Flowmeter technology; the right flow meter for the right job

Winston Churchill once said “give us the tools and we will finish the job.” In terms of flowmeters and their technology and application, there are two parts of this quote. The flowmeter is the tool; the job is the application for which the design engineer requires a flowmeter. For a successful application the design engineer needs firstly an understanding of what tools – or flowmeter technologies – are available. Secondly, knowing how these technologies can be utilised in relation to specific applications will help the design engineer to finish the job.

There is a wide range of flowmeter technologies to choose from and each lends itself to a specific application.

Coriolis flowmeters

Two parallel flow tubes inside the Coriolis meter vibrate at their resonant frequency in opposite directions. Any mass flow passing through the tubes delays the vibration at the incoming side and accelerates the vibration at the outgoing side. This causes a small time delay between both ends of the tube. This time delay is measured and is used to calculate the mass flow through the tubes.

By measuring the resonant frequency of the tubes the mass of the medium and - given a constant volume inside the tubes - the density of the medium can be calculated. As both effects are temperature dependent, the temperature is measured via a precise sensor for correcting the temperature effects of flow and density measurement.

As a consequence, mass flow, density and temperature of the medium are directly measured. Because the mass flow and the specific gravity are known the volume flow can be calculated.

Coriolis meters are employed in a wide range of applications worldwide in the oil and gas, petrochemical, food and beverage and life sciences sectors, particularly in low flow and high viscosity applications.

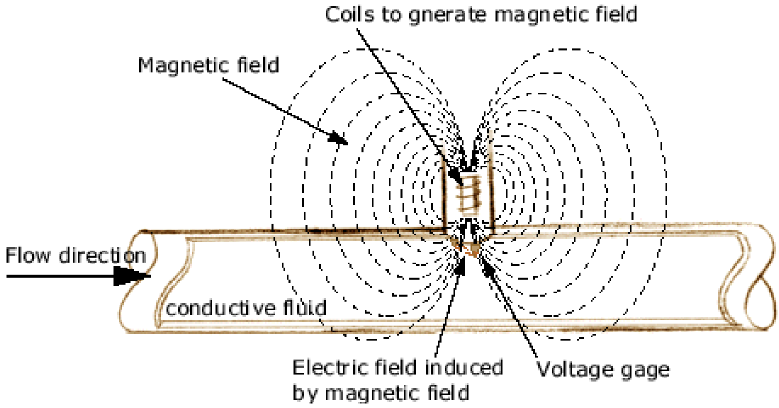
Processing

TRICOR Coriolis meters have been used in food production applications because no other flowmeter was robust enough with the required level of accuracy for the conditions. The meters were used by a leading food processor and manufacturer to measure the correct amount of palm oil and egg phospholipids going into some yoghurt products. The meters were required to be able to measure accurately fluids with a viscosity range of 1,200 centipoise (cPs) at 20°C to 3,200 cPs at 40°C. Normal operation had to take into account material with a specific gravity of 0.92 kg/l and flow range of 30-100 kg/hr.

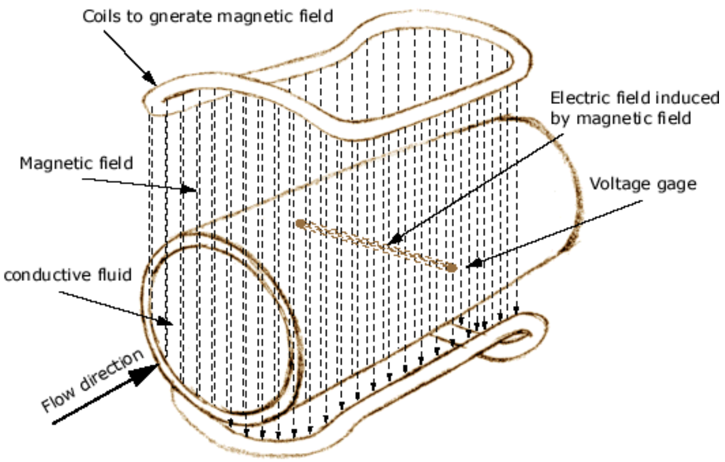
Electromagnetic flowmeters

Electromagnetic flow meters have a number of industrial and sanitary applications. They can be constructed with various liner materials and can cope with a wide range of flows and with liquids containing solid matter.

These meters are suitable for industries including water, wastewater, foods, beverage, chemicals, steel and nonferrous metals, fertilizers and pulp and paper.

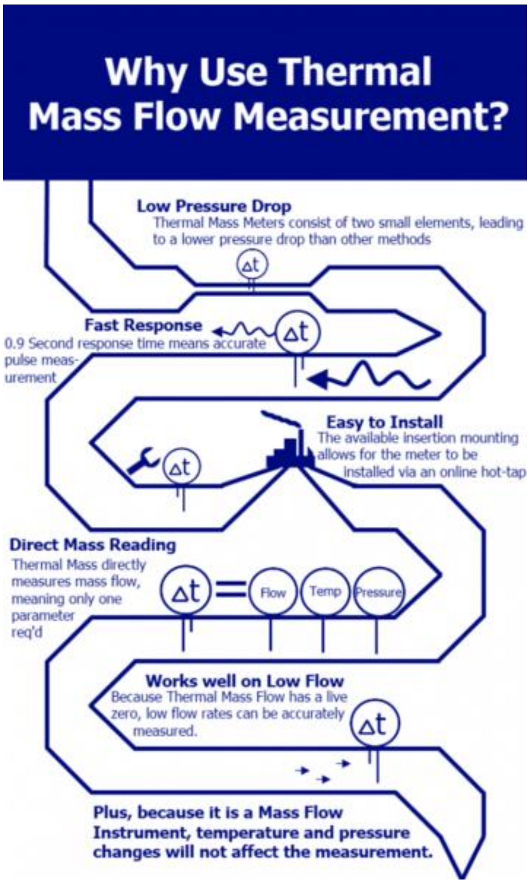


Electromagnetic flowmeters, also known as magnetic flowmeters or induction flowmeters, obtain the flow velocity by measuring the changes of induced voltage of the conductive fluid passing across a controlled magnetic field.



A typical magnetic flowmeter places electric coils around (inline model) / near (insertion model) the pipe carrying the flow to be measured and sets up a pair of electrodes across the pipe wall (inline model) or at the tip of the flowmeter (insertion model).

If the targeted fluid is electrically conductive, its movement through the pipe is equivalent to a conductor cutting across the magnetic field. This induces changes in the voltage reading between the electrodes. The higher the flow, the higher the voltage.



Mass flowmeters

There are several different types of mass flowmeter technology available. Here we explain three of the main types; thermal mass, ultrasonic and vortex shedding mass flowmeters.

Thermal mass flowmeters

There are two thermal mass flowmeter technologies, capillary thermal mass technology and the immersed thermal sensor.

The capillary thermal principle of operation is based on heat transfer and the first law of thermodynamics. During operation, process gas enters the instrument's flow body and it divides into two flow paths. The vast majority of the gas flow passes through the laminar flow element (LFE) bypass. A very small portion of the total flow is diverted through a small 'capillary' sensor tube with an internal diameter between 0.2 and 0.7 mm (0.007 and 0.028 inches).

The LFE bypass is designed so that the process gas maintains a smooth, uniform flow profile called laminar flow (in other words, the gas has a Reynolds number below 2,000). As a result, the small fraction of the total flow measured in the sensor tube remains in direct proportion to the gas flowing through the LFE bypass. By measuring the flow in the sensor tube, the total mass flow rate can be calculated. The instrument is calibrated over its full mass flow range.

The immersible thermal sensor

The immersible thermal sensor is completely immersed into the flow stream. As a result, immersible thermal mass flow meters measure much higher gas mass flow rates in harsher environments than capillary thermal mass flow meters. There is very little pressure drop across an immersible sensor and the flow does not have to pass through the LFE as it does with a capillary thermal mass flow sensor.

In operation, the reference thermistor measures the temperature of the gas, while the flow thermistor is electronically maintained at a temperature typically 40°C degrees hotter than the gas temperature.

Once the gas begins to flow, the flow thermistor is cooled as the molecules of gas take heat away from the heated flow thermistor (think of blowing on your wetted finger – it will feel cooler as your breath passes over it). The amount of heat removed from the flow thermistor is added back by the electronic heater circuit so a constant temperature differential ΔT between the two thermistors is maintained.

The heat being put into the flow thermistor (measured electronically) is equal to the heat being taken out of the sensor that is convected away by the flow stream.

Capillary thermal mass flowmeters tend to be high performance mass flow meters with mass flow controllers for nearly any gas application, usually for use within a laboratory environment. Immersible thermal mass flowmeters are intended for industrial applications where a more robust instrument is required.

Examples:

Air flow sensors have been used in Formula 1 for engine testing. Engine performance is checked by measuring the intake through the air manifold via the air box above the driver's head in order to maximise the combustion of the fuel in the engine and therefore the power delivered through the drive chain. Thermal flow instruments are designed to measure the flow of gases at pressures of up to 8 bar. The meters are highly stable and deliver a measurement accuracy of +/- 1 per cent full scale and a repeatability of +/- 0.2 per cent of full scale and, most importantly, a 200 millisecond response time to changes in flow rate.

Digital mass flow controllers supplied to a leading wound care solutions provider test wound care models by introducing a controlled air leak into a wound model at very low pressures at airflow rates of between one standard cubic centimetre per minute (sccm) and 50 sccm. The controller regulates the air flow in the system.

Vortex shedding

Vortex and other types of 'oscillatory' flow meters utilise the behaviour of fluid oscillations in order to derive flow rate. This technology works by inducing fluctuations in the fluid properties such as pressure, density or viscosity, which can be converted into a flow rate.

When the fluid stream encounters a fixed obstruction, the fluid must divide to pass around the barrier. Because of viscous adhesion, the boundary layer moves more slowly than the outer layer. At very low flow rates, the viscous forces dominate, keeping the fluid attached to the wall of the body and the fluid recombines in a symmetrical fashion.

However, as the flow rates increase there comes a point where the flow cannot withstand the adhesion pressure gradient along the surface of the body and the boundary layer separates to form rotating vortices that are carried downstream.

As the flow rates increase even further, the vortices become relatively stable and persistent so they line up directly behind the obstruction. The vortex shedding alternates from side to side in sequence due to the pressure pulse that accompanies the formation of the vortex from the opposite edge. By using this pressure pulse the frequency of this oscillation can be measured and a flow rate can be derived.

Ultrasonic

Ultrasonic flowmeters measure the travelling times (transit time models) or the frequency shifts (Doppler models) of ultrasonic waves in a pre-configured acoustic field through which the flow is passing in order to determine the flow velocity.

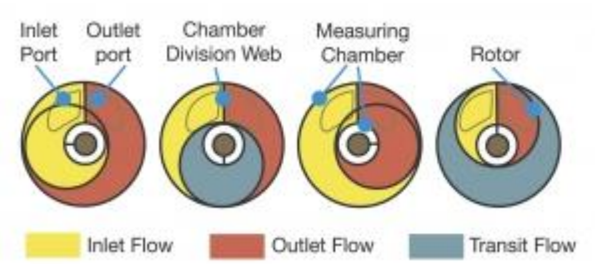
Ultrasonic flowmeters can be categorized into two types based on the installation method: clamped-on and inline.

- Clamp-on: The clamp-on type is located outside the pipe and there are no wetted parts. It can easily be installed on existing piping systems without worrying about corrosion problems. Clamped-on designs also increase the portability of the flowmeter.
- Inline: The inline type, on the other hand, requires fitting flanges or wafers for installation. However, it usually offers better accuracy and its calibration procedures are more straightforward.

Ultrasonic flowmeter sensors are often installed to measure the flow through large pipes to avoid the expense of a (large) full-bore spool piece. The ultrasonic sensors for most pipe sizes are similar so flowmeter cost is almost independent of pipe size. These attributes of ultrasonic flowmeters often make this technology less expensive and more convenient to install than others.

Ultrasonic flowmeters measure liquid velocity from which the volumetric flow rate is inferred. The measurement is linear with liquid velocity and exhibits a relatively large turndown. In addition, the range of flow measurement is relatively large. They can be applied to gas flows, particularly stack gas, flare gas, and natural gas. Some ultrasonic flowmeters can measure the flow of liquids in partially-filled pipes.

Positive displacement flowmeters



Positive displacement (PD) flowmeters are versatile and come in a number of designs. They have been around for more than 100 years and are commonly used in a wide range of applications from domestic water measurement to measuring ultra-low flow rates of chemical at high pressures subsea. PD technology involves the positive displacement of a volume of fluid – usually a liquid but there are some units suitable for gas. There is a chamber within the meter and inside the chamber, obstructing the flow, is a rotor.

The shape of the rotor and chamber vary greatly with each meter type but they all provide an output for each rotation. Most meter designs therefore lend themselves to being totalisers. Most can have the flow rate calculated from this primary data.

Advantages

An accurate PD meter will have minimal leakage across the rotor seal. This is more easily achieved when measuring the flow of more viscous liquids and accuracies of ±0.1per cent are sometimes quoted. On the other hand, rotary piston flowmeters are used by the water industry in the UK for measurement of water over a normal flow range to accuracies of ±2.0 per cent.

Because PD meters measure a volume precisely it does not matter if the flow is pulsing. They will follow the increase and decrease of flow found in reciprocating pumps of all types. With higher viscosities the turndown ratio can be high. Even with water 100:1 is not uncommon and 3,000:1 is possible at 250 cSt. Few applications require this but it does enable measurement of ultra-low flow rates without miniature parts or normal flow measurement at minimal pressure drop.

Most meters are simple to maintain as they have only one or two moving parts and are coupled with simple readouts that are easily understood in the field. There is no requirement for straight pipe lengths as might be needed for electromagnetic or turbine devices. PD meters can be connected directly to elbows or valves and in most cases in a variety of orientations.

Designs are relatively easy to adapt for high pressure applications of 100 bar or more.

The most common PD meters are as follows:

- Rotary Piston: As mentioned above, these form the basis of domestic water measurement. However, by modifying the design of the rotary piston that oscillates in a circular chamber with a fixed web these meters can be used for ultra-low flows and high flows, as well as for high pressures and for food applications. A good 'all-rounder'.

- Spur Gear: The fluid rotates two gears and is forced around the outside of the gears and the inside of the chamber. Depending upon the location of the sensor these can yield very high 'pulses per litre' values which are useful in batching and fast-acting processes.

- Diaphragm (or bellows meter): These are common in many people's home as their domestic gas meters. When the gas flows through the meter it alternately fills and empties bellows causing levers to crank a shaft providing an output. Very useful for wide-ranging gas totalisation.

- Oval Gear: Quite similar to the spur gear where two oval gears mesh together and sweep the chamber. The volume displaced is much larger than the round gear. Fairly low cost and some designs are available in plastic.

- Nutating Disc: This meter is the hardest to understand but is effective. The rotor is a circular disc attached to a ball. The shaft on the ball is inclined. As the disc rotates in a spherically sided chamber the disc and therefore the shaft wobble, creating an output.

- Helical Screw: Possibly the most accurate PD meter design this has two intersecting cylindrical bores fitted with two interlocking helical screws. As the fluid passes through the meter these screws rotate. On standard applications Litre Meter has observed differences of just ±0.37 per cent of reading over 50:1 turndown over annual recalibrations over ten years. This type of meter is now commonly fitted on petrol pumps.

- Slide Vane: Historically the most accurate of PD meters this design has a rotating element with a number of moving blades that rotate about a fixed cam. Linearities have been claimed of ±0.02 per cent.

- Others: If we go back to Felix Wankel's seminal work on rotary machines we see that there are as many designs for PD meters as there are pumps. While the majority have never been used commercially there are many in general use including the Roots meter, wet gas meter and multi rotor designs.

Two decades ago the PD meter was considered to be old technology and likely to be overtaken by ‘more modern’ electromagnetic and ultrasonic devices. In fact this has not happened because the PD meter still represents good value and can provide excellent measurement in a wide variety of duties.

PD meters are often used in oil and gas exploration for the measurement of fluids in chemical injection processes. The formation of inorganic salts such as calcium carbonate, calcium sulphate or iron oxide during oil and gas production, known as ‘scale’, is a major flow assurance problem. Scale forms and deposits under supersaturated conditions, wherever the mixing of formation water from the bottom hole and injected seawater takes place. The deposited scale sticks to surfaces of the producing well tubing and on parts of water handling equipment, where over time it builds up and leads to problems in reservoirs, pumps, valves and topside facilities.

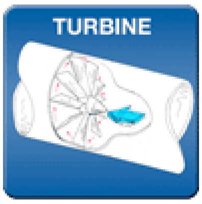
Scaling also takes place in heat transfer equipment such as boilers and heat exchangers, lowering flow rates and affecting performance during the heat exchange. A rapid increase of the mineral deposits can lead to damage of the equipment parts. As a consequence, suspension of oil operations is necessary for the recovery or replacement of damaged parts. In the oil field these interruptions are accompanied by extremely high costs.

Chemicals are injected into the system to prevent these problems – and many Litre Meter LF05 flowmeters are used to precisely measure the amount of chemical being added. This ensures that the correct amount of chemical is used, reducing waste and the cost of removal.

PD flowmeter technology is also suitable for use in the growing desalination plant market. Desalination is the process of removing salt and minerals from water to make it potable. This is mainly necessary in countries suffering water stress such as Oman, Kuwait and Saudi Arabia in the Middle East and in Australia, North Africa, Spain, the USA and China. Desalination is also used on ships, submarines and offshore facilities.

Turbine flowmeters

Axial turbine



Inline ‘axial’ turbine flowmeters are velocity measuring devices that measure the average velocity of a fluid flowing through the body of the meter. Mounted within the body of a liquid turbine flowmeter is a vaned rotor. The rotor is centred on a shaft and allowed to rotate on bearings. The shaft is supported in the housing by tube bundles that also provide a measure of flow conditioning for the fluid stream.

The rotor is made from a ferromagnetic material or contains a magnet within the hub of the rotor. Liquid flowing through the meter body engages the rotor, forcing it to rotate. The rotational velocity of the rotor is proportional to the average linear velocity of the liquid flow stream. This rotational velocity is transformed into an electrical frequency signal by means of a non-intrusive sensor or coil threaded partially into the body of the meter aligned with the rotational circumference of the rotor. Being in close proximity to the ferromagnetic or magnetic rotor creates an electromagnetic coupling with the coil. The output frequency of the coil then is directly proportional to the rotational velocity of the rotor. This frequency can then be converted to a flow rate indication or scaled signal by dividing the frequency by the meter’s scaling or K-factor (eg, pulses/gallon or pulses/litre). The K-factor is established by factory calibration of the flowmeter at the time of manufacture.

Pelton wheel (radial turbine)

Also known as a radial turbine the highly efficient Pelton Wheel meter has some major advantages. The very large blade area compared with the flow inlet port size produces an exceptionally wide range flowmeter which can measure very low flows. The flow through the inlet of the meter is accurately directed onto the rotor which rotates at a speed in linear proportion to the flow rate. A small sensing coil detects the ferrites mounted in the rotor blade tips as they pass. No drag is imposed on the rotor which assists in the measurement of extremely low flows. Sapphire bearings provide a very low friction mechanically-robust bearing with long life characteristics. Turndown can be as high as 280:1.

Alternatively, the Pelton Wheel can be mounted across an orifice plate to produce linear measurement over larger flows. Due to the unique characteristics of the Pelton Wheel there is a linear relationship between the frequency and flow rate over a wide range of up to 65:1.

A highly customised Litre Meter LMX Pelton Wheel flowmeter was installed within a missile casing to accurately measure flow rates of fuel while the missile is in flight.

The meter was manufactured in titanium to meet the 200 grams weight requirement. The flowmeters were designed to measure the flow of kerosene THDCPD fuel at flow rates of 0 to 30 l/min to an accuracy of better than ±2% of full scale instead of the standard 1-65 l/min at ±2% reading. The meters operate at temperatures of between -20 to 135°C at 30 bars, tested at 45 bars. The testing of fuel flows is carried out at the meter's maximum flow rate of 30 l/min.

Wet Drum

A Wet Gas (or Drum) meter consists of a horizontally disposed drum divided into sections. The drum is free to rotate about its axis and a fluid, usual water, is filled to just over the centre line.

The gas to be measured enters the drum at the centre and, as it fills a section, it displaces the fluid, allowing the drum to rotate. When the compartment is filled the inlet will be sealed by the fluid. The inlet port to the next section then opens, allowing the drum to continue to rotate. As it rotates the fluid enters the first section and the trapped gas is expelled through the outlet. Given this principle, once the drum has been calibrated, measurement is based on the fact that each revolution of the drum represents a known volume of gas.

Gas flow meters can be made from plastics which permit them be used for measuring the volume of highly aggressive flowing gases with laboratory precision.

For example, the patented volumetric MGC gas flowmeter from Ritter (www.ritter.de) is designed to measure small amounts of gas at ultra-low flow rates. With an accuracy of +/- 3 per cent the meters can measure flow rates of all clean gases (including corrosive gases) from 1 ml/hr to 1 litre/hr at input pressures of between 5 and 100 millibar. These meters are being used by researchers at Cranfield and other research institutions to measure the flow rate and total volume of biogas production in sludge anaerobic digesters of around 0.5 to one litre capacity which are placed in a warming water bath in laboratory conditions.

Conclusion

There are almost as many different types of flowmeter as there are applications that require some sort of flow measurement. The choice is bewildering.

The best way to determine which meter you require for a particular job is to consult an expert like Litre Meter.

Litre Meter has the tool that will let you finish the job. Contact us for more details of any of the flow meter technologies discussed in this white paper, we would be happy to hear from you.

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