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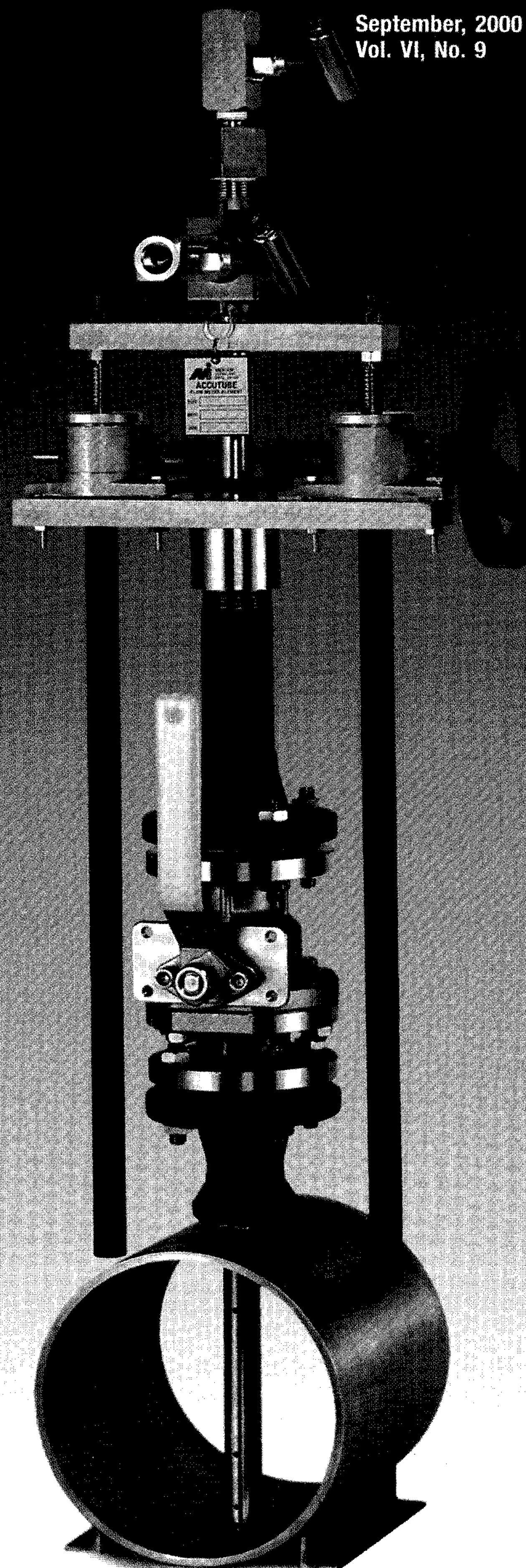

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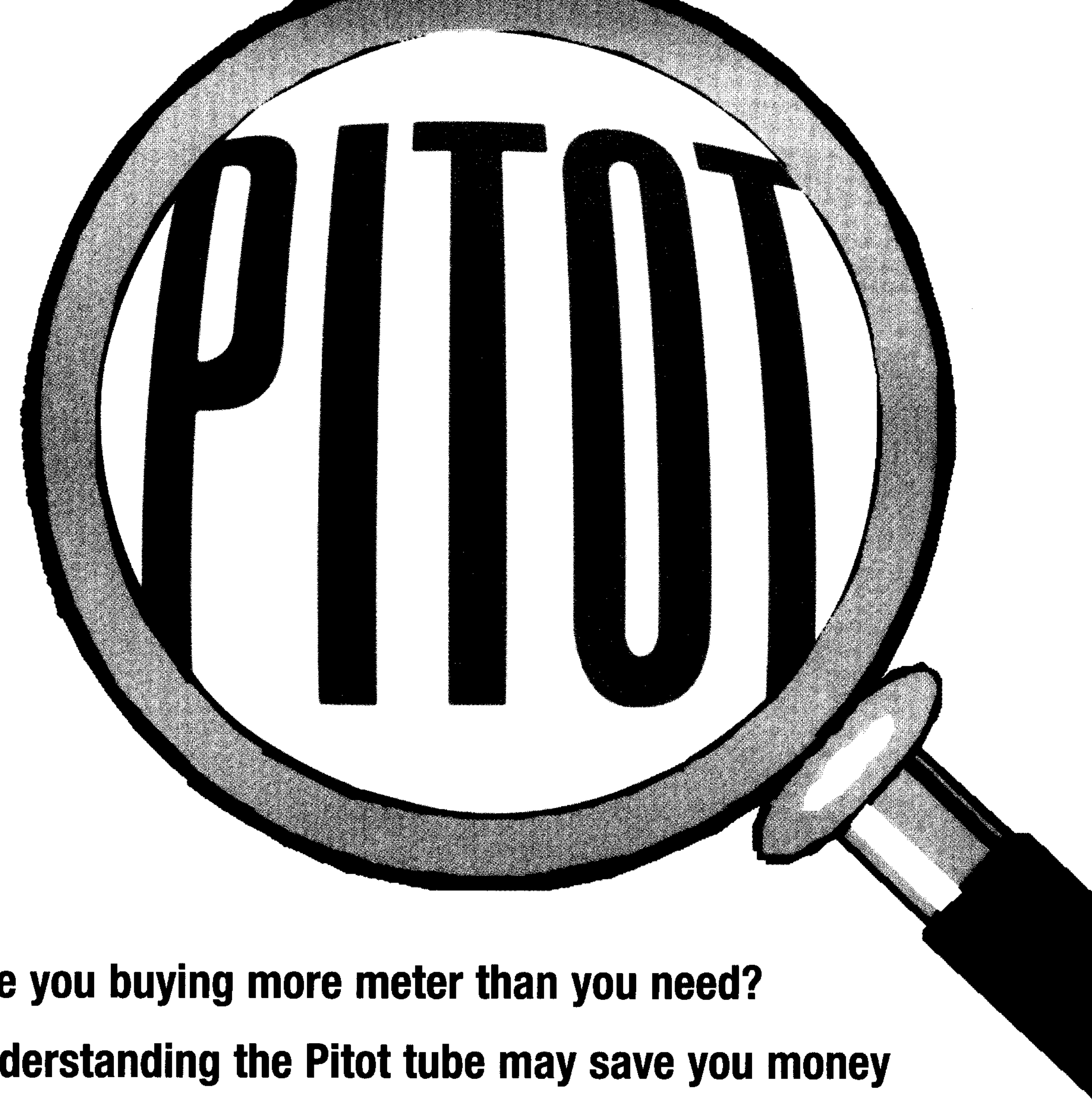
KNOW YOUR



Are you buying more meter than you need? Better understanding the Pitot tube may save you money when it comes time to purchase one.

by Dave Thomas and Rick D'Angelo

The wide variety of flowmetering instruments can create a bewildering choice for the engineer, who must measure and/or control the flow of liquid, steam or gas service in a process industry application. A broad range of technologies compete for each application, and each manufacturer is actively marketing the features of a particular type or variation.

To avoid buying more metering than necessary, the specifying engineer must know not only what fluid needs to be monitored and how large the pipe is, but also how much accuracy and range (turndown) are required to measure the variation in flow that the system will experience.

The multi-port averaging Pitot tube, a basic flow-sensing device widely used for many years in the process industries, provides a good example of the need to clearly understand manufacturers' advertised specifications before a cost-effective selection can be made.

Meet the Pitot

The multi-port averaging Pitot tube, a variation of the instrument invented by Henri Pitot in 1732, offers many features that make it suitable as the primary element in the measurement of liquid, steam or gas in process industry applications. As an insertion-type flowmeter, it is easily and quickly installed through a small hole drilled into the pipe. As a mechanical device with no electronics or moving parts, it is not subjected to electrical drift or physical wear, making it a dependable, repeatable primary element that needs no periodic recalibration.

Multi-port averaging Pitot tubes come in a wide range of sizes and materials for a broad range of applications. They are available for lines as small as ½," and for larger-diameter lines up to 72," where inline flowmeters may either be unavailable or considerably more expensive. Insertion-type flowmeters usually have lower unrecoverable pressure losses than inline meters because they create minimal obstruction of the flow area. Wet-tap insertion meters are also available where the process cannot be shut down for installation or maintenance.

There are certain applications where multi-port averaging Pitot tubes may not be the best choice, such as where flow contamination can block the sensing ports, or where very low velocities or very high-viscosity liquids are involved. However, they are cost-effective choices for a significant number of process flowmetering applications. (Figure 1 illustrates a typical installation, where a multi-port averaging Pitot tube is used as a primary element.)

Determining Flow Rate

Pitot tubes create differential pressure to determine flow rate. The

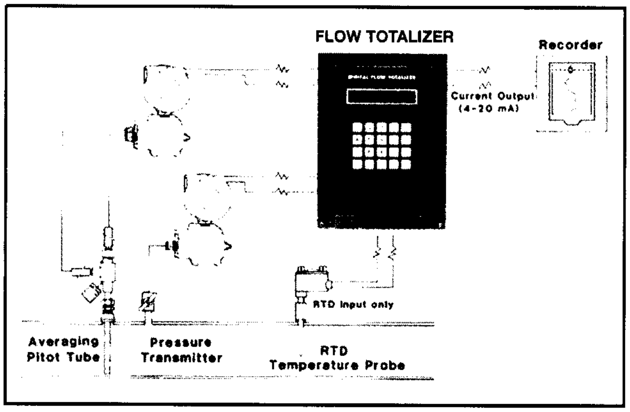


Figure 1. Typical installation, where a multi-port averaging Pitot tube is used as a primary element.

multi-port averaging Pitot tube probe incorporates two isolated plenum chambers in a single probe. Multiple sensing ports are strategically drilled into each chamber to sample both the higher fluid velocity occurring at the center of a straight pipe, and the lower fluid velocity occurring near the pipe wall. The probe is positioned so that the ports in one chamber are facing upstream, and the ports in the other are facing downstream. (See Figure 2, average Pitot cutaway.)

The probe's obstruction of the flow stream profile creates stagnation and static pressures. The upstream ports continually sample and average the stagnation or impact pressure, while the downstream ports sample and average the static pressure. A readout device is then used to indicate the differential between the two pressures. The velocity of the flow in the pipe is proportional to the square root of the differential pressure. (See following discussion of Bernoulli's equation.) By multiplying the velocity times the cross-sectional area of the pipe, the volume flow rate can be determined.

Square Root Device

The velocity equation is a form of Bernoulli's equation derived from the first law of thermodynamics, also referred to as the conservation of energy for a system.

$$V = \sqrt{2gDP/r},$$

Where: g is gravity, DP is differential pressure and r is density. The conservation of mass requires that $Q = VA$, where Q is the volume flow rate, V is velocity and A is area.

Substituting the velocity equation for V, and adding an empirical flow coefficient, K, yields:

$$Q = AK\sqrt{2gDP/r}$$

Notice that the Pitot tube is a "square root device." The square root of the differential pressure (DP) is proportional to the flow rate (Q).

Flow Coefficient

The flow coefficient, K, is necessary because the true flow is generally only 60 to 70 percent of that determined using the theoretical flow equations. Reasons for this include the fact that the Pitot tube intrudes on the flow, creating energy losses not accounted for with Bernoulli's equation, and a suction effect at the static pressure ports, caused by vortices that shed downstream of the probe.

Flow coefficients are empirically determined by testing various probe diameters and pipe diameters using NIST-traceable standards, and are provided for each multi-port averaging Pitot tube by the manufacturer.

For a given probe and pipe diameter, flow coefficients may vary with changes in operating conditions (fluid velocity, density, viscosity). These operating conditions can be combined to derive a dimensionless number, the Reynolds number, which indicates the degree of turbulence in the application.

Reynolds number = Velocity_{AVG} *Pipe I.D.* Density/Absolute Viscosity

By plotting the Reynolds number versus the flow coefficient, the appropriate coefficient can be determined for any operating condition (Reynolds number) that a given probe in a given diameter pipe may experience. (See Figure 3.)

Over a wide turndown, flow coefficients may vary by ±2 percent with the Reynolds number. Flow coefficient correction factor versus Reynolds number data is used to provide the most accurate flow rate calculation for any given application.

Manufacturers' published flow equations incorporate all applicable corrections, enabling multi-port averaging Pitot tubes to achieve published accuracies of from ±¾ percent, to ±1 percent of rate, and repeatability of ±1 percent.

How Pitot Tubes Shape Up

All manufacturers' multi-port averaging Pitot tubes are based on the same theory (flow is proportional to the square root of differential pressure), although they may have different mounting arrangements and accessories to integrate them with secondary elements and controllers.

Differences in averaging Pitot tubes may be seen in the cross-section of the probes, advertised turndowns and costs. To make a cost-effective selection, an understanding of the reasons for these differences is needed.

As a fluid stream moves around the upstream side of a multi-port averaging Pitot tube, vortices are created at some point along the sides of the probe. Depending on the shape of the probe, the velocity of the flow media and, to some extent, its density, these vortices are shed from various points around the perimeter of the probe. Since the multi-port averaging Pitot tube senses the static pressure on the downstream side of the probe, these shedding vortices can cause variations in the static pressure over the range of velocities the probe is likely to encounter.

The original multi-port averaging Pitot tubes shared a common round shape. As manufacturers differentiated themselves in the marketplace, new cross-sectional shapes were introduced. The new shapes provided distinct cross-sectional features in an attempt to control the vortex shed point locations, or to eliminate vortices altogether.

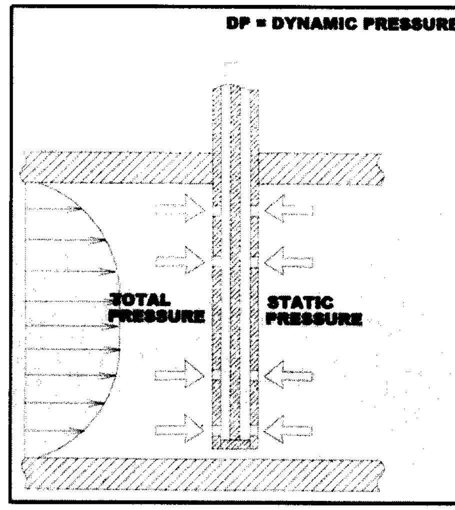


Figure 2. Averaging Pitot tube cut away.

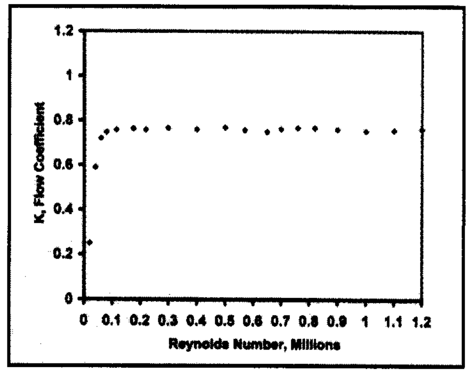


Figure 3. Flow coefficient vs. Reynolds number.

The new shapes were believed to be desirable to eliminate the variable vortex shed points associated with round probes. New claims for turndown (some as high as 17:1) were made. Comparisons to the "old"and "inferior" round probes were frequently made.

Despite the comparisons, however, the performance of round probes has been, and continues to be, well documented. Flow coefficients for a large variety of probe diameters and pipe sizes are available from their manufacturers. Flow coefficient versus Reynolds number correction factors (F_{RA}) have been determined by independent flow laboratories over Reynolds numbers covering as much as a 15:1 turndown. The data accounts for, and accurately describes, any effects that vortex shedding may have on static pressure. Whatever the operating condition and wherever the vortex shedding occurs, accuracy of ±1 percent is achievable with round probes. (See Figure 4 on this page.)

Calculating Turndown

As shown in Figure 4, below, the turndown ratios for the different probe shapes range from 4:1 for the conventional round-shaped probe, to 10:1 for diamond shapes, to 17:1 for the elliptical shape. Since there is little difference in accuracy for the various shapes, the eight to 40 percent premium (varies with pipe size) paid for a non-round probe is essentially buying greater turndown.

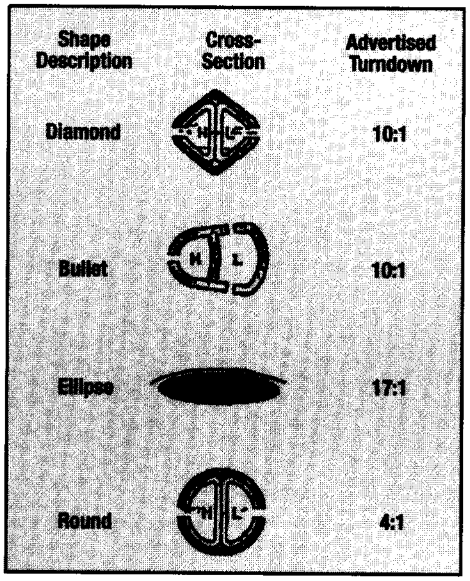


Figure 4. Probe shapes and turndown.

In process industry flow applications, the objective is primarily to maintain the process conditions at some optimum level. The process is designed to operate within a reasonable percentage of that optimum, to assure repeatability of the process and the quality of the end-product. Seldom does the flow go above or below that level by more than 25 to 30 percent, much less by a factor greater than 4:1. Flow variations of 10:1 or 17:1 are not normal to most process industry applications. Thus, the extra cost of a non-round probe becomes difficult to justify for such applications.

Even in applications where broader flow ranges are encountered, the use of a multi-port averaging Pitot tube with a high advertised turndown ratio may be difficult to justify economically. As mentioned before, Pitot tubes, regardless of shape, are square root devices. In other words, the square root of the measured signal, the differential pressure, is what is proportional to the flow rate. (See Figure 5.)

At 100 percent of flow with a square root flow element, 100 percent of the differential pressure is generated by the probe. But at 4:1 turndown of the flow, only $\frac{1}{16}$ (6.24 percent) of the *DP* is left. With a 10:1 ratio probe, if flow is reduced to $\frac{1}{10}$ of the full flow, only $\frac{1}{100}$ (one percent) of the *DP* remains to be measured.

With a 17:1 ratio probe, if flow is reduced to $\frac{1}{17}$ of the full flow, only $\frac{1}{289}$ (0.35 percent) of the *DP* is available to sense. If the system developed 100 inches of *DP* at full flow, there would only be about 0.35 inches left at 17:1 turndown of flow, a very small amount to accurately detect. Modern DP transmitter performance is impressive, but this type of performance remains elusive. So, the buyer must beware when evaluating and interpreting turndown specifications.

What about Accuracy?

As mentioned, advertised accuracies of the various manufacturers' probes range from ±$\frac{3}{4}$ percent, to ±1 percent. While this difference may be significant in some flowmetering applications, it is relatively insignificant in many industrial process applications, since repeatability is often of greater importance. Also, the development of smart multivariable (SMV) transmitters has made the discussion of accuracy differences, stemming from differences in probe shapes, a smaller issue.

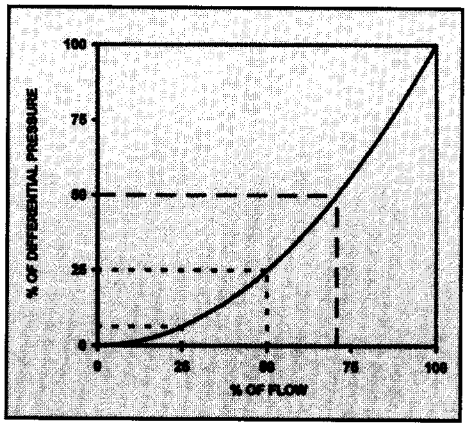


Figure 5. Square root type device.

Smart multivariable transmitters allow the characteristic of flow coefficient versus Reynolds number to be programmed into the transmitter, or approximated with straight line segments. This allows the most accurate calibration data to be used to determine flow rate. (The multivariable transmitter can also integrate the input from a temperature probe to calculate volumetric or mass flow rate.)

In addition to greater accuracy, a smart multivariable transmitter mounted directly on the probe significantly reduces the cost of installation, compared to the use of separate conventional transmitters, temperature probes and flowmeters. (See Figure 6.)

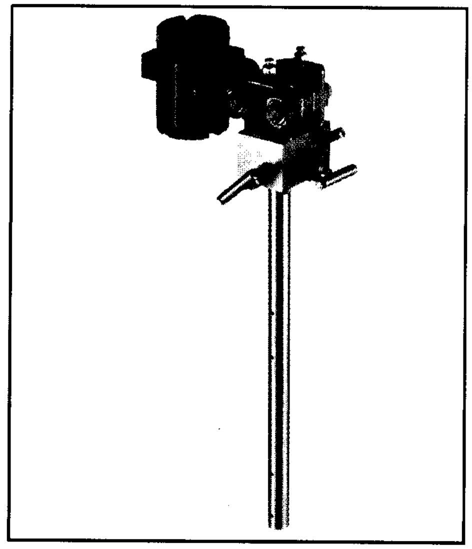


Figure 6. Averaging Pitot tube with SMV transmitter.

Range of Costs

In addition to widely varying turndown ratios, probes of various shapes may carry widely varying prices for the same application. The differences in price often result from the higher costs to produce non-round shapes. Manufacturers justify them on the basis of accuracy and turndown.

If the application can use a stainless steel probe, the price difference for a non-round ranges from eight to 10 percent more than a round probe. Non-round shapes are relatively easy to extrude from stainless steel.

However, if the application requires an exotic, material, such as Inconel or Hastelloy, the price may be much greater than for round tubes. While these materials are commonly available in round cross-section tubing, non-round shapes are machined from bar stock to create the outer profiles and gun-drilled to create the plenum chambers.

Many people believe that "if it costs more, it must be better." This is not always true when it comes to primary elements for flowmetering. Intuitively selecting a more expensive option for an industrial process application, without knowing exactly what you need, may give you more range and somewhat greater accuracy. However, it may well be range and accuracy you do not need, and added expense you did not have to incur. FC

About the Authors

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