INDUSTRIAL PROCESS MEASUREMENT – Industrial Transducer Systems.

The aim of this unit is to introduce the learner to principles and techniques related to the Performance, Operation and Application of a range of Industrial Transducer Systems.

2 APPLICATION, SELECTION AND OPERATION OF TRANSDUCER TYPES.

flow *– Venturi, orifice plate, Pitot static tube, DP cell, conventional/smart electronic and pneumatic types, variable area, vortex, ultrasonic;*

Flow measurement

Flow measurement is essential in many industries such as the oil, power, chemical, food, water, and waste treatment industries. These industries require the determination of the quantity of a fluid, either gas, liquid, or steam, that passes through a pipeline check point (flowmeter). Quantities to be determined may be volume flow rate, mass flow rate, or flow velocity.

Overview of Flow Measurement

Some flowmeters measure flow as the amount of fluid passing through the flowmeter during a time period (such as 1000 litres per minute). Other flowmeters measure the totalised amount of fluid that has passed through the flowmeter (such as 1000 litres).

Flowmeters consist of a primary device, transducer and transmitter. The transducer senses the fluid that passes through the primary device. The transmitter produces a usable flow signal from the raw transducer signal. These components are often combined, so the actual flowmeter may be one or more physical devices.

The development of a flowmeter involves a wide variety of disciplines including the flow sensors, the sensor and fluid interactions through the use of computation techniques, the transducers and their associated signal processing units, and the assessment of the overall system under ideal, disturbed, harsh, or potentially explosive conditions.

Flow measurement can be described by

Q = A x V, which means that the volume of fluid passing through a flowmeter is equal to the cross-sectional area of the pipe (A) times the average velocity of the fluid (V); and

W = r x Q, which means that the mass flow of fluid passing through a flowmeter (A) is equal to the fluid density (r) times the volume of the fluid (Q).

Volumetric flowmeters directly measure the volume of fluid (Q) passing through the flowmeter. The only flowmeter that measures volume directly is the positive displacement flowmeter.

Velocity flowmeters use different techniques that measure the velocity (v) of the flowing stream to determine the volumetric flow. Examples of flowmeter technologies that measure velocity include magnetic, turbine, ultrasonic, and vortex shedding flowmeters.

Mass flowmeters utilise techniques that measure the mass flow (W) of the flowing stream. Examples of flowmeter technologies that measure mass flow include Coriolis mass flowmeters.

Inferential flowmeters do not measure volume, velocity or mass, but rather measure flow by inferring its value from other measured parameters. Examples of flowmeter technologies that measure inferentially include differential pressure, target and variable area flowmeters.

Regardless of the actual physical quantity measured, the goal of a typical flowmeter is to give information about one of the following values:

- Volume flow rate (Volume)
- Mass flow rate (Mass)
- Flow velocity (Velocity)

Flowmeters can therefore be categorized accordingly (Volume, Mass, or Velocity).

Volumetric flow rate, also **volume flow rate** and **rate of fluid flow**, is the volume of fluid which passes through a given surface per unit time

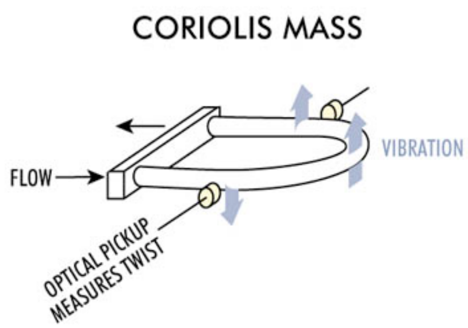
Mass flow rate is the movement of mass per time, The mass flow rate can also be calculated by multiplying the volume flow rate by the density.

The following table shows a range of flow measurement devices, and the flow type they can indicate.

Measurement Technology			Measurement	Resulting flow type
1.	**Coriolis**		Acceleration	Mass
2.	**Differential Pressure**	**Orifice**	Pressure	Volume
		Pitot Tube	Pressure	Volume
		Venturi	Pressure	Volume
3.	**Magnetic**		Electromagnetic Field	Velocity
4.	**Positive Displacement**	**Nutating Disc**	Volume	Volume
		Oscillating Piston	Volume	Volume
		Oval Gear	Volume	Volume
5.	**Turbine**		Rotation	Volume
6.	**Ultrasonic**	**Doppler**	Acoustic Waves	Velocity
		Transit Time	Acoustic Waves	Velocity
7.	**Variable Area**	**Rotameter**	Pressure	Volume
8.	**Vortex**		Frequency	Velocity

Coriolis Mass Flowmeters

Coriolis mass flowmeters measure the force resulting from the acceleration caused by mass moving toward (or away from) a centre of rotation.

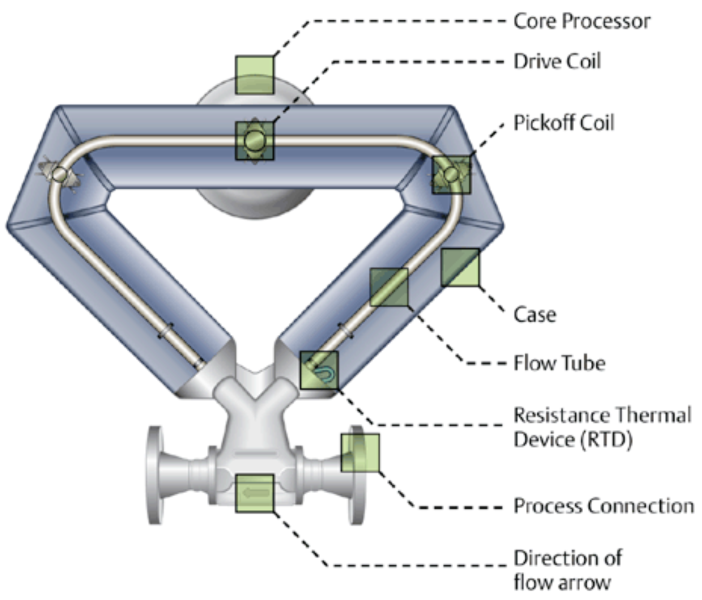


They are primarily used to measure the mass flow of liquids, such as water, acids, caustic, chemicals, and gases/vapours. Straight-tube designs allow measurement of some dirty and/or abrasive liquids.

In a Coriolis mass flowmeter, the tube (or tubes, – in a double tube device) are caused to vibrate.

When there is no flow present, the vibration is uniform along the length of the tube.

When fluid is fed through the flow meter, ie when there is mass flow, the fluid starts to twist as it flows down the tube (due to coriolis force), and the vibration along the tube becomes non-uniform, resulting in the tube twisting slightly. The amount of twist, causes a phase difference in vibration between the inlet to the tube and the outlet, the amount of which is proportional to the mass flow rate of fluid passing through the tube(s).



Sensors are then used to measure the frequency of vibration, and from this generate a linear flow signal.

The actual frequency of the vibration depends on the size of the mass flow meter, and ranges from 80 to 1000 vibrations per second. The amplitude of the vibration is too small to be seen, but it can be felt by touch.

Differential Pressure Flowmeters

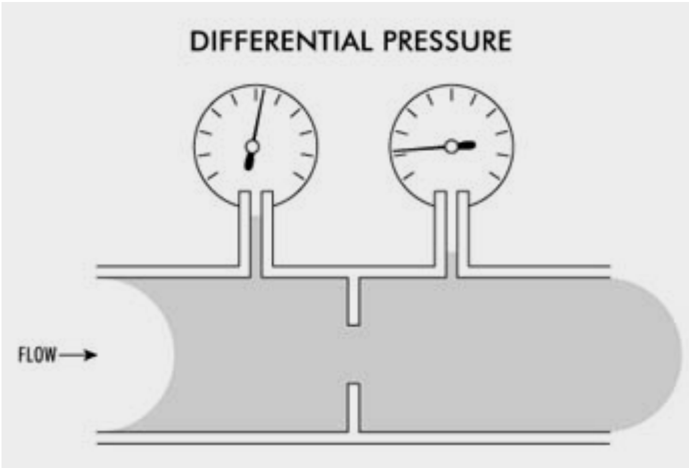
Differential pressure flowmeters inferentially measure the flow of liquids, gases and vapour in pipes, such as water, cryogenic liquids, chemicals, air, industrial gases, and steam.

These flowmeters use *Bernoulli's equation* to measure the flow of fluid in a pipe.

$$P_1 + \frac{1}{2} \cdot \rho_1 \cdot V_1^2 = P_2 + \frac{1}{2} \cdot \rho_1 \cdot V_2^2$$

A constriction is introduced into the pipe that creates a pressure drop.

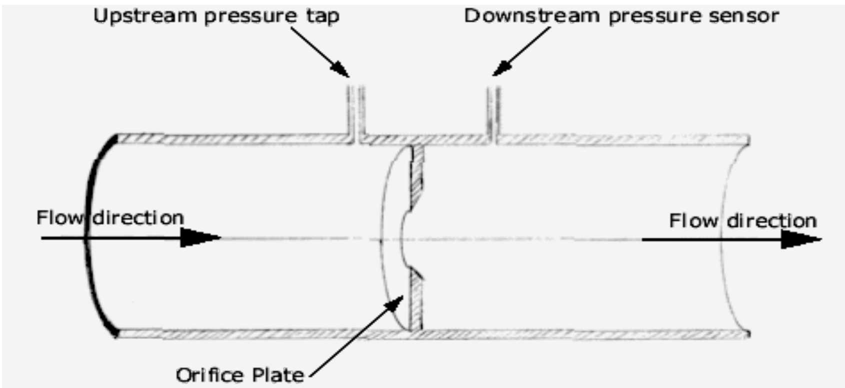
These devices guide the flow into a section of pipe with different cross sectional areas (different pipe diameters), that causes variation in flow velocity and pressure. A flowmeter is introduced which can measure the changes in pressure, the flow velocity and therefore the flow rate can then be calculated. When the flow increases, more pressure drop is created. Bernoulli's equation states that the pressure drop across the constriction is proportional to the square of the flow rate. Impulse piping routes the upstream and downstream pressures to suitable devices that measure the differential pressure to determine the fluid flow.



Because of the nonlinear relationship between flow and differential pressure, the accuracy of flow measurement in the lower portion of the flow range can be degraded.

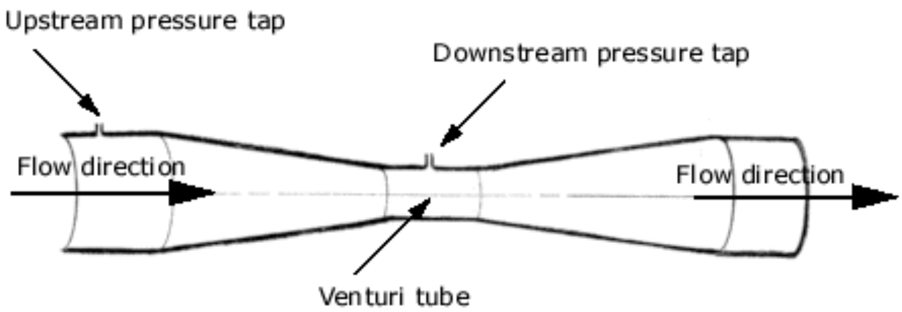
Orifice Plate

A flat plate with an opening is inserted into the pipe and placed perpendicular to the flow stream. As the flowing fluid passes through the orifice plate, the restricted cross section area causes an increase in velocity and decrease in pressure. The pressure difference before and after the orifice plate is measured, is used to calculate the flow velocity.



Venturi Tube:

A section of tube forms a relatively long passage with smooth entry and exit. A Venturi tube is connected to the existing pipe, first narrowing down in diameter then opening up back to the original pipe diameter, this has the effect of manipulating the fluid through the different sections within the pipe, therefore increasing its efficiency. The

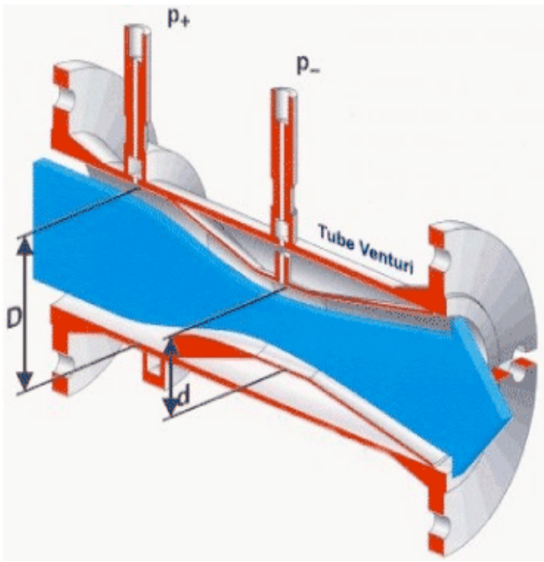


changes in cross section area cause changes in velocity and pressure of the flowing fluid. Bernoulli's equations can be used to relate these changing quantities into flow rate.

Bernoulli's Equation.

The following information will be required to use Bernoulli's equation, some of which will be known, and some of which will need to be calculated from existing information.

Q = volumetric flow rate (at any point), m^3/s
$\dot{m}$ = mass flow rate (at any point), kg/s
A_1 = cross-sectional area of the pipe, m^2
A_2 = cross-sectional area of the orifice hole, m^2
d_1 = diameter of the pipe, m
d_2 = diameter of the orifice hole, m
V_1 = upstream fluid velocity, m/s
V_2 = fluid velocity through the orifice hole, m/s
P_1 = fluid upstream pressure, Pa with dimensions of $kg/(m \cdot s^2)$
P_2 = fluid downstream pressure, Pa with dimensions of $kg/(m \cdot s^2)$
ρ_1 = upstream fluid density, kg/m^3



$$P_1 + \frac{1}{2} \cdot \rho_1 \cdot V_1^2 = P_2 + \frac{1}{2} \cdot \rho_1 \cdot V_2^2$$

or:

$$P_1 - P_2 = \frac{1}{2} \cdot \rho_1 \cdot V_2^2 - \frac{1}{2} \cdot \rho_1 \cdot V_1^2$$

with:

$Q = A_1 \cdot V_1 = A_2 \cdot V_2$ or $V_1 = Q / A_1$ and $V_2 = Q / A_2$:

$$P_1 - P_2 = \frac{1}{2} \cdot \rho_1 \cdot \left(\frac{Q}{A_2}\right)^2 - \frac{1}{2} \cdot \rho_1 \cdot \left(\frac{Q}{A_1}\right)^2$$

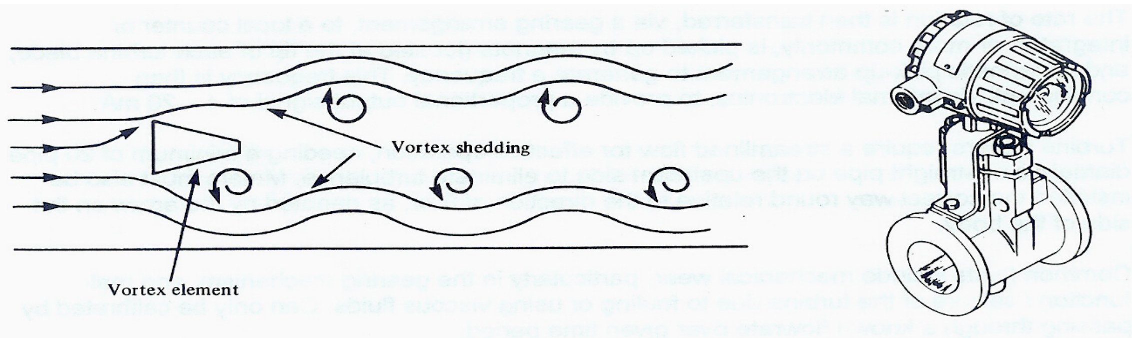
Solving for Q:

$$Q = A_2 \sqrt{\frac{2\,(P_1 - P_2)/\rho_1}{1 - (A_2/A_1)^2}}$$

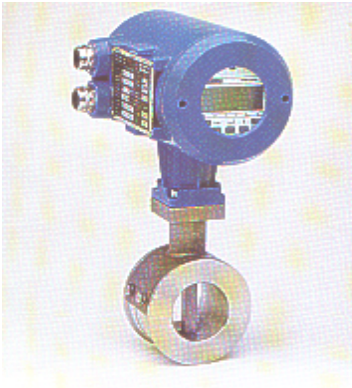
Vortex Meter:

Vortex meters use a phenomena known as *Vortex shedding* as their principle of operation.

When a fluid flow (gas, liquid or steam) hits a non-streamlined obstruction in a pipe, currents or 'vortices' - or areas of turbulence - occur on the downstream side. The rate at which these vortices form and disperse is known as *Vortex shedding.* If accurately measured, the rate of vortex shedding is directly proportional to the rate of flow.



Vortex meters employ what is known as the *bluff body* in their construction to provide the non-streamlined obstruction in the flowstream - this part of the meter also housing the detecting or sensing element. There are several methods by which the rate of vortex shedding

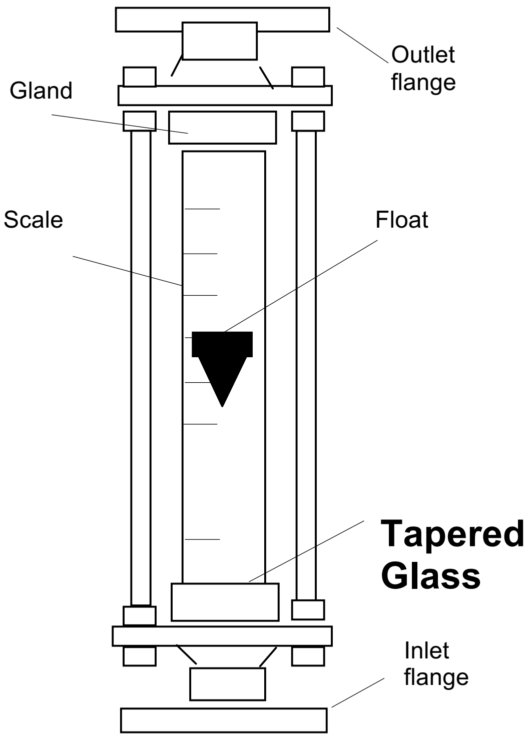


can be measured including minute changes in pressure, temperature or more commonly, frequency.

Like the conventional 'Rosemount' electronic transmitter, Vortex meters can be loop powered (24v d.c.) and can be used in conventional 4-20 mA flow control loops.

Vortex meters are extremely accurate, sensitive and reliable, requiring little or no maintenance other than periodic removal and inspection, especially around the bluff body - which must be clean and free from erosion or corrosion - and periodic calibration checks. (On the frequency type, calibration is achieved by injecting equivalent frequencies using a signal generator.)

Variable Area (or V.A.) flowmeters.

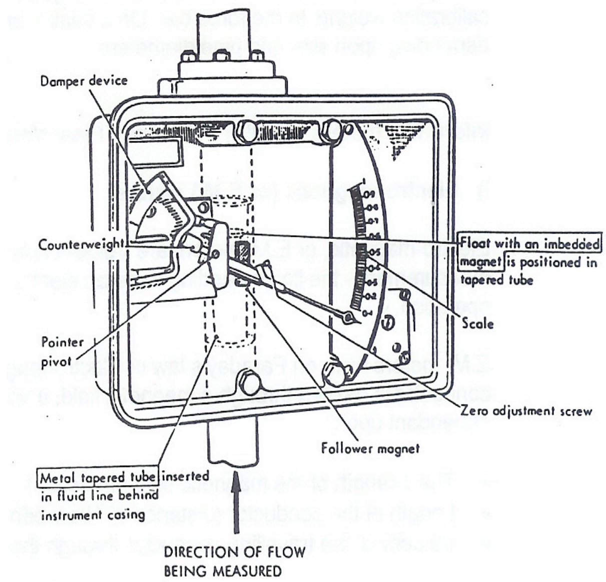


The V.A. - or Rotameter as it is commonly called, consists of a simple tapered glass tube with a metal float inside it.

As fluid flow enters the bottom of the tube, a D/P is created across the float (H.P. underneath) causing it to lift. As the forces across the float equalise, (due to the widening neck of the glass glass tube) the float becomes stationary - a scale alongside enabling flow readings to be taken (readings taken from top of float).

Rotameters can only be used on clean, non - viscous fluids or gases at relatively low pressure whilst ranges are dependant upon pipe diameter, the size and weight of the float and fluid density.

A variation on the simple glass tubed Rotameter is the *Magnetic V.A.*, which incorporates a metal tube – usually stainless steel – and a magnetic follower to provide an pointer indication on a front scale. More sophisticated versions are also able to generate a pneumatic or electronic output signal as well as high / low alarms.



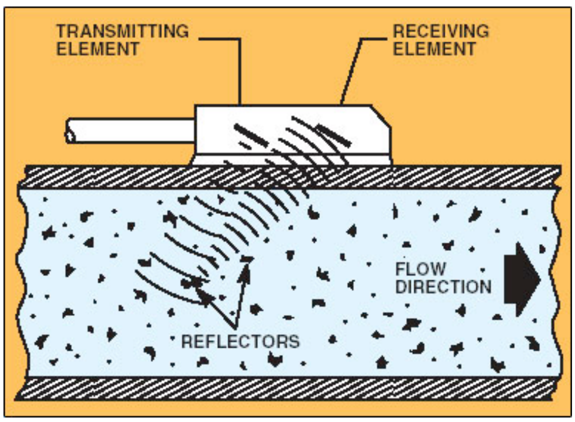
Magnetic V.A's are suitable for relatively clean liquids or gases but may also be used with certain corrosives, depending upon construction materials.

Both versions must be installed in the vertically upright position, away from sources of excess vibration and with up and down stream isolation valves.

Both the glass and magnetic versions must be periodically removed, cleaned and inspected whilst accuracy can only be checked by passing through a known flowrate in a given time period.

Ultrasonic Flow Meters

An ultrasonic flowmeter (non-intrusive Doppler flow meters) is a volumetric flow meter which requires particulates or bubbles in the flow. Ultrasonic flowmeters are ideal for wastewater applications or any dirty liquid which is conductive or water based. Ultrasonics flowmeters will generally not work with distilled water or drinking water.



Ultrasonic flowmeters are also ideal for applications where low pressure drop, chemical compatibility, and low maintenance are required.

The basic principle of operation employs the frequency shift (Doppler Effect) of an ultrasonic signal when it is reflected by suspended particles or gas bubbles (discontinuities) in motion. This metering technique utilizes the physical phenomenon of a sound wave that changes frequency when it is reflected by moving discontinuities in a flowing liquid. Ultrasonic sound is transmitted into a pipe with flowing liquids, and the discontinuities reflect the ultrasonic wave with a slightly different frequency that is directly proportional to the rate of flow of the liquid. Current technology requires that the liquid contain at least 100 parts per million (PPM) of 100 micron or larger suspended particles or bubbles.

Installation Cautions for Flowmeters

In liquid service, be sure that the flowmeter is installed such that it remains full of liquid, because gas/vapor in the flowmeter can alter its geometry and adversely affect accuracy.

In gas/vapor service, be sure that the flowmeter is installed such that the flowmeter remains full of gas/vapor, because liquid in the flowmeter can alter its geometry and adversely affect accuracy.

Disturbances located upstream (and sometimes downstream) of the flowmeter, such as pipe elbows and control valves, can adversely affect measurement accuracy, because the flowmeter may not be able to accurately measure disturbed flow streams. Be sure to locate control valves downstream of the flowmeter so their flow disturbances are not introduced directly into the flowmeter (as they would be if located upstream).

Be especially careful when flow is two-phase, such as liquid/gas flow and liquid/solid flow, because these flows can adversely affect the accuracy of many flowmeters. Be careful because some flowmeters can become plugged and stop working in liquid/solid flow streams.

Application Cautions for Flowmeters

Each type of flowmeter has its own specific applications and installation constraints. There is no "one size fits all" flowmeter