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Generation-next mass flowmeter arrives

By John Olin

This vortex mass flow device directly measures three parameters. Then, it computes seven more properties of liquids, gases, and steam.

The next generation of mass flowmeters offers improved accuracy, lower installed cost, and enhanced functionality, including multiple outputs of process conditions. The multiparameter vortex mass flowmeter (MVMF) was developed to reduce total cost of ownership and provide a reliable, accurate instrument for monitoring mass flow rate and the other major process variables.

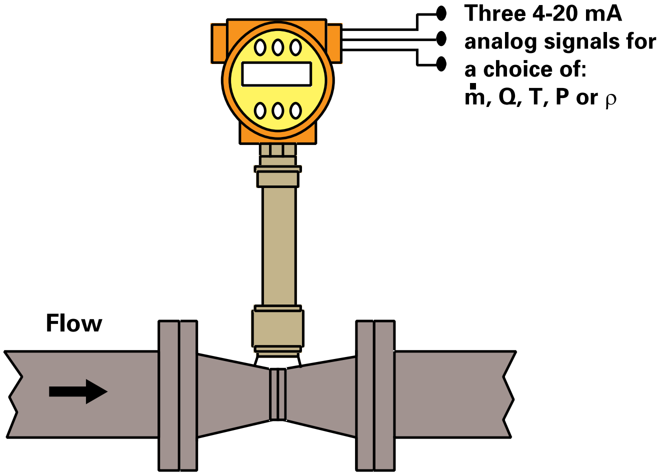


Figure 1. A multiparameter vortex mass flowmeter

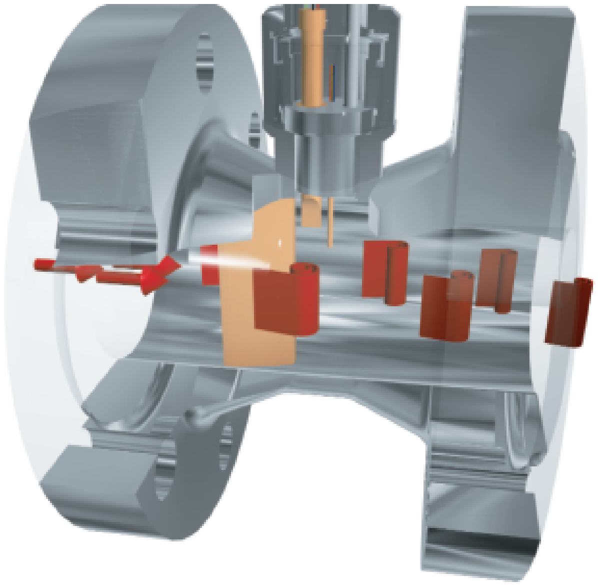
The MVMF monitors mass flow rate by directly measuring three variables: fluid velocity, temperature, and pressure. The built-in flow computer calculates mass flow rate and volumetric flow rate based on these three direct measurements (see Figure 1).

The removable velocity-, temperature-, and pressure-sensing head is built into the vortex meter's body. To measure fluid velocity, the flowmeter incorporates a bluff body (shedder bar) in the flow stream and measures the frequency of vortices created by the shedder bar. A platinum resistance temperature detector (PRTD), which automatically corrects for ambient temperature changes, measures temperature. Pressure measurement is achieved using a solid-state pressure transducer. All three elements are combined into an integrated sensor head assembly located downstream of the shedder bar.

Born in Germany

Velocity measurement is based on the phenomenon of vortex shedding. A vortex is an eddy, or swirl, of fluid. Around the turn of the century, German scientist Theodore Von Karman investigated the vortex-shedding phenomenon, which was later exploited to form the basis for vortex-shedding flowmeters. Von Karman demonstrated that when a fluid flows past a nonstreamlined body, or "bluff body," an alternating series of vortices is shed from each side of the nonstreamlined body. This alternating series of vortices is termed a "Von Karman Street" (see Figure 2).

Various flowmeter manufacturers have different shapes of shedder bars. Their common trait is sharp corners, which enhance the strength, or energy, of the vortices and ensure boundary-layer separation at two defined points: the two sharp corners. This feature is responsible for the extra-



ordinary linearity of the frequency of vortex shedding over a wide velocity range.

In the MVMF, the shedder bar is located across the flowmeter's diameter, as shown in Figure 2. The vortex velocity sensor is located just downstream of the shedder bar. Von Karman vortices form downstream of the shedder bar into two distinct wakes. The vortices of one wake rotate clockwise, while those of the other wake rotate counterclockwise. Vortices form one at a time, alternating from the left side to the right side of the shedder bar.

They interact with their surrounding space and overpower every other nearby swirl on the verge of development. Thus, the volume encompassed by each vortex remains constant (see Figure 2). By sensing the number of vortices per unit time passing by the velocity sensor, the flowmeter is able to compute the fluid's volumetric flow rate.

Von Karman discovered that the distance between vortices, or the wavelength, is constant for higher Reynolds numbers. The Reynolds number is a parameter used to describe fluid flow. It encompasses the fluid's velocity, density, and viscosity and the pipe's diameter.

Strouhal, another German scientist, expands on Von Karman's findings. He discovered that the frequency of the vortices times the width of the shedder bar divided by the velocity of the vortex street was constant for higher Reynolds numbers.

Frequency yields velocity

The velocity sensor in the vortex mass flowmeter consists of a fin immersed in the flow behind the shedder bar. The alternating lift forces created by the vortices cause the fin to deflect back and forth at the exact frequency of the vortices. The fin in the vortex mass flowmeter is mechanically connected to piezoelectric elements.

Many techniques have been applied to sense the passage of vortices, including pressure sensors, ultrasonic sensors, capacitance-based sensors, heated thermistors, and strain gauges. Strain-gauge velocity sensors based on the piezoelectric effect have the highest sensitivity and rangeability.

When piezoelectric elements are strained, they produce an electric charge, which is converted to a current. Thus, the output of the velocity sensor is a sinusoidal current with a frequency equal to that of the vortices. Since frequency is the basic output of the velocity sensor, vortex flowmeters have zero drift, in contrast to other flowmeters with analog sensors.

The fin frequency (pulses/second) is divided by that particular meter's calibration factor (pulses/cubic foot) and the cross-sectional area (square feet) of the opening to yield the fluid velocity (feet/second).

Several traditional vortex flowmeters have the velocity sensor embedded in the shedder bar itself. Because the shedder bar has a relatively high mass, the amplitude of the frequency signal of such devices is attenuated, resulting in reduced rangeability at low flows.

In contrast, the velocity sensor in the MVMF has its lightweight fin located just behind the shedder bar where the strength of the vortices is highest.

Three's a crowd

Most real-world industrial pipelines experience vibration caused by pumps, machinery, and flow-induced oscillations. The *velocity* sensors in traditional vortex flowmeters are designed for maximum sensitivity and often pick up the spurious signals generated by pipeline vibrations. The resulting noise creates erroneous vortex frequency signals, which degrade the meter's accuracy.

The MVMF eliminates this problem via a piezoelectric sensor geometry, which cancels out any signals generated by pipeline vibrations. The resulting "clean" output signal is strictly related to

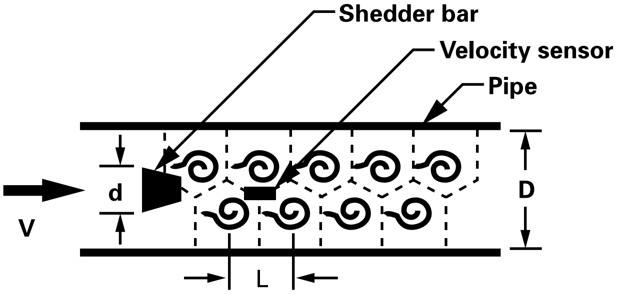


Figure 2. A "Von Karman Street"

The seven calculations performed

The sensing head of the flowmeter directly measures the fluid's velocity (V), temperature (T), and pressure (P). Then, in real time, the built-in flow computer calculates the following:

1. The fluid density, ρ, using the P and T measurements and the fluid's equation of state, which is stored in memory. For incompressible fluids (liquids), only T is needed for this calculation.
2. The fluid viscosity, μ, using T and an onboard equation.
3. The Reynolds number from ρ, μ, and the pipe's inside diameter, D, which is stored in memory.
4. A Reynolds number correction factor for low-velocity fluids.
5. The volumetric flow rate, Q, from V and the pipe's cross-sectional area.
6. The mass flow rate using ρ and Q.
7. Three 4-20 mA output signals for the user's choice of three of five variables: mass flow, Q, T, P, or ρ.

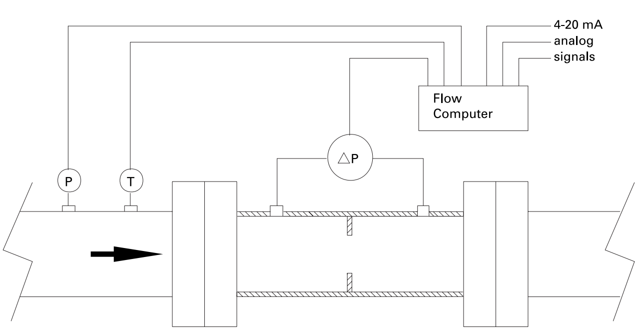


Figure 3. Traditional orifice-plate system

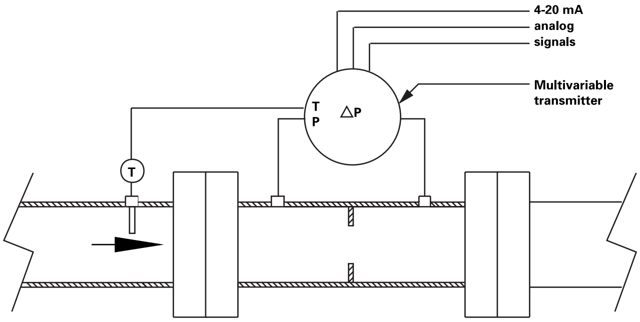


Figure 4. Four invasions of the pipeline

Conventional thermowell temperature sensor error is a problem that is almost always overlooked in mass flow monitoring systems.

the frequency of the vortices in the flowmeter. The overall result is greater accuracy and reliability, particularly at lower flow rates.

An error in measuring the *temperature* of flowing fluids is another annoying problem in real-world industrial mass flow monitoring systems. Conventional vortex and turbine meter systems and orifice-based systems of either the traditional or multivariable-transmitter variety measure fluid temperature with a resistance temperature detector (RTD) or thermocouple temperature sensor separately mounted in a heavy-walled thermowell for protection.

Such temperature sensors have high stem conduction and therefore measure a value of flowing fluid temperature that lies somewhere between the actual fluid temperature and the temperature of the pipe's wall. This problem is not so severe in applications where the convective heat-transfer coefficient is high, such as liquid flows and flows at high velocity. On the other hand, the problem is exacerbated in gas and steam flows, especially at lower velocities and at higher temperatures.

The design of the temperature sensor in the MVMF solves this problem. The temperature-sensing element is a 1,000-ohm PRTD—a highly accurate temperature measurement device.

This temperature sensor has low intrinsic stem conduction. Also, it has a unique and patent-pending configuration, which eliminates all residual effects of stem conduction. The result is fast time response and superb accuracy (within 1°C). It is ideal for steam flow and other low-velocity, high-temperature fluid measurements.

Conventional thermowell temperature sensor error is a problem that is almost always overlooked in mass flow monitoring systems.

The MVMF incorporates a solid-state *pressure* transducer isolated by a 316 stainless steel diaphragm. The transducer itself is micromachined silicon, fabricated using integrated-circuit-processing technology. A multipoint pressure/temperature calibration is performed on every sensor. Digital compensation allows these transducers to operate within a 0.4% of full-scale accuracy band within the entire ambient temperature range of –20° to +60°C (–4° to +140°F). Thermal isolation of the pressure transducer ensures the same accuracy across the allowable process fluid temperature range of –40° to +400°C (–40° to +750°F).

So, here's the skinny

Some conventional vortex flowmeters accept inputs from external temperature and pressure transmitters, thereby providing an inferred mass flow rate output. In these conventional inferential mass flow devices, temperature and pressure sensors are located somewhere in the pipeline either upstream or downstream of the vortex flowmeter, but typically not at the same location in the pipeline.

This causes errors in calculating fluid density from the temperature and pressure measurements, resulting in mass flow rate errors. Extensive testing has revealed that the only acceptable location for accurate temperature and pressure monitoring is just downstream of the shedder bar adjacent to the velocity sensor.

In this new flowmeter, all three sensors—velocity, temperature, and pressure—are located adjacent to one another in a single, removable sensing head. This integrated multiparameter design concept ensures accurate direct mass flow monitoring. Sensing heads are completely interchangeable, facilitating easy field replacement.

The MVMF simplifies process measurement because it provides output signals for five parameters: mass flow rate, volumetric flow rate, temperature, pressure, and density. It does this with only one break in the pipeline. As shown in Figure 3, the traditional orifice-plate system with temperature and pressure compensation requires five invasions of the process line.

Multivariable transmitters combine a differential pressure transducer, absolute pressure

Cost element[1]	Traditional mass flow system[2]	Multivariable transmitter[2]	MVMF
Initial cost			
Flowmeter	$1,500	$2,500	$2,500
Flow computer	300	Included	Included
Pressure transmitter	450	Included	Included
Temperature transmitter	500	300	Included
Total initial cost	$2,750	$2,800	$2,500
Installation cost			
Flowmeter	$1,500	$1,500	$1,000
Flow computer	750	Included	Included
Pressure transmitter	750	Included	Included
Temperature transmitter	750	750	Included
Total installation cost	$3,750	$2,250	$1,000
Annual maintenance costs			
Flowmeter	$200	$200	$200
Flow computer	200	Included	Included
Pressure transmitter	200	Included	Included
Temperature transmitter	200	100	Included
Total annual maintenance costs	$800	$300	$200
Total cost of ownership	$7,300	$5,350	$3,700
Overall accuracy (% of rate)	**4–5%**	**3–4%**	**1–1.5%**

Notes: [1]Based on average 1997 list prices in U.S. dollars. [2]Includes cost for orifice plate and flanges.

Table 1. Comparison of costs and accuracy for 25-mm (1-in) in-line mass flowmeter concepts

transducer, temperature-sensor electronics, and flow computer in one package, but, as shown in Figure 4, they require a separate temperature sensor, four invasions of the pipeline, and the installation of tubing, valves, and manifolds.

When factoring in the cost of installing electrical conduit and wiring and the associated engineering and equipment costs, the MVMF concept clearly exhibits the lowest total cost of ownership (see Table 1). Accuracy figures are included in Table 1 also.

Attribute	Multivariable pressure transmitter system	Coriolis mass flowmeter	MVMF
Accuracy	3–5% of rate	0.2–0.5% of rate	1–1.5% of rate
Cost			
Initial*	1/3	1	1/2
Installation	High	Moderate	Low
Maintenance	High	Moderate	Low
Operating	Moderate	High	Low
Total cost	Moderate	High	Low
Other features			
Pressure loss	Moderate	High	Low
Turndown	4 to 1	100 to 1	30 to 1
Multivariable?	Yes	No	Yes
Usable with gases?	Yes	Marginal	Yes

Note: *Initial costs are stated as the fraction of the cost of a Coriolis meter.

Table 2. Cost and accuracy comparison for three mass flowmeters

Select the accuracy needed

When specifying a mass flowmeter for an application, the process control engineer must carefully weigh cost versus accuracy. In this deliberation, the proper *cost* to consider is the total cost of ownership over the flowmeter's lifetime. Therefore, the correct cost includes initial cost, installation cost, and maintenance costs. It also must include operating costs, such as the additional cost of electricity that pumps will require overcoming the flowmeter's permanent pressure loss.

The proper *accuracy* to select is the accuracy band that is appropriate for the application. Accuracy that is too low will result in unnecessary process costs. Accuracy that is too high means an unnecessarily expensive flowmeter. The engineer must find the most cost-effective solution.

Table 2 compares the three major candidates for industrial mass flowmeter applications. The table shows that a multivariable pressure transmitter mass flow system has the worst accuracy band (3–5%) and a moderate total cost of ownership. The Coriolis mass flowmeter is the most accurate (0.2–0.5%) but has the highest total cost of ownership. This is due to its high initial cost and its associated high pressure drop. Coriolis meters trade pressure drop for accuracy.

The MVMF has a good midrange accuracy band (1–1.5%) and a relatively low total cost of ownership. Since most industrial process control applications require an accuracy band of approximately 1–2% of rate, the new flowmeter is the most cost-effective solution in approximately 80% of all mass flowmeter applications. **IT**

Behind the byline

John Olin is chief executive officer of Sierra Instruments in Monterey, Calif. He has a Ph.D. in mechanical engineering, holds eight patents for instrumentation, and has authored numerous technical papers.

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