FLOW MEASUREMENT

TTE TRAINING LIMITED

INSTRUMENT COURSE

SECTION 7

FLOW MEASUREMENT

SECTION	CONTENT

FLOW MEASUREMENT.

7.1 Introduction.

Just as the accelerator in a car controls the fuel flow to the engine, for the successful operation of most chemical plant operations and manufacturing processes it is essential that the flow of products in its pipelines needs to be monitored, and were necessary controlled or maintained within predetermined limits to ensure safe and economic operation of the plant.

In the early days of industrial development, the methods used to measure flowrate were very primitive and relied heavily on the skill of the process operator or technician.

Due to the very nature of some of the chemicals being dealt with, for example strong acids and toxic gases, where it is essential for these to be contained inside robust vessels and pipelines, such primitive measurement techniques would have proved hazardous therefore such conditions may only be monitored and measured by more complex instrumentation.

As a result of continuously changing technology the variety, reliability and functions performed by such instrumentation has increased tremendously. Although some of the early methods still exist most are now obsolete.

7.2 Characteristics of Flow measurement.

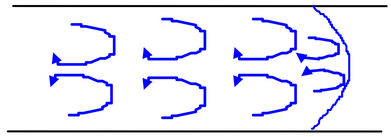
Flow measurement can be split into two main areas or categories of measurement, these are in terms of *Rate of flow* or *Quantity*.

A rate of flow meter indicates the quantity of fluid passing a particular point at a specified moment of time. A common unit of expression in this category would be litres per second, however because the flowrates we tend to deal with are quite large the more common expressions are for example, metres cubed per hour (M^3/Hr). Flowmeters in this category are also known as *Inferential* flow meters.

A quantity type meter indicates the total volume of a fluid which has passed in a given time period, for example one hour. Flowmeters in this category are also referred to as *Positive Displacement* meters.

Another important factor in flow measurement is the actual characteristic of flow travelling through a pipeline often referred to as the *flow profile*. There are 2 main ways by which the fluid travels through the pipe, these are Turbulent or Streamlined (often called *Laminar*). With streamlined flow the liquid in the pipe travels in layers relative to each other, these layers are cylindrical around the inside of the pipe, the outer layers adhere to the pipe wall therefore the velocity of the liquid is zero, however the nearer the centre of the pipe the greater the liquid velocity having minimum resistance from the pipe wall. Newton forces are created between the layers, and the fluids are therefore referred to Newtonian or Non - newtonian depending upon the degree of force or shear stress between the layers, another way of describing this is viscosity. The following diagrams show these two types of flow:-

Streamlined Flow



Turbulent Flow

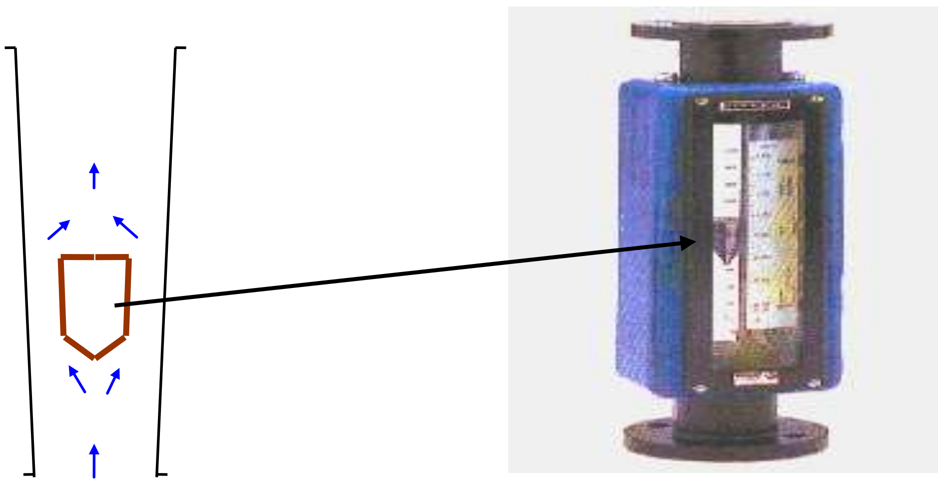
As is shown from the above diagrams with streamlined flow, the flow is travelling in layers with the greatest velocity in the centre, whereas with turbulent flow there are currents known as eddy's within the travelling liquid. When selecting a flow meter for use it would be essential to determine the type of flow. This can also be calculated via something known as the Reynolds number, which takes into account flow velocity (v), inside pipe diameter (d), viscosity (u),and density (ρ) put into the formula $Re= vd\rho /u$. Where the value is less than 2300 the flow is usually laminar and above 4000 the flow is expected to be turbulent, however between these values this is known as the critical zone where the flow is unstable.

The following sections will look at the flow meters in more depth. As previously mentioned these can be either Positive Displacement or Inferential meters which can be subdivided into Velocity, Differential pressure and Variable area type meters, and it is these that will be covered first.

7.3 Variable Area flow meters.

Rotameter.

Probably the simplest and earliest form of variable area flow meter is a simple tapered glass tube with a float in it. This device is more commonly referred to as a *Rotameter*. The diagram below shows a simple rotameter:-

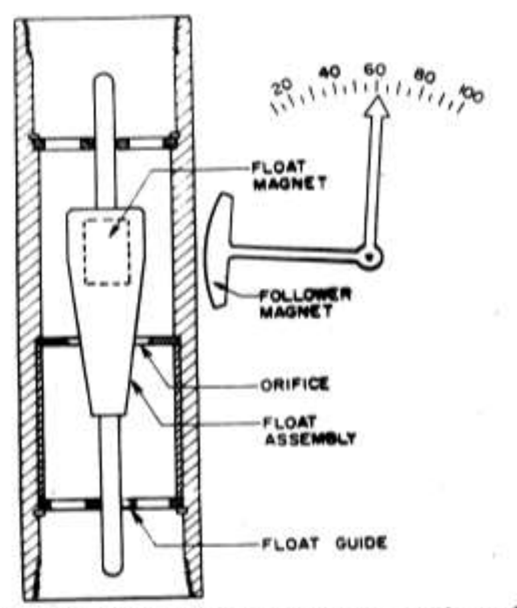


As the liquid pushes up against the float, a differential pressure is created across it with the highest pressure being under the float and causing it to rise up the tube until the forces balance across it as the neck of the tube widens. When the forces are equal the float will remain in position and this can be scaled accordingly up the side of the tube in units of flowrate. The problem with these devices is they are restricted to clean, non viscous fluids, at relatively low pressures. For installation purposes the tube is housed between two metal pipe flanges, and installed vertically in the pipeline. The range of these devices is dependant upon the pipe diameter, size and weight of the float and the density of the fluid. Over a period of time the inside of the glass becomes tarnished and requires cleaning, caution must be taken to avoid over overtightening the flange bolts as this would result in smashing the tube.

One of the primary limitations of these devices is there inability to send signals, the use of a light beam through the tube onto a photocell, when broken by the float may be used as a simple flow switch. Inorder for signals to be generated and transmitted modifications need to be made to the basic design.

Magnetic Rotameter.

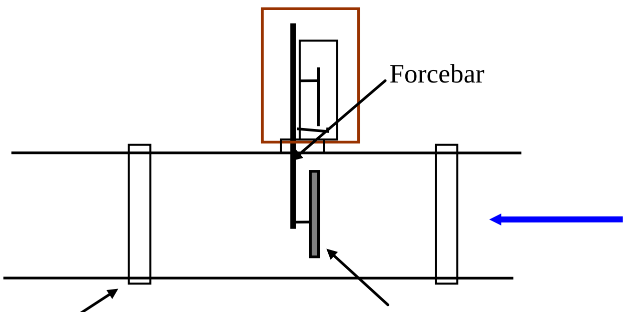
From the basic design rather than using a glass tube, this is replaced by metal tube, this is normally stainless steel however others may be used dependant upon the process being measured. The theory of its operation remains the same however in this type the float normally contains a magnet, on the outside of the tube is a magnetic follower which is connected to an indication mechanism. For some these provide merely an indication of the flow however with some it is possible to generate either an electrical or pneumatic output in this case by using a series of levers attached to a flapper nozzle mechanism . The diagram shows a magnetic rotameter:-



Typical arrangement of orifice and plug-type variable area flowmeter

Target flow meter.

Another flow meter in this category is the target flow meter, the next diagram shows an example:-



With the Target flow meter a metal disc known as a target in inserted into the pipeline so that the passing liquid will hit the target and depending upon the flowrate the amount of force hitting the target will make it move, this inturn is connected directly to the forcebar of a traditional transmitter so that the movement can be used to generate an output, the older variety of these meters used the force balance flapper nozzle mechanism, however some used the feedback coil system to generate electronic outputs.

The used of this type of flow meter requires either mass flowrates or alternatively substances which are viscous in nature requiring effort to move the forcebar. They would need a streamlined flow for effective operation and therefore the larger diameter pipe versions would be considerably large in weight and expensive to produce, typically a 4 inch inside diameter pipe meter would be approx 2 feet in length, and therefore require reasonable pipeline support. These are normally available from diameters of 1/2 to 8 inch diameter pipe.

Testing of this flow meter would have to be carried out using either known flowrates or alternatively turning the meter through 90° and hanging calibrated weights off the target equivalent to the force created by a specific flowrate hitting the target.

Build up of material infront and behind the target can affect the output. These tend only to be used were accuracy is not essential.

7.4 Velocity flow meters.

Flowmeters in this category although differing in principle of operation, rely on the velocity of the fluid to create a reading. It is the methods involved in creating the readings that we will deal with.

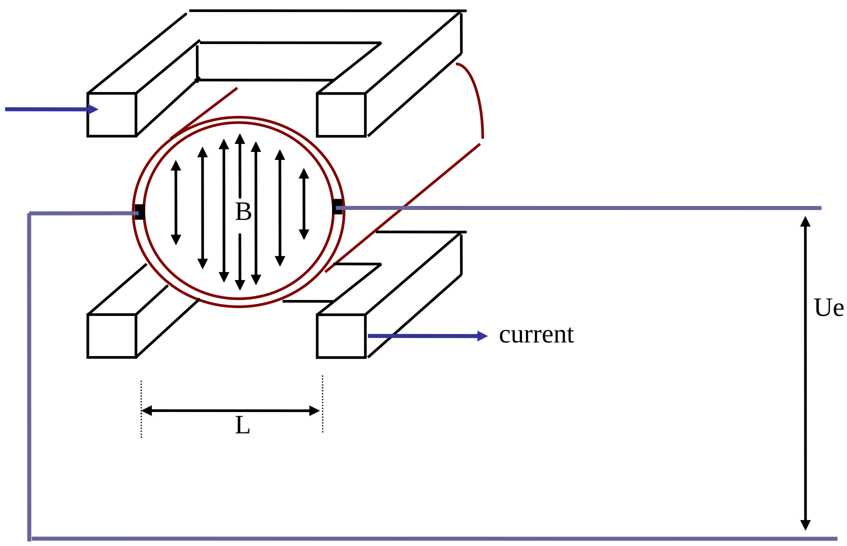
Electromagnetic flowmeters.

One of the first magnetic flowmeters was developed in 1939, however they have only been used in practice for about the last 30 years. The construction and operating principle of these flowmeters mean that they are only suitable for liquid applications and the liquid must be an electrolyte (conductor). The electromagnetic flow meter, *E.M meter or Magflow meter* as it is often referred works on Faradays law of electromagnetic induction, which states that " when a conductor passes through a magnetic field a voltage is induced (generated) in the conductor ", the voltage (Ue) being dependant upon:-

B= strength of magnetic field (induction)
L= length of conductor (distance of / between the electrodes)
v= velocity of the travelling conductor through the field(average flow velocity)

according with the formula Ue = B.L.V

In this type of flow meter the conductor is the flowing electrically conductive liquid, the electrodes are situated horizontally opposite each other in the pipe and the magnetic field is created electrically via an energised coil using an A.C supply. The following diagram shows the set-up and principle of operation:-



From the above diagram the induced voltage in the liquid is picked up via the two electrodes in the side of the pipe. The pipe has a lining to prevent conductance between the liquid and the pipe wall. For effective operation the pipe must have liquid between the electrodes at all times, otherwise the measured output between the detector electrodes will become erratic. It is usual to measure voltages between 0.1 and 20mV, which thus requires a signal amplifier to provide useful outputs of i.e.:- 4 -20mA.

The type of liquids that can be measured with this type of meter are water, acids, alkalis, effluents, solvents and some slurries and sludge's. Liquids not suitable for this method are low conductivity solutions, petroleum, diesel etc.

The measurements are not affected by temperature, pressure, density or viscosity.

Installation of this meter can be at any angle although vertical minimises build-ups on the electrodes, and these should be 3 - 5 pipe diameters away from sources of turbulence as this introduces air pockets into the following liquid.

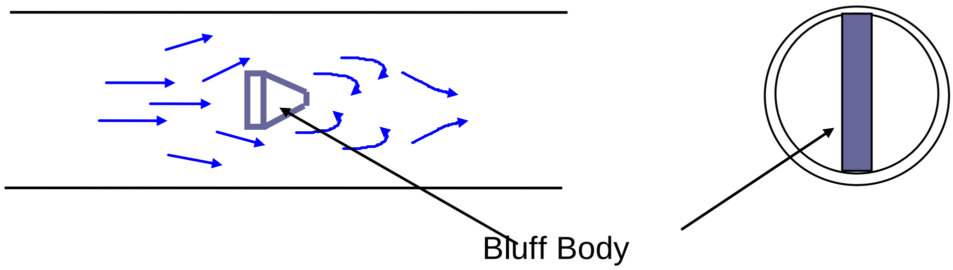
The supply voltage for the coil is usually an A.C supply at 240volts, as such it is of utmost importance that these flowmeters are well earthed to minimise the potential for electric shock. For some applications for these flowmeters extra protection is required for use in potentially hazardous or flammable atmospheres, they can be made *intrinsically safe*.

Some specific advantages of these flowmeters are no moving parts, no wear and tear, maintenance free, no pressure loss or effects on the flow of liquid.

Vortex flowmeters.

As early as 1513 Leonardo da Vinci described his observations of a vortex formed in water flowing downstream from an object. Vortex meters have been used for industrial flowmetering since the early 1970's and use the phenomenon called " Vortex shedding" which occurs when a fluid (gas, liquid or steam) flows against non streamlined obstruction in the pipeline, this obstruction is commonly called the *bluff body*. The resulting flow around the body creates vortices or turbulence on the downstream side, with the vortices being create at a frequency proportional to the flowrate.

The next diagram shows the basic principle of operation of the Vortex meter:-



As can be seen from the diagram, as the fluid hits the bluff body its flow is diverted around the object, the result is to create turbulence or vortices, the amount of vortices created being proportional to the flowrate. The bluff body is essentially a sensing element into which there can be various types of sensor such as thermistors, piezo electric diaphragm or capacitance sensor. The devices are built into the body so as to detect any change in pressure or velocity caused by the changing frequency of the vortices due to flowrate. The corresponding output from the bluff body is fed to an electronic circuit board were it is processed to produce a range of usable outputs, such as 4 - 20mA.

There are various types of bluff body, choice of which depends on the application, however it has been proved through extensive testing and experience that the delta shaped body (shown in the diagram above) is almost ideal since its accuracy is unaffected by pressure, viscosity and other fluid conditions, and that its output is linear, whereas other shapes display some of these disadvantages.

Thermistor sensors:- are heat sensitive semi-conductor resistors with high temperature coefficients, the cooling of the electrically heated thermistor causes a change in resistance of the sensor and the output is generated. Unfortunately these are sensitive to dirt and rely on suitable location.

Pressure sensors:- Vortex shedding causes changes in pressure across the bluff body, this fluctuation distorts the pressure diaphragm which is inturn used to change the distance of a capacitance sensor device thus creating a measurable output which may be converted into usable transmission signal format. These tend to be restricted to temperatures below 150°C, and rupture of the diaphragm is always a possibility though unlikely. Can be relatively insensitive for low flow applications due to the lack of pressure differential across the body.

Strain gauges:- these are also used as sensors within the bluff body as pressure changes will place strain on the sensor element. Movement of this sensor is less than 0.0004″.

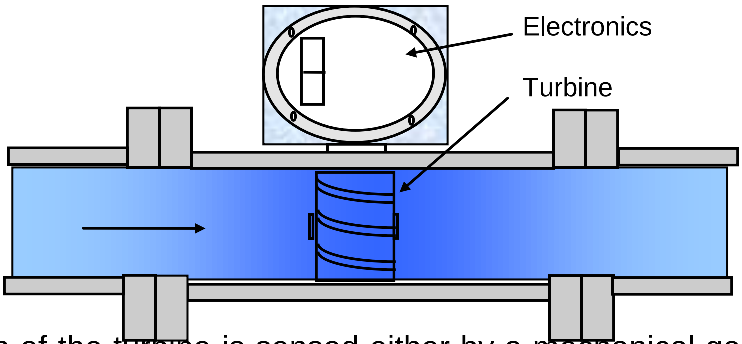
The diagram left shows a typical Vortex flow meter:-

As was mentioned previously the vortex meter can be used for the measurement of liquids, gases and steam flows, the application will determine the type and shape of sensor, for example the pressure sensor is best suited for liquids, some gases and low pressure steam, whereas the latter is unsuitable with the thermistor based sensor.
For installation purpose these are available from 1/2 to 12 inch internal pipe diameters, and ideally require streamlined flow for effective operation. The installation in the

pipeline can be vertically upwards or upside down but not at angles and the flow must approach from the correct direction for the sensor to work.

Turbine flowmeters.

As the name suggests this type of flow meter consists of a pipeline with a turbine situated inside it along its length, this is sometimes referred to as a helix meter. The size of the turbine being determined by the inside diameter of the pipe. When the liquid travels along the pipeline it causes the turbine to rotate, the rotation speed being directly proportional to the flow velocity. The next diagram shows this: -



The rotation of the turbine is sensed either by a mechanical gearing, or more commonly via a magnet situated in the end of each turbine blade which passes a magnetic pickup and the number of counts made (frequency) is converted into one of the transmittable signals.

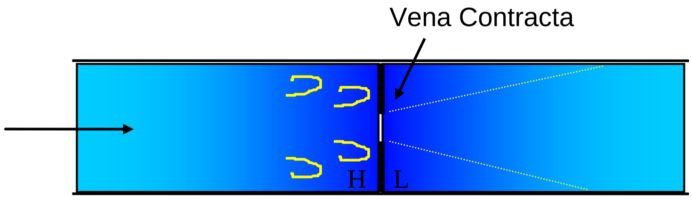
For this type of flow meter the ideal flow needs to be streamlined, with some flowmeters having inbuilt flow straightening vanes a suggested 10 pipe diameters of straight pipe before the meter is useful to minimise turbulence. The size range of these meters is from 3/4 to 20 inches (20 to 500mm), and therefore depending on size having flow ranges upto 6540 (24000gpm) however manufactures advise not exceeding 70 to 80% maximum calibrated flow capacity to allow for future expansion. They may be sited vertically or horizontally in the pipeline however it is possible to lose 3-5 psi pressure across the meter it is also essential to provide sufficient line pressure to avoid cavitation at the rotor, which would cause high readings and potential destruction of the rotor or bearings caused by overspeeding.

Some of the common applications of this meter include flow metering of liquid oxygen and nitrogen, oil, petrol, general clean liquid chemicals but avoiding viscous substances. Another common use of this type of meter is in aircraft flow metering systems, on for example Concorde, for this purpose special light weight construction materials must be used. A company called Faure-Hermann specialise in this high quality meter manufacture.

7.5 Differential pressure flowmeters.

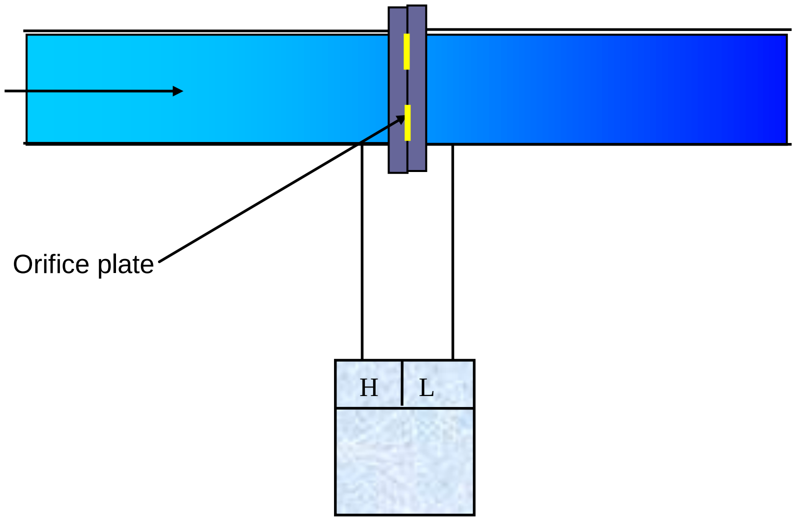
These types of flow meter require the restriction of the flow through the pipeline, and when the flow is restricted an increase in velocity occurs through the restriction leaving an area of reduced pressure downstream side.

Therefore the resulting differential pressure across the restriction is due to changes in flowrate, as shown in the following diagram:-



There are two effective methods in use for creating a restriction in the pipeline the cheapest and by far the most common is the orifice plate (defined as a thin plate with a hole in, the other being the venturi tube. Once the restriction is placed in the line there needs to be a method set up of measuring the differential pressure the most common method for this is the differential pressure transmitter talked about in one of the earlier sections.

The basic system set up is shown in the next diagram:-



In the above diagram the orifice plate is held between the two pipe flanges, as the fluid flow hits the plate the velocity through it increases and a differential pressure can be measured across the plate which increases with flowrate, for this purpose a differential pressure transmitter is used. When measuring the differential pressure you will notice that its relationship to the flowrate is non linear and follows a square root pattern, hence this needs to be taken into account with the output from the transmitter and the effects it may have on any controlling devices, it will also be noticed that there will be a small permanent pressure loss.

The relationship between these can be simplified into the following mathematical formula:-

$$\text{Flowrate} = \sqrt{\frac{\text{Measured differential pressure}}{\text{Maximum differential pressure}}} \times \text{maximum flowrate}$$

The formula can be used as shown in the next example:-

An orifice installation is designed to develop a differential pressure of 100″wg at a maximum flowrate of 500 m^3/hr. Calculate the flowrate if the measured differential is at 25″wg.

$$\text{Flowrate} = \sqrt{\frac{\text{Measured differential pressure}}{\text{Maximum differential pressure}}} \times \text{maximum flowrate}$$

$$\text{Flowrate} = \sqrt{\frac{25}{100}} \times 500$$

$$\text{Flowrate} = \sqrt{0.25} \times 500$$

Flowrate = 250 m^3/hr.

The Orifice plate - This is a plate inserted into the pipeline to create a restriction resulting in pressure drop. By far the most common type of orifice plates are metal although the material varies depending on the process application. The hole through the orifice is normally in the centre of the plate , however some others do exist which are off centre (eccentric) or segmental, the application of these devices tends to be where the nature of the process would case blockage or build-up if the hole was dead centre, this could be the case on slurries for example. The most common plate normally has a square edge on the high pressure side and a tapered edge on the low pressure side, the angle of the taper may be adjusted to assist flow and pressure recovery. The size or diameter of the hole is determined by the pipe diameter and then a complex formula which takes into account maximum flow, pressure loss, temperature, density and the required pressure differential in relation to flow.

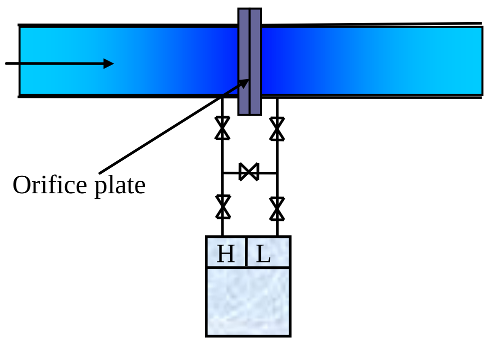
The major disadvantage of using the orifice plate is the permanent pressure loss which can be as much as 50% of the upstream line delivery pressure. The following table shows a selection guide for orifice plates:-

Orifice type	Appropriate process fluid	Reynolds number range	Pipe-size range (inches)
Concentric - square edge	Clean gas and liquids	over 2000	0.5 to 60
Concentric - quadrant, conical	Viscous clean liquids	200 to 10,000	1 to 6
Eccentric or segmental	Dirty gas or liquids	over 10,000	4 to 14

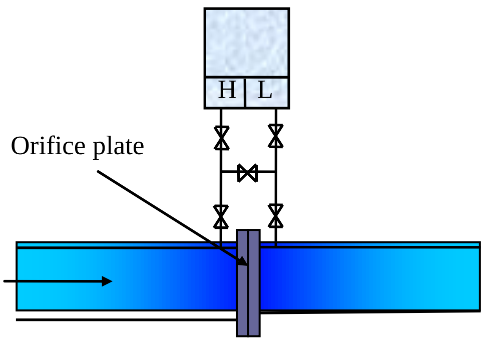
The installation of the orifice can either be directly between 2 flanges or another method is to use a device called an orifice carrier, this is essentially a thick bore pipe with a recess machined into it, into which the orifice plate is inserted an clamped, this is then held between 2 flanges into the pipe, the carrier also has the pressure tappings built into it, the transmitter can then be attached to this.

The location of the pressure tappings for measurement is of vital importance, one of the common ways is for the tappings to be horizontal to the pipeline particularly were the process is gas another way is for the transmitter to be thus allowing any liquid or condensate to drop back into the pipeline, however where the process fluid is liquid then these should be located so that the transmitter is below the pipe so that any gas may rise upwards and more importantly these should be first filled will liquid similar to that in the process line to eliminate any effects due to static pressure so with both the high and low pressure sides filled this effect is eliminated (this process is often referred to as liquid circulating). The position of the downstream tapping in relation to the flow through the orifice is also important, this needs to be in or at an area called the *vena contracta.* The vena contracta is the point of highest velocity and minimum pressure, this is shown on the first diagram.

The following series of installation diagrams are a general guide to installing differential pressure flow installations:-



Below the line for liquids



Above the line for gases

The inclusion of a bypass allows onsite zero checking and for the simulation of maximum differential pressure relating to full flowrate.

Due to the square root scale some application may require a square root extraction device on the output of the transmitter. Using the following formula it is possible to determine the output of the transmitter from given inputs etc:-

$$R = A + [(B - A) \times (Q / Qm)^2]$$

where R= output, Q = flowrate, Qm = maximum flowrate, B = output at maximum input, and A = output at zero flow.

If maximum flow is 100m^3/hr, calculate output at 1/2 flowrate if the system uses a pneumatic transmitter:-

$R = A + [(B - A) \times (Q / Qm)^2]$

$R = 3 + [(15 - 3) \times (50/ 100)^2]$

$R = 3 + [12 \times 1/4]$

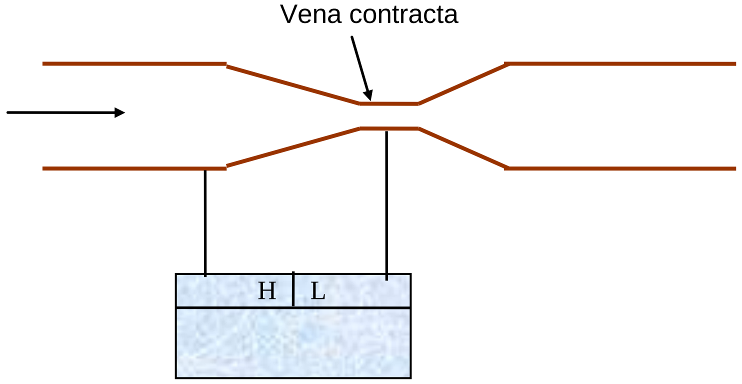
R = 6psi

It can be seen from the above example that 1/2 flowrate produces 1/4 output supporting the square root relationship.

Some of the major limitations of the orifice plate are the pressure loss, the potential to block and erosion of the orifice thus increasing its effective diameter, where these factors can not be tolerated it may be necessary to use a venturi installation.

Venturi tube.

From the early theories in differential pressure devices it could be seen the way in which the flow travels and passes through the orifice. A venturi tube is a machined tube that actually manipulates and reproduces the flow shape so as to minimise the limitations seen earlier. A venturi tube is shown below:-



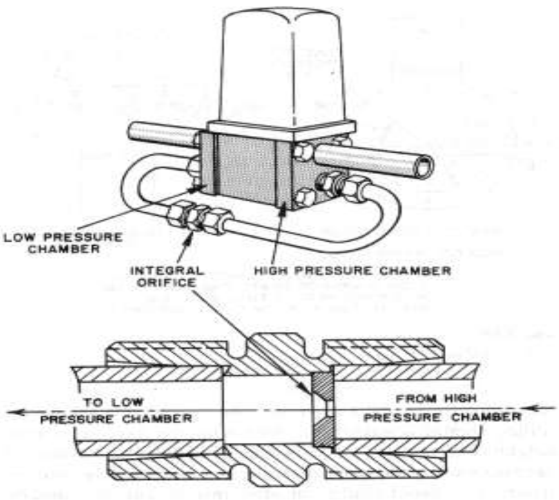
The angles of the pipe leading into and away from the vena contracta are what determine the pressure recovery and the differential pressure as well as the diameter. Such can be the size of the venturi tube that it may be required to be made in sections, for example a venturi for a 6 inch diameter pipe could be upto 2 feet in length and will weigh considerably.

The advantage of the venturi is its pressure recovery rate which can be upto 85% in relation to the orifice installation.

All other information relating to theory of operation, calculations, installations etc is the same as for the orifice plate.

Integral Orifice

Another form of orifice installation is the *integral orifice.* The orifice is installed into a loop similar to a bypass and mounted straight across a differential pressure transmitter, this being for very small flows, this is shown in the simple diagram opposite:-



The integral orifice application, tends to be used in laboratory-scale processes, pilot plants, and to measure additives to major flow streams, and for other small flow measurements.

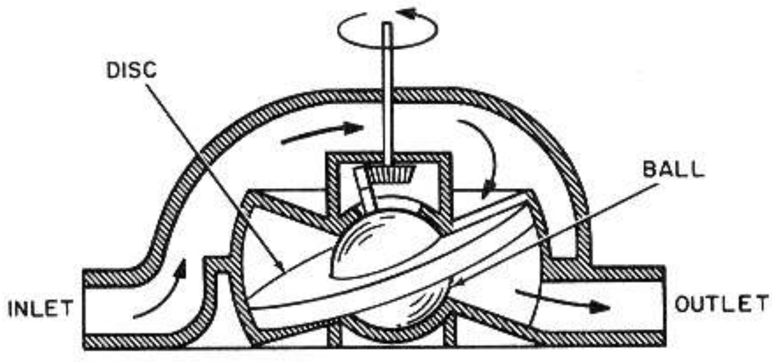
Clean fluids are required for these particularly to avoid blockages, and also to prevent small build ups which could cause large errors.

7.6 Positive Displacement flow meters.

The basic principle of positive displacement (p.d) meters is to split the flow of liquid into known separate volumes based on the physical size of the flow meter, and then count or totalise them. They are mechanical meters in that one or more moving parts, located in the flow stream physically separate the liquid into increments. The energy to drive the moving parts is extracted from the flow of liquid through the meter. The negative to this being that there is considerable pressure loss through the meter. Probably two of the most common meters in this category are the oscillating piston and the nutating disc meter.

Nutating disc.

This meter, often called the disk meter or wobble meter is used predominantly in water installations, as well as other liquid chemical processes, consists of a moving assembly that separates the liquid into increment parts, the main part being a radially slotted disc with an integral ball bearing and axial pin it is this part the fits into and divides the metering chamber into four volumes, two above on the inlet side and two below the disc on the outlet side. As the liquid attempts to flow through the meter, the pressure drop from inlet to outlet causes the meter or disc to nutate or wobble about the bearing axis. The movement of each rotation is transmitted via the axial pin to cam which is magnetically coupled to a geared assembly which inturn displays the flow through the meter or can be used to generate a suitable transmittable output.



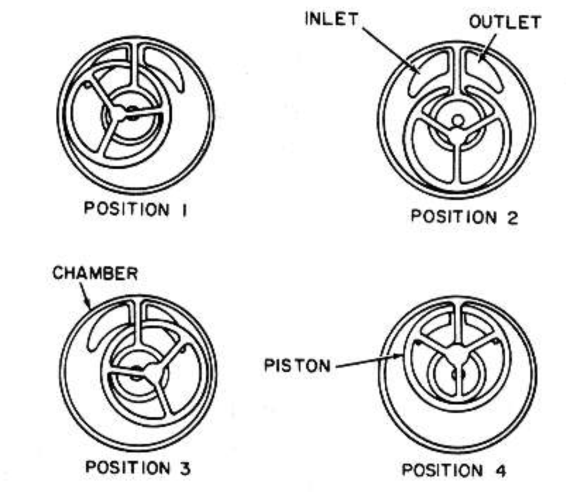
This type of flow meter as with other p.d meters is restricted to liquid flow applications only. They are generally suitable for small pipe diameters although a 2 inch diameter pipe would require a disc approximately 8 inches in diameter, thus making these meters rather heavy. The following table shows the relationship between size of pipe and flow meter capacity for a water system:-

SIZE (inches)	CAPACITY (gpm)
1/2	2 - 20
1	5 -50
1- 1/2	10 -100
2	16 - 160

Oscillating piston meter.

Similar to the nutating disc this type of meter works by transferring known volumes of liquid from the inlet to the outlet. The moving part of the meter consists of a slotted cylinder(piston) that oscillates about a dividing bridge that separates the inlet port from the outlet. The force of the flowing liquid causes the piston to rotate allowing liquid into one of the chambers and filling it, the continuous motion shifting this eventually to the outlet. As there are known volume sections within the meter, one revolution of the piston is equivalent to the sum of all the smaller volumes added together. On the top of the piston is an axial pin which is attached to a cam, which is inturn magnetically coupled to a gearing mechanism which is used to display the flow information or used to generate a transmittable output.

The diagrams that follow show the 4 positions in the rotation of the piston:-



Probably the most common application of this meter is for domestic water metering, although it can be used for clean viscous and corrosive liquids. They are generally used in pipe diameters less than 2 inch.

There are other positive displacement meters, these include reciprocating piston, oval gear, rotating vane to name but a few.

7.7 Coriolis flow meters.

The advantages of Coriolis mass-flow measurement are self-evident. It comes as no surprise, therefore, to find that this principle is used in a huge range of industry sectors, including oil/gas, food, pharmaceuticals, chemicals /petrochemicals. Virtually all fluids can be measured, such as:-

cleaning agents and solvents, fuels, vegetable oils, animal fats, latex, silicon oils, alcohol, fruit solutions, toothpaste, vinegar, ketchup, mayonnaise, gases, liquefied gases, etc.

The Coriolis flow meter comes in several different design shapes. A couple are shown below.

General operating principle

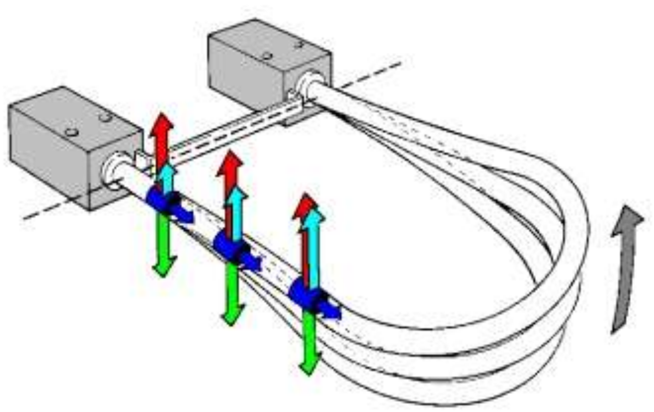
If a moving mass is subjected to an oscillation perpendicular to its direction of movement, Coriolis forces occur depending on the mass flow. A Coriolis mass flowmeter has oscillating measuring tubes to precisely achieve this effect. Coriolis forces are generated when a fluid (= mass) flows through these oscillating tubes. Sensors at the inlet and outlet ends register the resultant phase shift in the tube's oscillation geometry. The processor analyzes this information and uses it to compute the rate of mass flow. The oscillation frequency of the measuring tubes themselves, moreover, is a direct measure of the fluids' density.

The temperature of the measuring tube is also registered for compensating thermal influences. This signal corresponds to the process temperature and is also available as an output signal.

Tube Designs

A tube can be of a curved or straight form, and some designs can also be self-draining when mounted vertically. When the design consists of two parallel tubes, flow is divided into two streams by a splitter near the meter's inlet and is recombined at the exit. In the single continuous tube design (or in two tubes joined in series), the flow is not split inside the meter.

In either case, drivers vibrate the tubes. These drivers consist of a coil connected to one tube and a magnet connected to the other. The transmitter applies an alternating current to the coil, which causes the magnet to be attracted and repelled by turns, thereby forcing the tubes towards and away from one another. The sensor can detect the position, velocity, or acceleration of the tubes. If electromagnetic sensors are used, the magnet and coil in the sensor change their relative positions as the tubes vibrate, causing a change in the magnetic field of the coil. Therefore, the sinusoidal voltage output from the coil represents the motion of the tubes.



When there is no flow in a two- tube design, the vibration caused by the coil and magnet drive results in identical displacements at the two sensing points (B1 and B2). When flow is present, Coriolis forces act to produce a secondary twisting vibration, resulting in a small phase difference in the relative motions.

This is detected at the sensing points. The deflection of the tubes caused by the Coriolis force only exists when both axial fluid flow and tube vibration are present. Vibration at zero flow, or flow without vibration, does not produce an output from the meter.

Wall thickness varies considerably from design to design; however, even the sturdiest tubing will be thinner than the process piping. In addition, some designs use small bore tubing, which drastically increases the flowing velocity (from 5-10 ft/sec to more than 25 ft/sec). Designs with thin walls and high fluid velocities (that is, small bore tubing), may require the use of exotic materials because of erosion concerns. One will obtain the longest meter life by selecting the design with the thickest wall and the slowest flow velocity that can provide the required accuracy and range.

7.8 Flow meter selection summary

The flow rate measurement of liquid, steam, and gas is one of the most important areas of application for today's field instrumentation, therefore demanding the most modern and innovative measurement techniques only. These principles are characterised by high precision, reduced wear, longer life, and cost effectiveness.

KEY

- ● Best for this application
- ◑ OK with some exceptions
- ⦶ OK for some applications but check first
- ✕ Do not use in this service

Technology \ Application	Vapor or Gas	Clean Liquids	Corrosive Liquids	Dirty Liquids	Viscous Liquids	Slurries	Hi-Temp Service	Semi-Filled Pipes	Open Channel
Magnetic / Electromagnetic	✕	●	●	●	⦶	●	◑	◑	◑
Thermal Mass	●	◑	◑	◑	◑	◑	◑	✕	✕
Ultrasonic - Transit Time	◑	●	◑	◑	◑	✕	✕	✕	◑
Ultrasonic - Doppler	✕	✕	◑	●	◑	◑	✕	✕	✕
Vortex Shedding	●	●	⦶	⦶	◑	✕	◑	✕	✕
Turbine / Paddlewheel	●	●	◑	◑	⦶	✕	⦶	✕	◑
Variable Area	●	●	⦶	⦶	⦶	✕	⦶	✕	✕
Positive Displacement	●	●	◑	✕	●	✕	◑	✕	✕
Differential Pressure	●	●	◑	◑	◑	◑	◑	✕	✕
Coriolis	●	●	●	●	●	●	●	✕	✕