Selecting Flow Measurement Devices

Five flow meters to consider for chilled-water applications

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Flow meters are often taken for granted because they are installed and "work" most of the time. What is often meant by "work" is that moving a valve to change the flow rate seems to change the flow measurement appropriately. Notice that the measure of success is of a subjective nature in that flow measurement accuracy is not even mentioned.

In some installations, it is remarkable that even this rudimentary level of success is achieved. For instance, one such control loop "worked" for 15 years without a square root extractor, which caused the measurement to be half of the actual flow rate.

As more measurements are analyzed to better control processes, more emphasis should be put on what is actually being measured and the quality of the data produced. This process often exposes existing flow measurement problems that often are caused by having different people specify, pipe, install, startup, and operate flow measurement instruments.

WHAT FLOW METERS MEASURE

How many times have you heard someone say that they want to measure the flow of a fluid, such as chilled water? Measuring flow entails the measurement of the quantity of fluid passing a given point in a conduit. However, this does not clearly define the measurement requirement due to the various types of flow and the different measurement principles used to measure flow. The following equations express the relationships between the types of flow.

$Q = Av$ (volumetric flow)

$W = \rho Q$ (mass flow)

where:

Q = volumetric flow rate

A = cross-sectional area of the conduit

v = average fluid velocity

W = mass flow rate

ρ = fluid density

Referring to the above equations, the volumetric flow rate is the volume of fluid that passes through the flow meter per unit of time. Flow meters that measure fluid volume directly should be considered volumetric flow meters.

Some flow meters measure the average fluid velocity. The volumetric flow rate can then be inferred from the average fluid velocity when the cross-sectional area is known. Uncertainty associated with the cross-sectional area can degrade the inferred volumetric flow measurement. Flow meters that measure velocity should be considered velocity flow meters.

Photo courtesy of Krohne Inc.

Example of magnetic flow meter with integral transmitter.

The mass flow rate is the mass of fluid that passes through the flow meter per unit of time. Flow meters that use the properties of mass to measure the fluid mass should be considered mass flow meters. Some flow meters (sometimes also called mass flow meters) infer a mass flow rate from measurements using fluid properties that are assumed to be constant or from multiple measurements that are used to compensate for changing fluid properties. Uncertainty associated with fluid properties can degrade the inferred mass flow measurement.

Inferential flow meters measure a quantity related to the velocity head ($\frac{1}{2}\rho v^2$). The volumetric flow rate can then be inferred when the density is known. Uncertainty associated with the fluid density can degrade the inferred volumetric flow measurement. Inferential flow meters do not measure volume, velocity or mass, but rather a quantity related to velocity head, from which a volumetric flow rate can be inferred.

The above equations describe the mathematical relationship between the volumetric flow, fluid velocity, and mass flow rate. Given a volumetric flow rate, fluid velocity, or mass flow rate measurement, the other two types of measurement can be calculated when the fluid density and/or cross-sectional pipe area are known. Uncertainty associated with the fluid density and/or cross-sectional pipe area can degrade the calculation. Flow meters are sometimes calibrated in units (such as kilograms per minute) that are different from the type of flow that is measured by the flow meter (such as volumetric). This may mislead an observer as to which type of flow is truly being measured by the flow meter.

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TYPES OF CHILLED WATER FLOW METERS

Which type of flow measurement would be desirable in a chilled water flow measurement application? The following equation can be used to calculate the thermal load.

$$Q_{thermal} = W\,c_p\,\Delta T$$

where:

$Q_{thermal}$ = thermal heat load
W = mass flow rate
c_p = heat capacity of the chilled water
ΔT = temperature difference between supply and return streams

From this equation, it can be seen that the mass flow of chilled water is used to calculate the thermal load. However, mass flow meters are rarely used for chilled water because they are relatively expensive and may not be available in the necessary sizes. Volumetric flow meters, such as a cold-water flow meter with a pulse contact head, can be accurate and inexpensive for small systems. In larger piping, insertion flow meters may be more economical than full-bore flow meters. These flow meters infer the flow in the entire pipe from a flow measurement at one location in the pipe. Insertion flow meters are generally less accurate than full-bore flow meters because they are sensitive to flow stream distortions (such as caused by an elbow), and sensor location and are subject to hydraulic issues.

Notwithstanding the above, in most systems, full-bore chilled water flow meters are installed that measure inferentially (differential pressure), or measure fluid velocity (magnetic, turbine, ultrasonic and vortex shedding).

DIFFERENTIAL-PRESSURE FLOW METERS

A differential-pressure flow meter utilizes the pressure drop that results from a piping restriction to infer the flow of a fluid in the pipe. A differential pressure flow meter system consists of a flow meter element (such as an orifice) installed in a pipe to produce the pressure drop, and a differential pressure transmitter that measures the pressure drop and generates an electrical signal. Impulse tubing or piping connects the flow meter element (taps) to the differential pressure transmitter.

Most differential pressure flow meter elements generate a pressure drop that is proportional to the square of the flow rate through the flow meter. This means that if the flow rate is doubled, the differential pressure will increase four-fold. Conversely, if the flow rate is reduced by a factor of four, the differential pressure will be reduced to $(1/4)^2$, or $1/16$ of the differential pressure at the original flow rate.

The following example illustrates the effect of the squared relationship on the flow measurement. In a typical application, it would be reasonable for a flow meter to operate between 10 and 100 percent of its full scale range. The squared output relationship between flow and differential pressure means that between 10 to 100 percent of the flow range, the differential pressure will vary over a 100-to-1 range because the differential pressure at 10 percent flow is $(1/10)^2$, or only 1 percent of the differential pressure at the original flow rate. To measure flow accurately, the flow meter must generate an accurate differential pressure from 10 to 100 percent of full scale flow, and the differential pressure transmitter must accurately measure from 1 to 100 percent of the differential pressure at full scale flow. Because many differential pressure transmitters can measure between 5-10 and 100 percent of full scale differential pressure, flow measurement accuracy could be significantly degraded or unknown at flow rates below approximately 30 percent of full scale flow.

Common differential pressure elements used to measure chilled water include the orifice-plate and Venturi flow elements. The orifice-plate flow element is a plate that is sandwiched between two flanges. A hole (orifice) in the plate allows the fluid to flow through the flow meter and forms a restriction to flow. The hole in the orifice plate can have different shapes, but most are concentric and have a round hole located in the center of the pipe. Taps for measuring the differential pressure produced are located at specific locations upstream and downstream of the orifice plate flow element.

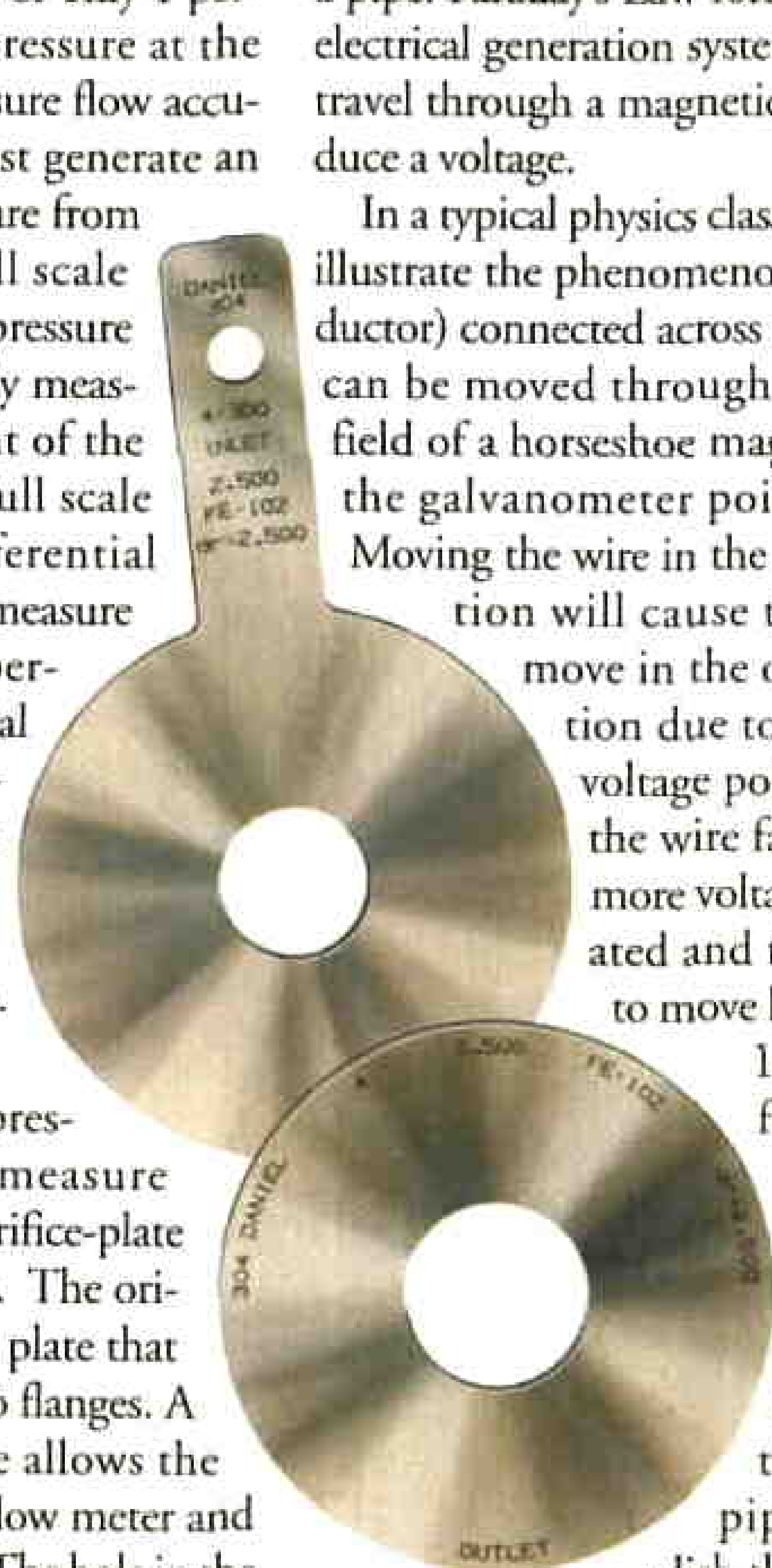
A Venturi flow element consists of a reduction and subsequent increase in pipe diameter that forms a restriction to flow. The restriction is smoother than that of an orifice plate flow element, so the differential pressure across this flow meter is generally lower under the same flowing conditions. As a result, the permanent pressure loss is also lower. Taps for measuring the differential pressure produced are located upstream and in the throat of the Venturi flow element.

MAGNETIC FLOW METERS

Magnetic flow meters utilize Faraday's Law of Electromagnetic Induction to determine the velocity of a liquid flowing in a pipe. Faraday's Law forms the basis for electrical generation systems where wires travel through a magnetic field and produce a voltage.

In a typical physics class experiment to illustrate the phenomenon, a wire (conductor) connected across a galvanometer can be moved through the magnetic field of a horseshoe magnet and cause the galvanometer pointer to move. Moving the wire in the opposite direction will cause the pointer to move in the opposite direction due to the changing voltage polarity. Moving the wire faster will cause more voltage to be generated and the movement to move higher.

In magnetic flow meters, a magnetic field is generated and channeled into the liquid flowing through the pipe. To accomplish this, the electromagnetic coils can be located outside of the pipe (flow tube); however, the flow tube must be non-magnetic to allow penetration of the magnetic field into the liquid. Locating the coils internal to the flow meter (closer to the liquid) can reduce the electrical power necessary to deliver the magnetic field, as well as reduce the size of the flow meter and fabrication costs.



Orifice plate differential pressure flow elements. Courtesy of Daniel Measurement and Control

Following Faraday's Law, flow of a conductive liquid through the magnetic field will cause a voltage signal to be generated. This signal is sensed with electrodes located on the flow tube walls. When the coils are located externally, a non-conductive liner is installed inside the flow tube to electrically isolate the electrodes and prevent the signal from being shorted. For similar reasons, non-conductive materials are used to isolate the electrodes for internal coil designs.

The fluid itself is the conductor that will move (flow) through the magnetic field and generate a voltage signal at the electrodes. When the fluid moves faster, more voltage is generated. Faraday's Law states that the voltage generated is proportional to the movement of the flowing liquid. The transmitter processes the voltage signal to determine liquid flow.

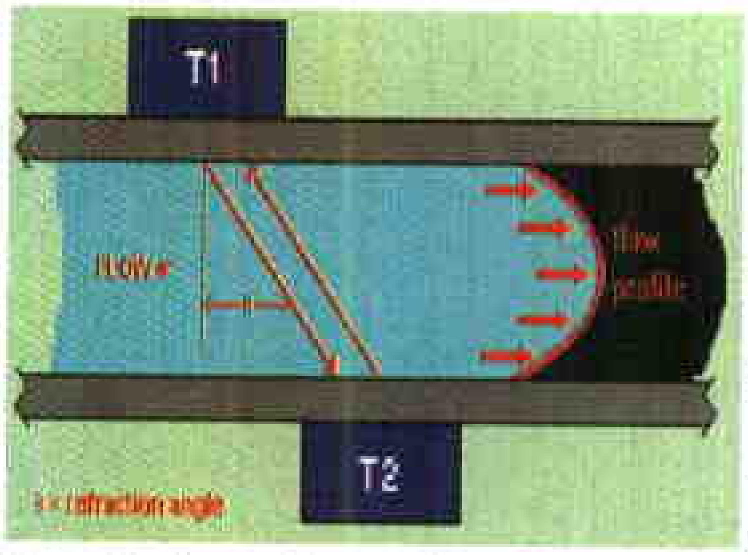
The voltage signal will take the same general form as its electromagnetic excitation. When a magnetic flow meter is excited by a sinusoidal magnetic field (AC waveform), the signal generated at the electrodes is also sinusoidal. In earlier designs, these signals were subject to a number of influences that affected measurement quality, including stray voltages in the process liquid, capacitive coupling between the signal and power circuits, capacitive coupling between interconnecting wiring, electrochemical voltage potential between the electrode and the process fluid, and inductive coupling of the magnets within the flow meter. These flow meters required a zero adjustment to compensate for these influences and the effect of electrode coating.

Turning the electromagnetic field on and off (DC waveform) causes the signal to resemble a square wave. When the electromagnetic field is on, the signal due to flow plus noise is measured. When the electromagnetic field is off, the signal due to only noise is measured. Subtracting these measurements cancels the effects of noise and eliminates the zero adjustment, reducing the above mentioned drift problems and improving performance. Waveforms other than those described above are also in use.

TURBINE FLOW METERS

Turbine flow meters use the mechanical energy of the fluid to rotate a rotor in the flow stream. A turbine flow meter consists of a turbine rotor with blades, shaft, and bearings located in the flow meter body in the pipe, and a mechanical registration device or a transmitter that generates an electrical signal. The turbine rotor shaft spins on bearings and transforms energy from the flow stream into rotational energy. The turbine rotor spins at a speed that is proportional to the velocity of the flow through the flow meter. This means that if the flow rate is doubled, the turbine rotor will spin twice as fast.

Various types of sensing systems are used to detect the turbine rotor speed to drive the registration device or transmitter. Rotation can be sensed mechanically via the shaft or by detecting the movement of the turbine rotor blades. Turbine rotor blade movement is often detected magnetically, with each blade generating a pulse. When the fluid moves faster, proportionally more pulses are generated. Optical and radio frequency (RF) sensing systems are also available.

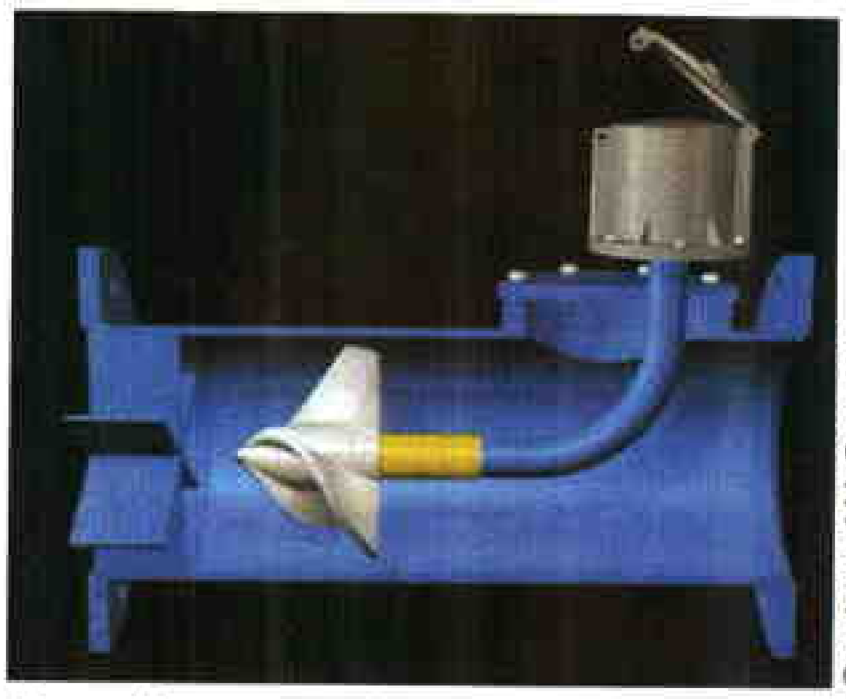


Courtesy of Controlotron

Transit-time ultrasonic flow meter.

Note that the sensing systems presented generally exert progressively less physical drag on the turbine rotor. Sensing systems that exert less drag on the turbine rotor generally provide better performance at low flow rates because of the lower drag. An electronic transmitter can be used to process the pulse signal to determine the flow of the fluid.

Turbine flow meters have moving parts that are subject to wear and damage. Worn bearings can increase drag and cause turbine flow meters to measure lower than actual flow well before a catastrophic failure occurs. In some applications, occasional calibration and maintenance may be required to ensure that wear has not compromised turbine flow meter accuracy.


Courtesy of McCrometer

Propeller-type turbine flow meter.

Paddlewheel and propeller flow meters are also turbine flow meters. They are generally less expensive and less accurate than conventional turbine flow meters. However, they can provide the performance and service life necessary in many applications.

ULTRASONIC FLOW METERS

Ultrasonic flow meters utilize sound waves to determine the velocity of a fluid flowing in a pipe. At no flow conditions, the frequencies of an ultrasonic wave transmitted into a pipe and its reflections from the fluid are the same. Under flowing conditions, the frequency of the reflected wave is different due to the Doppler effect. When the fluid moves faster, the frequency shift is proportional to the fluid velocity in the pipe. The electronic transmitter processes signals from the transmitted wave and its reflections to determine the flow rate.

Courtesy of ABB Inc.

Vortex-shedding flow meter.

Transit-time ultrasonic flow meters send and receive ultrasonic waves between transducers in both the upstream and downstream directions in the pipe. At no flow conditions, it takes the same amount of time to travel upstream and downstream between the transducers. Under flowing conditions, the upstream wave will travel slower and take more time than the (faster) downstream wave. When the fluid moves faster, the difference between the upstream and downstream times increases proportionally to the fluid velocity in the pipe. The electronic transmitter processes upstream and downstream times to determine the flow rate.

Ultrasonic transducers are either in contact with the flow stream (wetted) or clamped on the outside of the pipe (non-wetted). Because they are in direct contact with the fluid, wetted transducers generally provide a better sonic connection to the fluid. In contrast, a clamp-on transducer relies on its mechanical connection to the exterior of the pipe and a sonically conductive interface between the pipe and the fluid. Non-uniform, painted and corroded piping surfaces can degrade these mechanical connections. In some designs, a sonically conductive gel is applied between the transducer and the pipe to improve the connection. Due to dehydration, the gel may require periodic replacement.

Transit time ultrasonic flow meters are usually more accurate than Doppler ultrasonic flow meters. Doppler ultrasonic flow meters are usually more economical.

VORTEX SHEDDING AND FLUIDIC FLOW METERS

Vortex shedding and other fluidic effects are oscillations that occur when fluids pass by an object or obstruction. Examples of these effects in nature include the whistling caused by wind blowing by the branches of trees, the swirls produced downstream of a rock in a rapidly flowing river, and the waving of a flag in the wind. Note that in all of these examples, when the flow is slowed, the phenomenon ceases. That is, the whistling stops when the wind dies down, the water flows calmly around the rock when the river is not flowing rapidly, and the flag does not wave in a mild breeze.

Fluidic flow meters are a class of flow meters that generate oscillations as a result of flow. The number of oscillations

Continued on Page 59

Continued from Page 55

can be related to the rate of flow passing through the flow meter. Vortex shedding flow meters are a specific type of fluidic flow meter. Other fluidic flow meters include designs based upon the Coanda effect and vortex precession.

Vortex shedding flow meters present the flow in a pipe with an obstruction in the general shape of a bluff body or strut. At low flow rates, the fluid simply goes around the bluff body (or strut). As velocity increases, alternate vortices are formed (shed) on each side of the bluff body (or strut) and travel downstream. The number of vortices formed is proportional to the velocity of the fluid, such that doubling the flow will form twice as many vortices. A variety of electronic and mechanical techniques can be used to sense the vortices. The frequency of vortex formation is used to generate a flow measurement signal.

Bluff body vortex shedding flow meter designs have shedder bars that have a width of approximately 20 percent of the inside diameter of the pipe. As a result, the pressure drops associated with these designs are similar. It is advisable to use supplier information to determine the actual pressure drop across these flow meters. For estimation purposes, one rule of thumb is that the pressure drop from a water flow at 5 meters per second is approximately 400 mbar differential (or approximately 15 ft per sec and 5 lbs per sq in., respectively). Pressure drop varies as the square of the flow rate such that doubling the flow will result in four times the differential pressure across the flow meter.

The relatively thin strut shedder designs reduce the loss of hydraulic energy across the flow meter (pressure drop). Reducing the pressure drop across the flow meter can conserve hydraulic energy in some applications, such as when a pump is controlled with a variable speed drive. Note that, in many installations, installing a flow meter with a lower pressure drop in place of a flow meter with a higher pressure drop can cause the pressure drop to be transferred from the flow meter to the control valve, and result in no energy savings. Note that providing increased pressure drop through the control valve can affect the quality of control.

Coanda effect fluidic flow meters contain passages or other hydraulic mechanisms that allow a portion of the downstream fluid to be fed back near the inlet of its fluidic oscillator. By impacting the incoming fluid, the feedback flow causes the main flow to preferentially attach itself to the opposite surface of the flow meter. This increases the opposite feedback flow and forces the main flow away from that surface. This process repeats and causes flow in the feedback passages to oscillate in proportion to flow, such that doubling the flow will create twice as many oscillations. A variety of electronic and mechanical techniques can be used to sense the feedback flow oscillations. The frequency of feedback flow changes is used to generate a flow measurement signal.

In vortex precession fluidic flow meters (often called swirl flow meters), a static element is used to impart rotation to the incoming fluid and cause the fluid to form a vortex downstream that resembles a cyclone. The downstream portion of the vortex rotates around the axial centerline of the pipe. In other words, looking through the flow meter in the downstream direction, the downstream portion of the vortex is rotating in a circle at the pipe wall. A vortex breaker is installed at the outlet of the flow meter body to stabilize the vortex and to keep it from propagating downstream where it can disturb the process or other hydraulic devices, such as control valves. The speed with which the vortex rotates is proportional to the flow rate, such that doubling the flow will cause the vortex to rotate twice as many times. A variety of electronic and mechanical techniques can be used to sense number of vortex rotations. The frequency of vortex rotation is used to generate a flow measurement signal.

CONCLUSION

This article is intended to help you narrow your choices when in the process of selecting a flow meter for a specific application. Next month's article will review flow meter installation, followed by operation and maintenance in February and commissioning in March.

AD INDEX

CIRCLE NO.		PAGE NO.
275	Alerton Technologies	4
276	Automated Logic	12-13
277	Baldor Electric Company	BC
279	Belimo Air Controls	8
280	Bell & Gossett	10
281	Bryan Steam Corp.	15
282	Camfil Farr	25
317	Controlotron	53
283	MULTI-WING AMERICA, INC., A Crowley Company	19
284	Danfoss Inc.	IFC
285	Glasfloss Industries Inc	25
286	Heatcraft Commercial Products	33
287	HVLS Fan Co.	11
288	Knauf Fiberglass Co.	6
289	Lindab Inc	21
290	Lochinvar	IBC
291	Metal Fab Inc	15
292	New York Blower Co.	23
293	Orival Inc.	24
308	Pure Humidifier Company	47
294	Roth Pump Company	34
295	Ruskin	46
296	Shortridge Instruments Inc.	30
	Society Of Fire Protection Eng	36
298	Specific Systems	30
310-315	System Sensor	1
350	Trico Air Systems	11
300	TSI Inc.	16
301	Vaisala Inc.	32
302	York International Corp.	2

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