Measurement of Flow

Slide 3

Most. Naznin Nahar

Flow obstruction meter

Flow obstruction meter: A flow obstruction meter, also known as a flow restriction meter or differential pressure meter, is a device that measures the flow rate of a fluid by intentionally reducing the cross-sectional area of a pipe.

The basic principle of an obstruction flow meter is to create a pressure difference on either side of a device inserted into a pipe. This is done by increasing the velocity of the fluid through the restriction, which causes the pressure to decrease. The volume flow rate is then proportional to the square root of the pressure difference.

Some examples of devices used to obstruct flow include: Orifice plate, Venturi tube, Flow nozzle, etc.

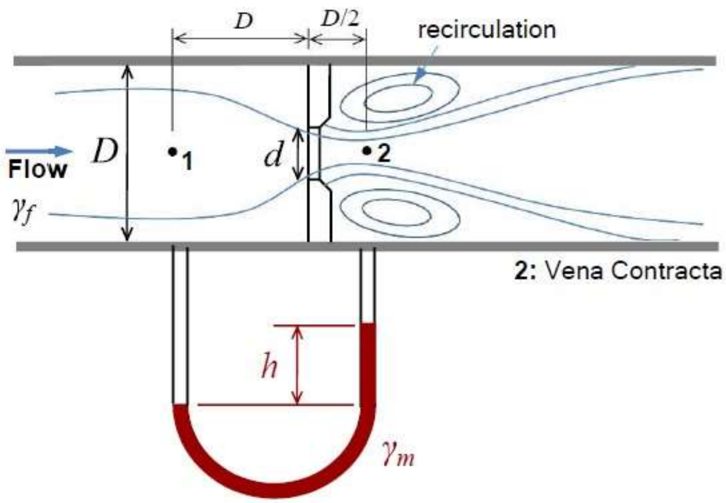
Flow Obstruction Meter

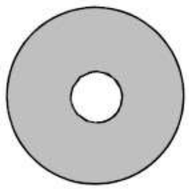
- Types: (1) Venturi, (2) Flow-nozzle (3) Orifice.
- $Q = \frac{C_D A_2}{\sqrt{1-\beta^4}}\sqrt{\frac{2}{\rho}\Delta P}$ $\qquad C_D \equiv \frac{Q_{actual}}{Q_{ideal}}$

Venturi	$0.95 < C_D < 0.98$
Nozzle	$0.99622 + 0.00059D - (6.36 + 0.13D - 0.24\beta^2)/Re_D$
Orifice	$0.60 < C_D < 0.65$

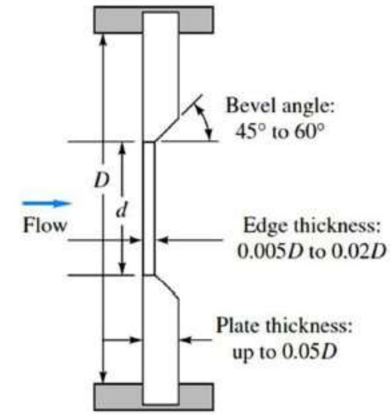
β=d/D
d=obstruction diameter
D=pipe diameter
A_2=obstruction area

Orificemeter





Orifice plate



ISO standard Orifice plate

An orifice meter is a flat plate with a sharp-edged hole in it that is placed in a pipe. As fluid flows through the pipe, it contracts as it approaches the orifice and expands again after it passes through. This creates a pressure difference which can be measured with a manometer.

$$Q_{theo.} \approx \frac{A_0}{\sqrt{\left(1-\frac{d^4}{D^4}\right)}} \sqrt{\frac{2(p_1 - p_2)}{\rho_f}} \qquad (iii)$$

Orificemeter

$$Q_{theo.} \approx \frac{A_0}{\sqrt{\left(1-\beta^4\right)}}\sqrt{\frac{2\left(p_1-p_2\right)}{\rho_f}} \qquad (iv)$$

$$\text{where } \beta = \frac{d}{D}$$

$$\therefore Q_{actual} = C_d Q_{theo.} = \frac{C_d\, A_0}{\sqrt{\left(1-\beta^4\right)}}\sqrt{\frac{2\left(p_1-p_2\right)}{\rho_f}} \qquad (v)$$

Pressure differential can be measured using different approaches; for example using U-tube differential manometer as:

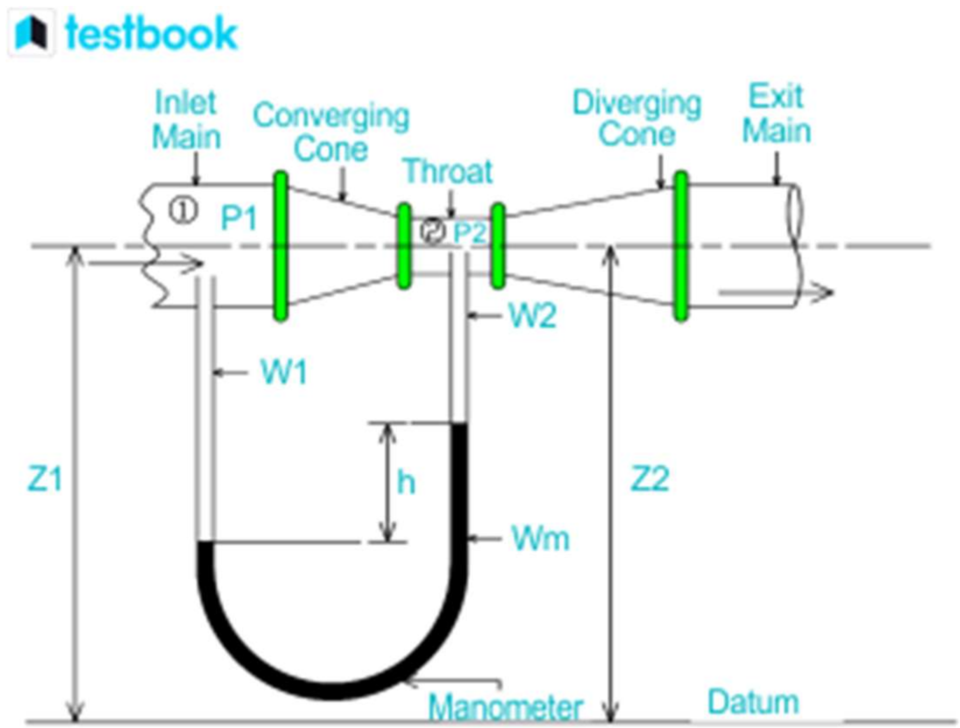
$$p_1 + \left(h' + h\right)\gamma_f = p_2 + h'\gamma_f + h\gamma_m$$

$$\Rightarrow p_1 + h\gamma_f = p_2 + h\gamma_m$$

$$\Rightarrow p_1 - p_2 = h\left(\gamma_m - \gamma_f\right)$$

$$\Rightarrow \frac{p_1-p_2}{\rho_f} = h\left(\frac{\gamma_m-\gamma_f}{\rho_f}\right) \qquad \Rightarrow \frac{p_1-p_2}{\rho_f} = gh\left(\frac{\rho_m}{\rho_f}-1\right)$$

Venturimeter



Venturimeter

Pipe or Cylindrical Inlet: This end of the meter is attached to the pipe through which the fluid flows.

Converging Cone or Part: A short pipe that converges from a diameter that is equal to that of the pipe to a smaller diameter is known as a converging cone or portion. The converging cone has an angle of 21° plus minus 2°.

Throat: It is a small cylindrical section. Typically, the diameter of the throat ranges between 1/2
and 1/4 of the diameter of the cylindrical inlet which is equal to its length. Here, pressure is reduced while velocity is increased.

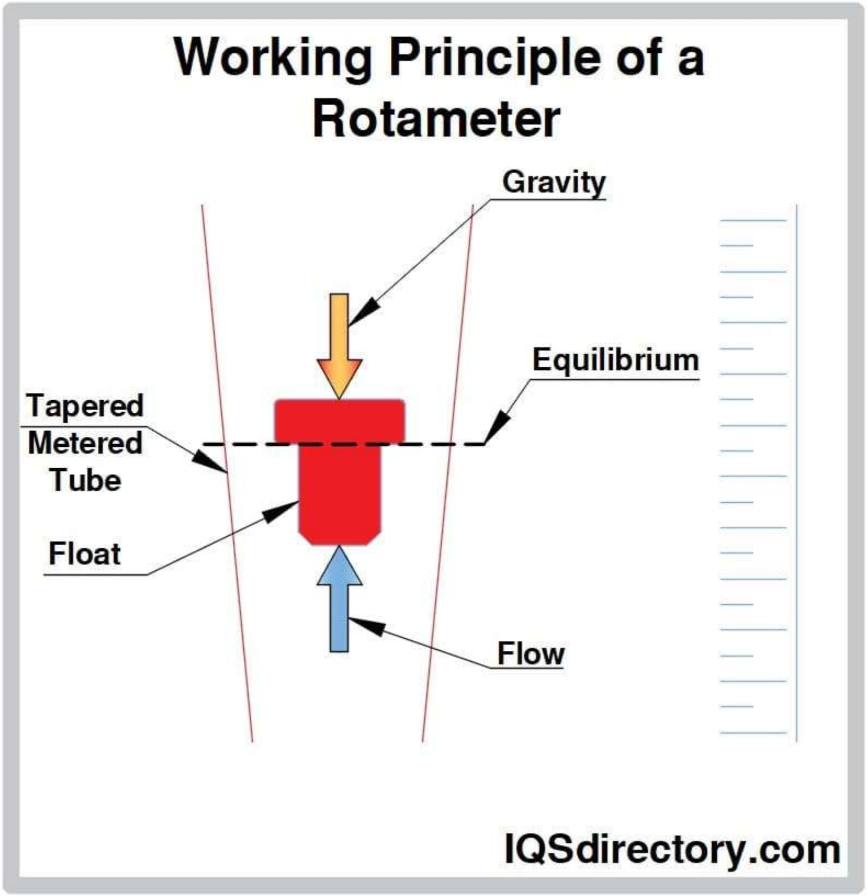
Diverging Cone or Part: The tube diameter steadily increases at this point. As a result, the pressure is increased again to its initial inlet pressure. The diverging cone angle ranges between 5° to 7°.

Differential Manometer: The manometer is a device for measuring the pressure exerted on a fluid column. Pressure differences are typically measured using differential manometers.

Venturi meter

- Venturi can be installed in large diameter pipes using flanged, welded or threaded-ended fittings. It can be used with most liquids, including those having a high solids content. High accuracy, good pressure recovery, and resistance to abrasion are the primary advantages of the venturi. These are offset, however, by considerably greater cost and space requirements than with the orifice and nozzle.
- Orifice is inexpensive, and may often be installed between existing pipe flanges. However, its pressure recovery is poor, and it is specially susceptible to inaccuracies resulting from wear and abrasion. It may also be damaged by the pressure transients because of its lower physical strength.
- The flow-nozzle possesses the advantages of the venturi, except that it has lower pressure recovery, plus the physical advantage of shorter physical length. It is expensive as compared to orifice and is relatively difficult to install properly.

Rotameter (Variable Area Meter)



Rotameter (Variable Area Meter)

A rotameter measures the flow of a liquid or gas based on the variable area principle.

Steps:

1. Fluid enters the rotameter's tapered tube from the bottom and flows upwards.
2. The fluid's force on the float causes it to move upwards.
3. The float continues to rise until the upward force of the fluid balances the float's weight.
4. The float's position in the tube is directly proportional to the flow rate.
5. The flow rate is read from a scale on the tube or from an attached indicator.

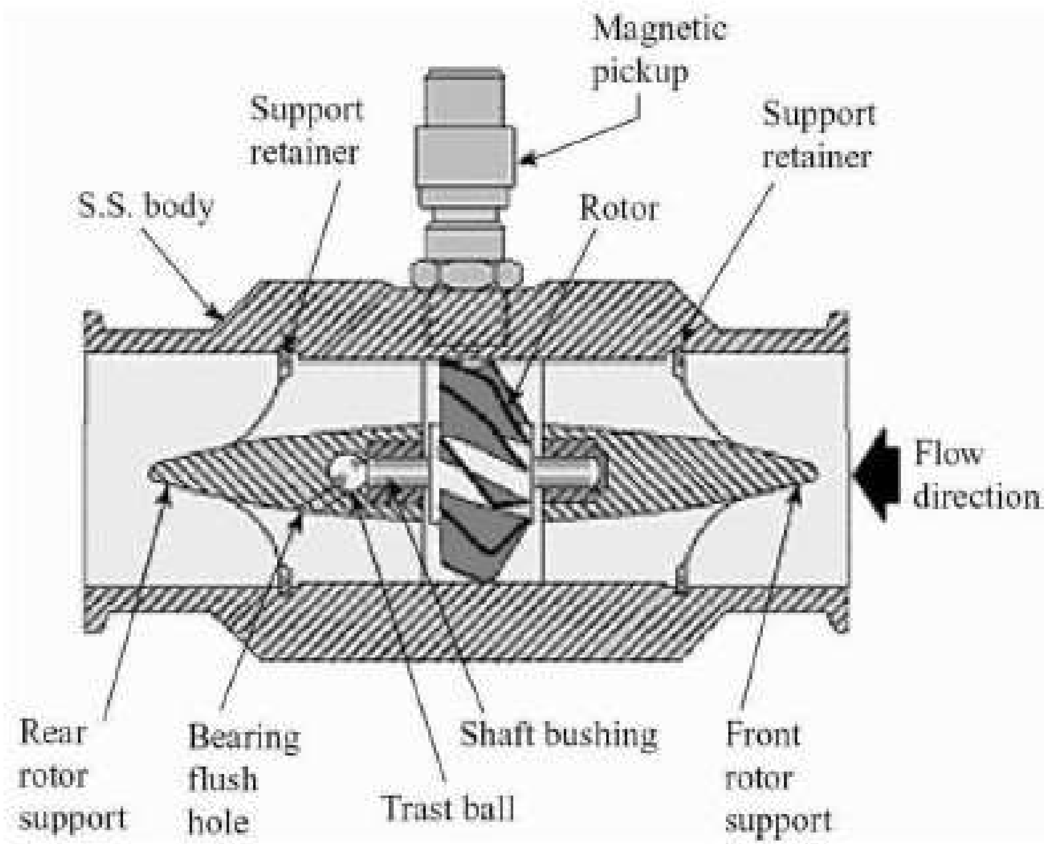
Measurement of Flow

Variable Area Meter (Rotameter)

- **Advantages:**
  - Flow rates can be read directly without any secondary reading devices,
  - Uniform scale over the range of the instrument,
  - Fixed pressure loss at all flow rates,
  - Many corrosive fluids may be handled without complication,
  - Capacity may be changed with relative ease by changing the float and/or tube.
- **Disadvantages:**
  - Meter must be installed vertically,
  - Float may not be visible when opaque fluids are used,
  - It cannot be used with liquids carrying large percentages of solids in suspension,
  - For high pressures and temperatures, it is expensive.

Measurement of Flow

Turbine Flow-meter



Measurement of Flow

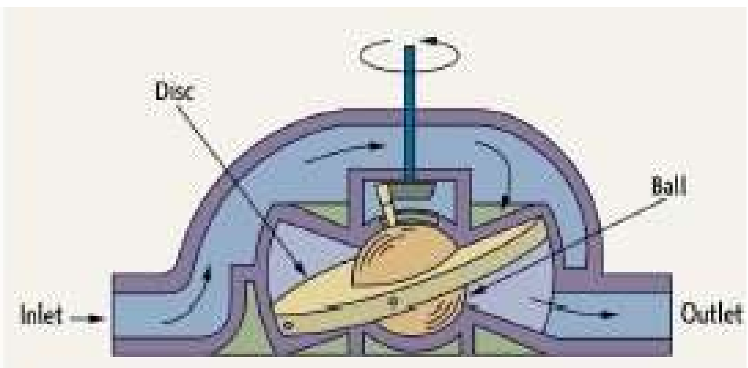
- Turbine flow-meter consists of a multiple-bladed rotor mounted within a non-magnetic stainless steel pipe, perpendicular to the fluid flow. The rotor spins as the fluid passes through the blades.
- The rotor speed is a direct function of the flow rate. Rotor speed can be measured simply and accurately by counting the rate at which turbine blades pass a given point, using a magnetic proximate detector to produce voltage pulses.
- By feeding these voltage pulses to an electronic pulse-rate meter, one can measure flow rate; by accumulating the total number of pulses during a time interval, the total flow is obtained.

Advantages/Disadvantages:

- Very good accuracy, particularly with low-viscosity fluids.
- Operation over wide range of pressure, temperature and fluids.
- Flexibility in flow control and computer interfacing.
- Intrusive method - pressure drops.
- Bearing wear is a major concern.

Positive Displacement Flow-meters

Positive displacement meters use the 'fill and dump' technique to measure the true flow rate. Designs vary but the fluid is allowed to fill a chamber until a limit is reached, at which point the chamber is discharged while a second one fills. Used to measure steady-state fluid flow-rate with high accuracy.



Nutating-disk Flow-meter

Inside a Nutating disk flow-meter, a disk nutates about the vertical axis to allow to pass a certain amount of fluid. It is probably the most commonly encountered flow-meter found throughout the world for commercial, utility and industrial applications. The meter is of particular importance in the measurement of household or domestic water.

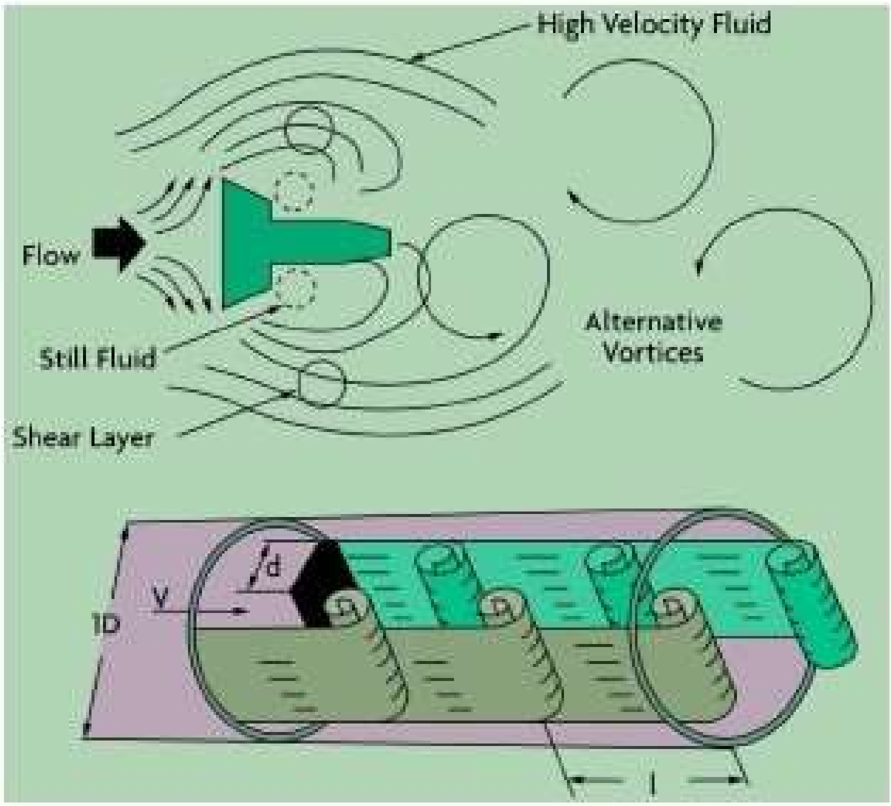
Nutating-disk Flow-meter

Nutating disk working principle: A nutating disk flow meter works by measuring the number of times a disc nutates within a chamber as liquid flows through it and measures the volume flow rate.

1. Liquid flows into a chamber that contains a disc and the chamber is sealed off once the chamber is full.
2. The liquid pressure causes the disk to nutate.
3. The fluid is displaced due to the nutation of the disk and the volume is registered by either an electronic pulse.
4. The frequency of the resulting pulse train is a measurement of flow rate.
5. By counting the number of passed isolated volumes, a flow measurement is obtained.

Measurement of Flow

Vortex Flow Meter



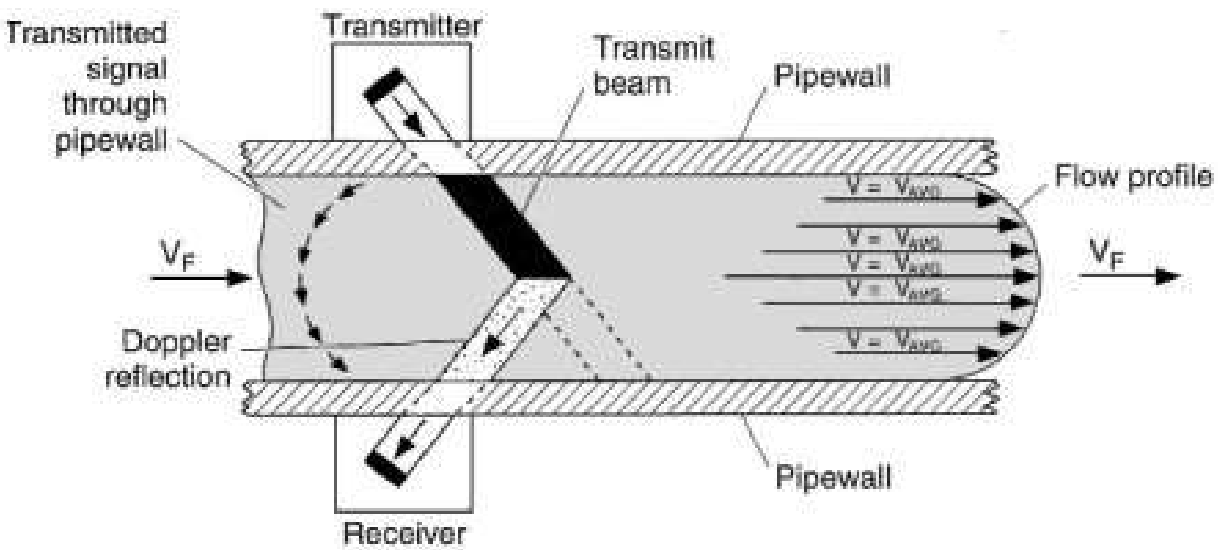
Vortex Flowmeter

Working Principle:

1. A bluff body is placed in the flow path of the fluid.
2. As the fluid passes the bluff body, vortices form on either side and break away in an alternating pattern.
3. Pressure decreases when a vortex(rotating motion) is formed and increases when it is shed. This causes pressure pulsations on both sides of the bluff body.
4. A sensing element picks up the pressure pulsations, amplifies the signal, and converts it to a digital signal.
5. The meter processes the digital signal to calculate flow.

Measurement of Flow

Ultrasonic Flow-meter



e415.eps

Doppler Effect of an ultrasonic signal reflected by suspended particles or bubbles present in the fluid is employed. Ultrasonic sound of known frequency is transmitted into the pipe & the reflected wave with slightly different frequency is received by the receiver. The frequency difference is directly proportional to the flow of liquid.

Measurement of Flow

- Most devices require that the fluid contain at least 25 ppm of particles or bubbles having diameters of 30 micron or more.
- Ultrasonic measurement of gas flow is not common.
- Meters available as in-line pipe sections with installed transducers or as clamp-on devices. Suitable electronics are used to display fluid flow rates or total flow quantities.

Advantages: $\odot$ Non-intrusive, $\odot$ No pressure drop, $\odot$ Good accuracy can be maintained without frequent field calibration, $\odot$ Can be used to measure the flow of liquids & slurries which ordinarily cause damage to conventional sensors

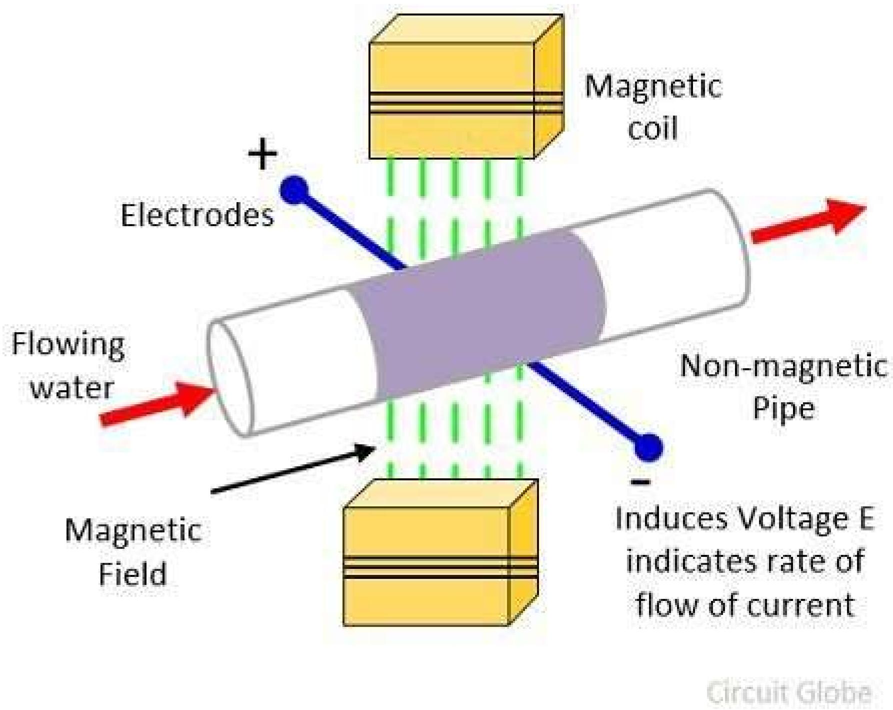
Disadvantages: $\odot$ Very expensive, $\odot$ Measures particle velocity which may be different from that of the fluid, $\odot$ Doppler shift is proportional to the sound velocity in fluid which depends on pressure & fluid composition.

Magnetic Flowmeter

Working principle: A magnetic flow meter uses Faraday's law to measure the flow of a conductive fluid through a pipe.

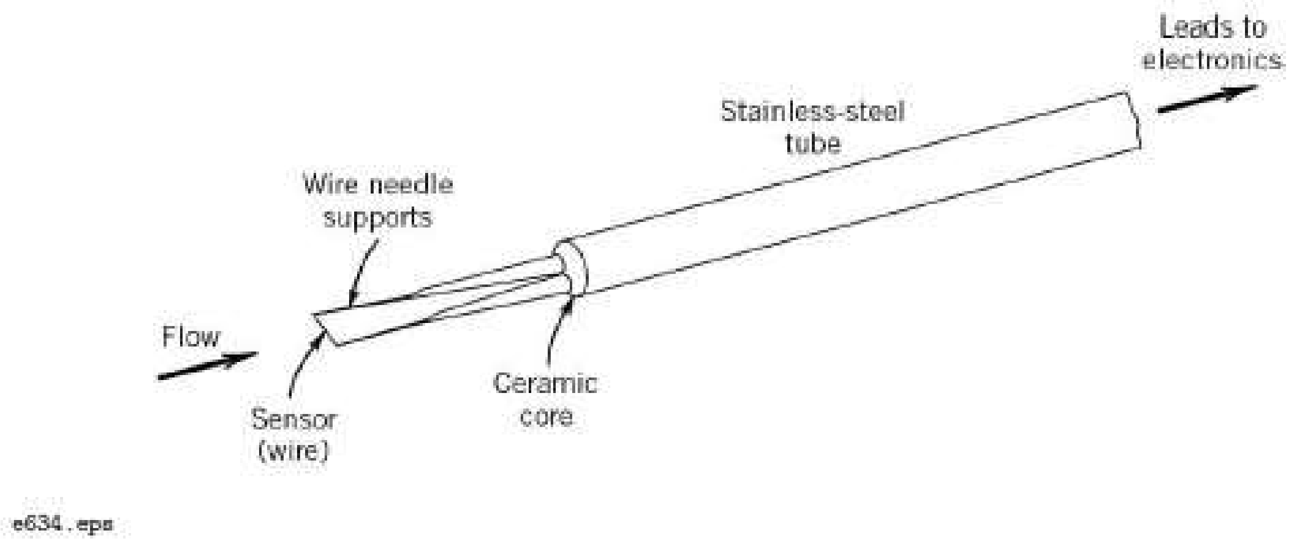
1. Faraday's law states that the voltage induced across a conductor moving at right angles through a magnetic field is proportional to the conductor's velocity.
2. When a conductive fluid flows through a pipe an electrode voltage is induced between two electrodes placed at right angles to the magnetic field.
3. The induced voltage is carried to a transmitter through an electrode circuit.
4. The transmitter converts the voltage into a quantifiable flow velocity.
5. The volumetric flow rate is calculated using flow velocity and pipe's area.

Magnetic Flowmeter



Measurement of Flow

Hot-wire Anemometer



$$q = i^2 R = i^2 R_o[1 + \alpha(T_w - T_o)] = (a + b\sqrt{V})(T_w - T_\infty)$$

T_w = *wire temperature*, T_∞ = *free stream temperature of fluid*,
V = *fluid velocity*

Hot Wire Anemometer

Working Principle: A hot wire anemometer measures the velocity of a fluid by measuring the heat loss of an electrically heated wire that's placed in the fluid stream.

1. An electric current passes through a fine wire, causing it to heat up. The wire is made from a material with a high-temperature coefficient of resistance, so its resistance changes as its temperature changes.
2. When the fluid passes over the wire, it cools the wire. The amount of time it takes for the wire to cool indicates the velocity of the fluid.
3. The wire's resistance changes in response to the temperature variation.
4. The change in resistance is converted into an electrical signal, and the magnitude of the signal is proportional to the fluid velocity.

Laser Doppler Anemometer

Working Principle:

1. A laser beam is split into two beams of equal intensity that travel in different paths.
2. The two beams are focused to intersect at a point in the fluid.
3. The intersecting beams create an interference pattern of alternating bright and dark regions.
4. Particles in the fluid scatter light from the beams when they pass through the intersection.
5. Photomultiplier tube detects the scattered light.
6. The scattered light's frequency shift is proportional to the flow velocity. The PMT's interference signal is used to calculate the velocity

Laser Doppler anemometer