

Industrial flow meters/flow transmitters

By Deepa Kalyanaraman

Business Development Manager, End-Equipment Solutions

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.

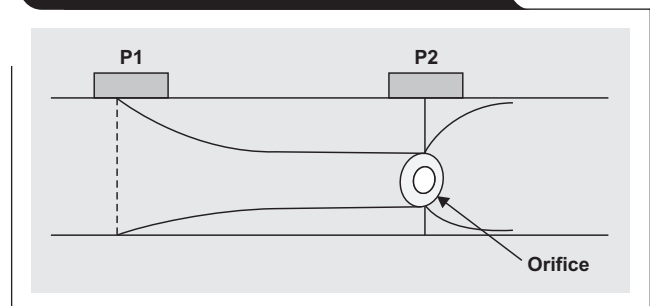
Differential-pressure flow meter

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

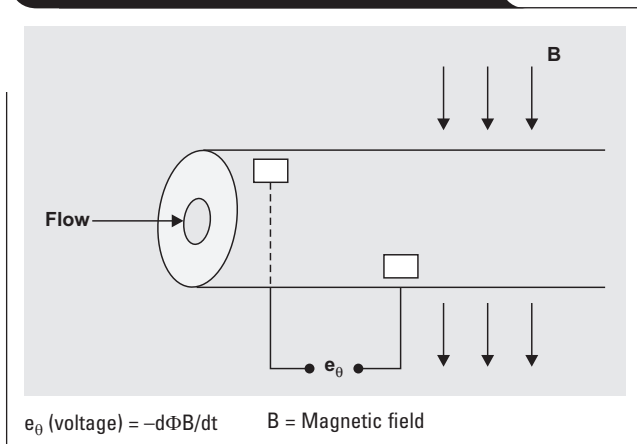
Figure 1. Differential-pressure orifice flow meter



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



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 (magneters)

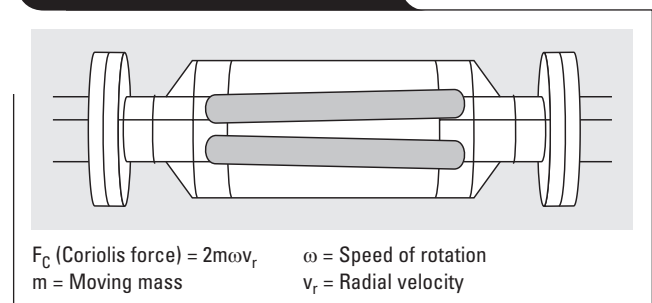
- Can measure only fluids with conductivity greater than 10 $\mu\text{S}/\text{cm}$, eliminating their use in the petroleum, oil, and gas industries, since hydrocarbons have poor conductivity
- Sensor-electrode choices change depending on fluid conductivity, pipe construction, and type of installation
- 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 $\pm 1\%$ 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.

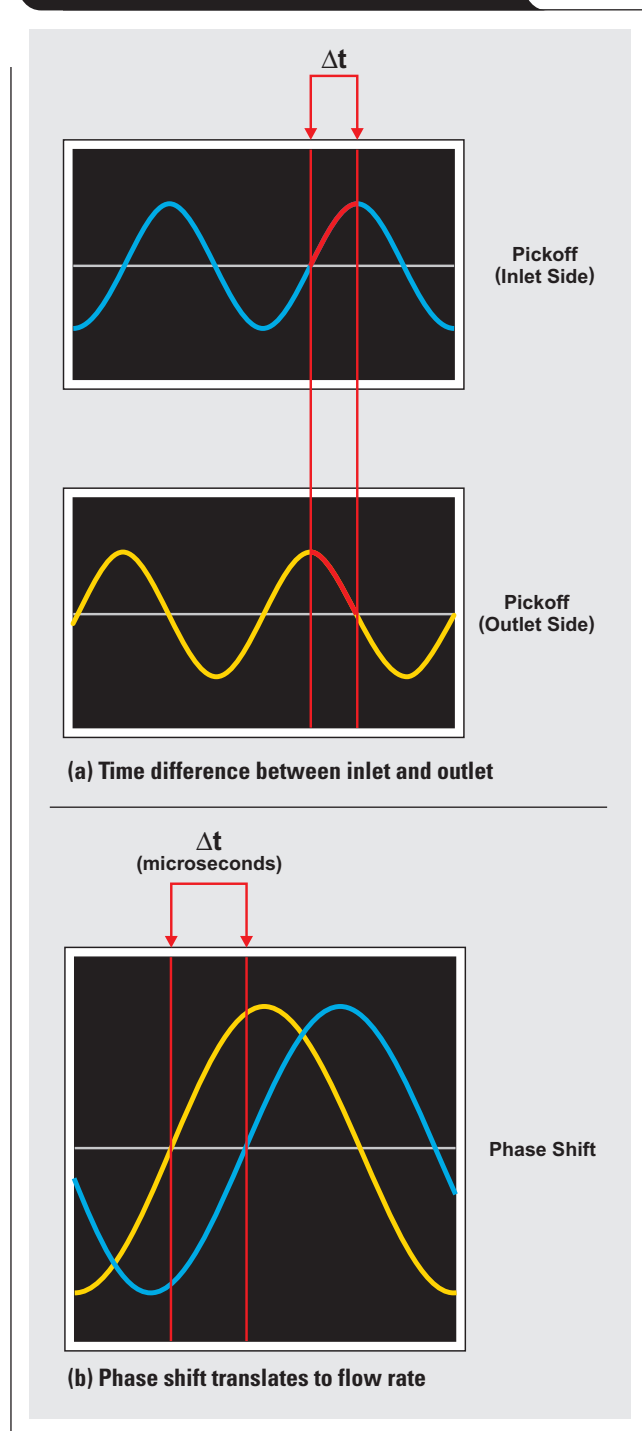
In Coriolis meters, the tubes through which the fluid flows are made to oscillate at a particular resonant frequency by forcing a strong magnetic field on the

Figure 3. Coriolis flow meter



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

Figure 4. Signals detected by sensor in Coriolis flow meter



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.

System considerations for Coriolis flow meters

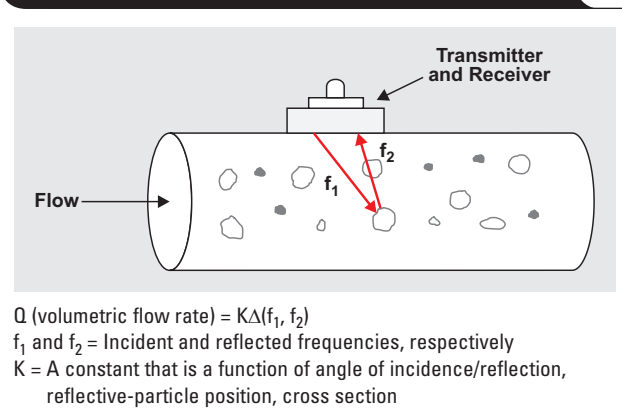
- Direct measurement of mass flow rate eliminates effects of temperature, pressure, and flow profile on the measurement
- High accuracy
- Sensor can make simultaneous measurements of flow rate and density because the basic oscillating frequency of the tube(s) depends on the density of the fluid flowing 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



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.

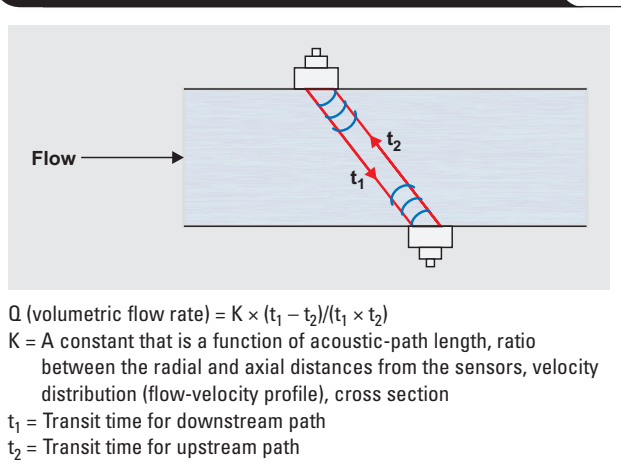
The difference in transit time is typically on the order of nanoseconds. Hence, precise electronics are needed to make this measurement, whether the time is measured directly or a conversion corresponding to frequency difference is made. The latter is more popular and involves an

FFT analysis of the difference in frequency between waves received in and against the flow direction.

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

Figure 6. Transit-time ultrasonic flow meter



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

TI Worldwide Technical Support

Internet

TI Semiconductor Product Information Center Home Page

support.ti.com

TI E2E™ Community Home Page

e2e.ti.com

Product Information Centers

Americas	Phone	+1(972) 644-5580
Brazil	Phone	0800-891-2616
Mexico	Phone	0800-670-7544
	Fax	+1(972) 927-6377
	Internet/Email	support.ti.com/sc/pic/americas.htm

Europe, Middle East, and Africa

Phone	
European Free Call	00800-ASK-TEXAS (00800 275 83927)
International	+49 (0) 8161 80 2121
Russian Support	+7 (4) 95 98 10 701

Note: The European Free Call (Toll Free) number is not active in all countries. If you have technical difficulty calling the free call number, please use the international number above.

Fax	+ (49) (0) 8161 80 2045
Internet	www.ti.com/asktexas
Direct Email	asktexas@ti.com

Japan

Phone	Domestic	0120-92-3326
Fax	International	+81-3-3344-5317
	Domestic	0120-81-0036
Internet/Email	International	support.ti.com/sc/pic/japan.htm
	Domestic	www.tij.co.jp/pic

Asia

Phone	
International	+91-80-41381665
Domestic	<u>Toll-Free Number</u>
Note: Toll-free numbers do not support mobile and IP phones.	
Australia	1-800-999-084
China	800-820-8682
Hong Kong	800-96-5941
India	1-800-425-7888
Indonesia	001-803-8861-1006
Korea	080-551-2804
Malaysia	1-800-80-3973
New Zealand	0800-446-934
Philippines	1-800-765-7404
Singapore	800-886-1028
Taiwan	0800-006800
Thailand	001-800-886-0010
Fax	+8621-23073686
Email	tiasia@ti.com or ti-china@ti.com
Internet	support.ti.com/sc/pic/asia.htm

Important Notice: The products and services of Texas Instruments Incorporated and its subsidiaries described herein are sold subject to TI's standard terms and conditions of sale. Customers are advised to obtain the most current and complete information about TI products and services before placing orders. TI assumes no liability for applications assistance, customer's applications or product designs, software performance, or infringement of patents. The publication of information regarding any other company's products or services does not constitute TI's approval, warranty or endorsement thereof.

A011012

E2E, MSP430 and TMS320C5000 are trademarks of Texas Instruments. All other trademarks are the property of their respective owners.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Mobile Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Automotive and Transportation	www.ti.com/automotive
Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Video and Imaging	www.ti.com/video

TI E2E Community Home Page

e2e.ti.com

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2012, Texas Instruments Incorporated