Industrial flow meters/flow transmitters

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Introduction

Flow meters are an integral tool for measuring the flow of liquid, gas, or a mixture of both in applications used in the food and beverage industry, oil and gas plants, and chemical/pharmaceutical factories. There are many different types of flow meters available on the market. Fluid characteristics (single or double phase, viscosity, turbidity, etc.), flow profile (laminar, transitional, or turbulent, etc.), flow range, and the need for accurate measurements are key factors for determining the right flow meter for a particular application. Additional considerations such as mechanical restrictions and output-connectivity options also impact this choice. The overall accuracy of a flow meter depends to some extent on the circumstances of the application. The effects of pressure, temperature, fluid, and dynamic influences can potentially alter the measurement being taken.

Industrial flow meters are used in environments where noise and sources of high-voltage surges proliferate. This means that the analog front end (AFE) needs to operate at high common-mode voltages and have extremely good noise performance, in addition to processing small electrical signals with high precision and repeatability. The 4- to 20-mA loop is the most common interface between flow transmitters and flow-control equipment such as programmable logic controllers. Flow transmitters can either be powered by this loop or have a dedicated power line. Flow transmitters designed to use the loop have extremely stringent power constraints, as all of the electronics for signal acquisition/processing and transmission may need to operate solely off the 4- to 20-mA loop. Ultra-low-power processors such as the Texas Instruments MSP430™ and TMS320C5000™ DSP families, in conjunction with high-precision, low-power AFE solutions, are commonly used in loop-powered transmitters. Transmitters with digital-connectivity features such as a process field bus (PROFIBUS), I/O links, and/or wireless connectivity are increasingly popular, as they reduce start-up times and provide continuous monitoring and fault diagnostics. All these factors greatly improve productivity and efficiency of the automation loop.

This article provides an overview of the working operation of the four most common flow meters: differential-pressure, electromagnetic (magmeter), Coriolis, and ultrasonic, the last of which includes Doppler-shift and transit-time flow meters. The key uses of these meters are presented along with their advantages/disadvantages and system considerations.

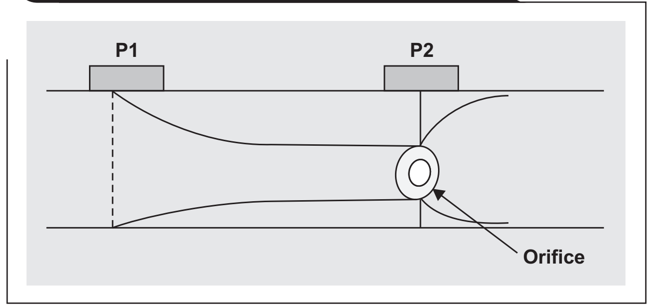
Differential-pressure flow meter

This meter operates based on Bernoulli's principle. It measures the differential-pressure drop across a constriction in the flow's path to infer the flow velocity. Common types of differential-pressure flow meters are the orifice, the pitot tube, and the venturi tube. An orifice flow meter (Figure 1) is used to create a constriction in the flow path. As the fluid flows through the hole in the orifice plate, in accordance with the law of conservation of mass, the velocity of the fluid that leaves the orifice is more than the velocity of the fluid as it approaches the orifice. By Bernoulli's principle, this means that the pressure on the inlet side is higher than the pressure on the outlet side. Measuring this differential pressure gives a direct measure of the flow velocity from which the volumetric flow can easily be calculated.

System considerations for differential-pressure flow meters

- Robust and mature technology with easy maintenance (no moving parts)
- Suitable for turbulent flow
- Poor accuracy for low-flow measurements
- Uses extractive flow-measurement technique, so there is always a permanent pressure loss that must be overcome with extra pumping energy
- Requires strict placement of pipe fittings, elbows, and bends for downstream and upstream constriction taps

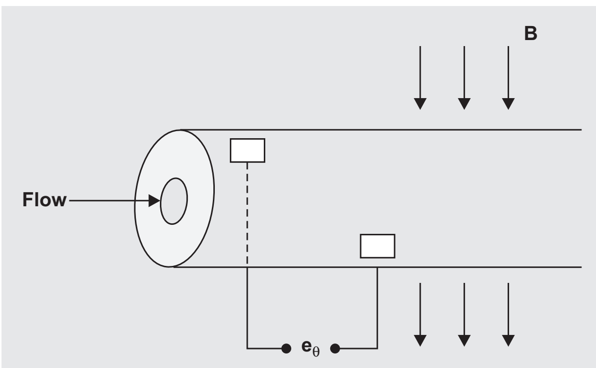
Figure 1. Differential-pressure orifice flow meter



Electromagnetic flow meter (magmeter)

The electromagnetic flow meter, also known as a magmeter, is based on Faraday's law of electromagnetism and can be used to measure the flow only of conductive fluids. Two field coil magnets are used to create a strong magnetic field across a pipe (Figure 2). Per Faraday's law, as the liquid flows through the pipe, a small electric voltage is induced. This voltage is picked up by two sensor electrodes located across the pipe. The rate of fluid flow is directly proportional to the amplitude of the electric voltage induced.

Figure 2. Electromagnetic flow meter



e_θ (voltage) = $-d\Phi B/dt$ B = Magnetic field

The coils used to create the magnetic field can be excited with AC or DC power sources. In AC excitation, the coils are excited with a 50-Hz AC signal. This has the advantage of drawing a smaller current from the system than the DC excitation technique. However, the AC excitation method is susceptible to interference from nearby power cables and line transformers. Thus, it can introduce errors into the signals measured. Furthermore, null drifting is a common problem for AC-powered systems and cannot be calibrated out. Pulsed DC excitation, where the polarity of the current applied to the field coils is periodically reversed, is commonly employed as a method to reduce the current demand and mitigate the problems seen with AC-powered systems.

System considerations for electromagnetic flow meters (magmeters)

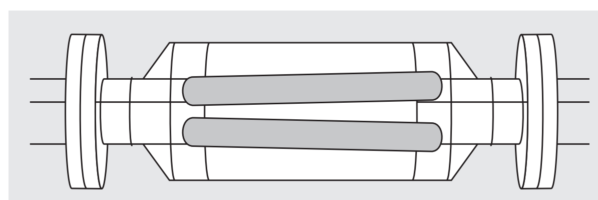
- Can measure only fluids with conductivity greater than 10 µS/cm, eliminating their use in the petroleum, oil, and gas industries, since hydrocarbons have poor conductivity
- Sensor-electrode choices change depending on fluid conductivity, pipe construction, and type of installation
- No losses in system pressure, which may be critical in applications that cannot tolerate pressure drops, such as applications with low-velocity flow
- Ideal for corrosive and dirty fluids, slurries, etc., provided the liquid phase has sufficient conductivity, since the flow meter has no internal parts
- High accuracy to within ±1% of indicated flow
- Higher cost

Coriolis flow meter

This popular flow meter directly measures mass flow rate. The installation can include a single straight tube or, as shown in Figure 3, a dual curved tube. The architecture with a single straight tube is easier to construct and maintain because it is subject to fewer stress forces, but it is susceptible to interference and noise. The architecture with dual curved tubes cancels out any noise picked up because the two tubes oscillate in counterphase.

In Coriolis meters, the tubes through which the fluid flows are made to oscillate at a particular resonant frequency by forcing a strong magnetic field on the

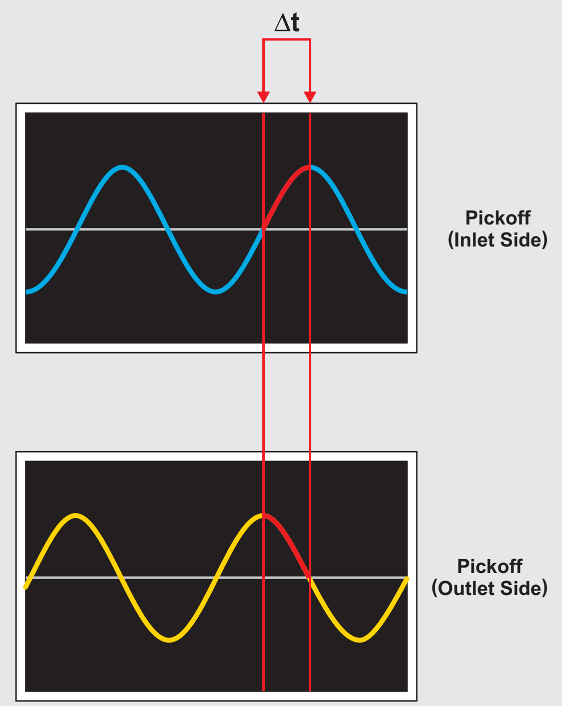
Figure 3. Coriolis flow meter



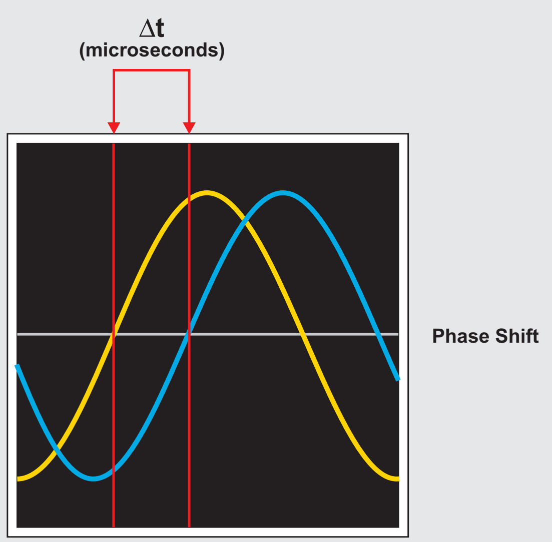
F_C (Coriolis force) = $2m\omega v_r$ ω = Speed of rotation
m = Moving mass v_r = Radial velocity

tubes. When the fluid starts flowing through the tubes, it is subject to Coriolis force. The oscillatory motion of the tubes superimposes on the linear motion of the fluid, exerting twisting forces on the tubes. This twisting is due to Coriolis acceleration acting in opposite directions on either side of the tubes and the fluid's resistance to the vertical motion. Sensor electrodes placed on both the inlet and outlet sides pick up the time difference caused by this motion. This phase shift due to the twisting forces is a direct measurement of mass flow rate. Figure 4 shows typical detection results.

Figure 4. Signals detected by sensor in Coriolis flow meter



(a) Time difference between inlet and outlet



(b) Phase shift translates to flow rate

System considerations for Coriolis flow meters

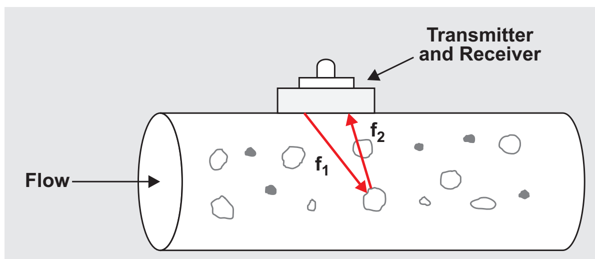
- Direct measurement of mass flow rate eliminates effects of temperature, pressure, and flow profile on the measurement
- High accuracy
- Sensor can make simultaneous measurements of flow rate and density because the basic oscillating frequency of the tube(s) depends on the density of the fluid flowing inside
- Cannot measure flow rate of fluids with entrained particles (liquids with gas or solid particles; gas with liquid bubbles; etc.) because such particles dampen the tube's oscillations, making it difficult to take accurate measurements

Ultrasonic flow meter

Doppler-shift meter

The Doppler-shift ultrasonic meter, as the name suggests, is based on the Doppler effect. This meter (Figure 5) consists of transmit- and receive-node sensors. The transmit node propagates an ultrasound wave of 0.5 to 10 MHz into the fluid, which is moving at a velocity v. It is assumed that the particles or bubbles in the fluid are moving at the same velocity. These particles reflect the propagated wave to the receiver with a frequency shift. The difference in frequency between the transmitted and received ultrasound wave is a measure of the flow velocity. Because this type of ultrasound flow meter requires sufficient reflecting particles in the fluid, it does not work for extremely pure single-phase fluids.

Figure 5. Doppler-shift ultrasonic flow meter



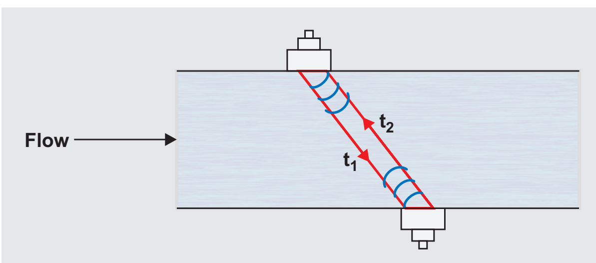
Q (volumetric flow rate) = $K\Delta(f_1, f_2)$
f_1 and f_2 = Incident and reflected frequencies, respectively
K = A constant that is a function of angle of incidence/reflection, reflective-particle position, cross section

Transit-time meter

On the contrary, the transit-time ultrasonic meter can be used for measuring only extremely clean liquids or gases. It consists of a pair of ultrasound transducers mounted along an axis aligned at an angle with respect to the fluid-flow axis (Figure 6). These transducers, each consisting of a transmitter/receiver pair, alternately transmit to each other. Fluid flowing through the pipe causes a difference between the transit times of beams traveling upstream and downstream. Measuring this difference in transit time gives flow velocity.

The difference in transit time is typically on the order of nanoseconds. Hence, precise electronics are needed to make this measurement, whether the time is measured directly or a conversion corresponding to frequency difference is made. The latter is more popular and involves an FFT analysis of the difference in frequency between waves received in and against the flow direction.

Figure 6. Transit-time ultrasonic flow meter



Q (volumetric flow rate) = K × $(t_1 – t_2)/(t_1 \times t_2)$
K = A constant that is a function of acoustic-path length, ratio between the radial and axial distances from the sensors, velocity distribution (flow-velocity profile), cross section
t_1 = Transit time for downstream path
t_2 = Transit time for upstream path

System considerations for ultrasonic flow meters

- The Doppler-shift flow meter is relatively inexpensive
- The transit-time flow meter provides one of the few techniques for measuring nonconductive slurries and corrosive fluids
- The ultrasonic flow meter is externally clamped onto existing pipes, allowing installation without cutting or breaking pipes, which minimizes personal exposure to hazardous liquids and reduces possible system contamination
- The ultrasonic flow meter's most significant disadvantage is its dependence on the fluid's flow profile; for the same average flow velocity, the meter could give different output readings for different flow profiles

Conclusion

This article has discussed the working operation of the four most common flow meters. Their key uses and design considerations, summarized in Table 1, were also discussed.

There is a wide range of solutions available for flow meters, including interfaces for industrial field-bus transceivers, a variety of AFEs, and low-power processing solutions. Selecting the right flow meter for an application from the various different technologies and designs available on the market can be rather challenging. By understanding the properties of the fluid being used, knowing the application's flow rates and required measurement accuracy, and being aware of physical constraints and operating conditions, the designer can narrow down the choices faster.

Related Web site

www.ti.com/solution/flow_meter

Table 1. Characteristics of the four most common flow meters

FEATURE	DIFFERENTIAL-PRESSURE	ELECTROMAGNETIC	CORIOLIS	ULTRASONIC
Volume/mass measurement	Volume	Volume	Mass	Volume
Fluid/flow rate	Not suitable for gases with low flow rate	Not suitable for gas flow	Not suitable for very high flow rates (>20,000 l/min)	Not suitable for gas flow
Particulate flow/slurries	Conditionally suitable	Suitable	Conditionally suitable	Conditionally suitable
Liquid/gas mixture	Not suitable	Conditionally suitable	Conditionally suitable	Conditionally suitable
Liquid conductivity	Suitable for all	Only conductive liquids	Suitable for all	Suitable for all
Food and beverage (consumable liquids)	Not suitable	Suitable	Suitable	Most suitable for non-intrusive measurement
Installation/maintenance	Easy installation; periodic cleaning required	Moderate installation effort; minimal maintenance	Installation outlay can be considerable; relatively maintenance-free	Easy installation and maintenance
Typical accuracy	0.6 to 2% of full scale	0.2 to 1% of reading	0.1 to 0.5% of reading	Doppler-shift meter: 1% of reading to 2% of full scale
				Transit-time meter: 0.35% of reading to 2% of full scale

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