measure payload weight at the beginning of the cycle

Cooktop / Household Oven

- Temperature sensor monitors glass surface temperature for cooking control and “hot” indication lights for user safety
- Temperature probe monitors cooking temperature
- Temperature sensor monitors pyrolytic cleaning temperature and controls door latch

Dishwasher / Refrigerator

- Temperature sensor measures water temperature and controls heating elements
- Magneto-resistive (MR) sensor and magnet verifies spray arm rotation
- Liquid level sensor monitors water level and detergent dispenser level

Microwave Oven / Small Appliances

- Temperature sensors measure liquid and heating element temperatures in toaster ovens, coffee makers, popcorn poppers, etc.
- Humidity sensor monitors relative humidity and steam production for espresso machines, clothes steamers, etc.
- Humidity sensor monitors food moisture content during cooking
- Thermopile measures food temperature without the need to make physical contact
- Force sensor measures food weight on the turntable

8 sensors to help us to create a smart home

https://www.ibm.com/blogs/internet-of-things/sensors-smart-home/

1. Fire/CO detection
2. Leak/moisture detection
3. Window & door open and close
4. Video doorbell
5. Smart thermostat
6. Motion sensors – Passive IR, MW, Area Reflective type, Ultrasonic, Vibration
7. Smart garage door
8. Intercom/hub

Application of sensors in home appliances

Introduction

- Sensors in industrial applications reveal the entire spectrum of parameters coveredlight, radiation, pressure, flow,or level.
- In this respect, sensors often form the core element in their products and solutions and have a decisive influence on the quality, economic efficiency, and safety of the application by controlling key process parameters.

Applications of sensors in industry:

- Laser rangefinders
- Laser scanners/LIDAR
- Laser alignment systems
- Encoders
- Spectrometers
- Container scanners
- Baggage scanners
- Radiation detectors
- Passenger counters

Continued…

- Volumetric flow controllers
- Filter monitoring
- Condition monitoring
- Leak detection
- Level sensing
- Industrial printers
- Cabin air pressure

Types of Sensors Used in Industrial Automation

The following are the various types of sensors used in automation:

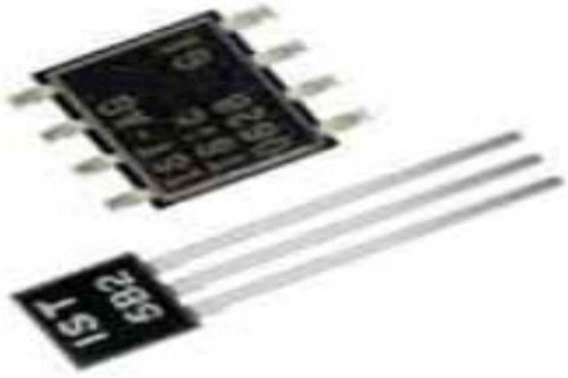
- Temperature Sensors
- Pressure sensors
- MEMS Sensors
- Torque Sensors

Temperature Sensors

- A temperature sensor is a device that collects information concerning the temperature from a resource and changes it to a form that can be understood by another device. These are commonly used category of sensors which detect Temperature or Heat and it also measures the temperature of a medium.
- Digital Temperature Sensors and Humidity & Temperature Sensors are few of the main temperature sensors used in automation.

Digital Temperature Sensors:

- These <u>Digital Temperature Sensors</u> are silicon-based temperature- sensing ICs that provide accurate output through digital representations of the temperatures they are measuring. This simplifies the control system's design, compared to approaches that involve external signal conditioning and an analog-to digital converter (ADC).



Humidity & Temperature Sensors

- The Temperature & Humidity sensors attribute a temperature & humidity sensor complex with a measured digital signal output. By utilizing the technique and temperature & limited digital-signal-acquisition humidity sensing technology, it ensures high consistency and exceptional long-standing stability.

Pressure Sensors

- The Pressure Sensor is an Instrument that apprehends pressure and changes it into an electric signal where the quantity depends upon the pressure applied.
- Turned parts for Pressure Sensors and Vaccum Sensors are few of the major pressure sensors used in Industrial automation.
- These Pressure sensors are widely used in Industrial and hydraulic systems, these are high pressure industrial automation sensors also used in climate control systems.

Vaccum Sensors

- Vaccum Sensors are used when the Vaccum pressure is below atmospheric pressure levels and it can be difficult to sense through mechanical methods. These sensors generally depend on a heated wire with electrical resistance correlating to temperature. When vaccum pressure increases, convection falls down and wire temperature up rises. Electrical resistance increases proportionally and is calibrated adjacent to pressure in order to give an effective measurement of the vaccum.

Applications of Pressure Sensors:

- Used to measure pressure below than the atmospheric pressure at a given location
- Used in weather instrumentation, aircrafts, vehicles, and any other machinery that has pressure functionality implemented
- Pressure sensors can be used in systems to measure other variables such as fluid/gas flow, speed, water level, and altitude

MEMS Sensors (Micro-electro-mechanical Systems)

- These MEMS industrial automation sensors convert measured mechanical signals into electrical signals.
- Acceleration and Motion MEMS are few important sensors used in industrial automation.
- **Acceleration sensors**
- Micro-electro-mechanical Systems (MEMS) Acceleration Sensors are one of the main inertial sensors; and are dynamic sensor competent of have a greater range of sensing capabilities.

Motion sensors

- Micro-electro-mechanical system (MEMS) motion sensors use data processing algorithms designed on a motion interaction platform which integrates numerous low-cost MEMS motion sensors with ZigBee wireless technology to carry personified interactions while working together with machines. Sensor signal processing systems mainly solve noise cancellation; signal smoothing, gravity influence partition, coordinate system alteration, and position information recovery .Widely used in the automotive Industry in ABS technology.

Applications of MEMS Sensors:

- These have numerous applications ranging from industry, entertainment, sports to education. For example, triggering airbag deployments or monitoring of nuclear reactors
- Used to measure static acceleration (gravity), tilt of an object, dynamic acceleration in an aircraft, shock to an object in a car, vibration of an object. Cell phones, washing machines or computers
- Used to detect motion

Torque sensors

- The torque sensors complete with essential mechanical stops, raise overload capacity and offer additional guard during mounting and operation.
- Rotating Torque & Torque Transducers are few important sensors used in industrial automation.

Rotating Torque Sensors

This Rotating Torque industrial automation sensors used for measuring reaction of rotating torque. These torque meters complete with essential mechanical stops increase surplus capacity and offer extra safety during mounting and operation.

Torque Transducers

These torque transducers utilize superior strain gage technology to indulge the most challenging necessities for static and dynamic applications of sensors.

Applications of Torque Sensors:

- Used to Measure the speed of rotation and maintenance necessities
- Used to measure Mass and mass moment of inertia
- The amount of the torque to be calculated, from the point of vision of quasi-static process
- Used to measure the highest speed of rotation, oscillating torque