

ASGMT / Averaging Pitot Tube Flow Measurement

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Averaging Pitot Tube Meters

Introduction

Reliable, accurate flow measurement continues to be a high priority for today's instrument engineer. The technology options available for flow measurement are greater now than ever before. Many new and developing technologies are now becoming more accepted in gas flow and other fluid flow applications. Despite all of the new technology, the majority of flow measurement devices installed today are traditional differential pressure (DP) sensors.

The operation of all DP devices is governed by Bernoulli's theorem which relates the velocity of a fluid in a pipe to its pressure. A blockage or restriction in the pipe produces a change in pressure that is measured by the user and related to the flow rate by the flow equations established for each particular device. The orifice plate, flow nozzle and venturi are still in wide use today in industrial and commercial applications and are considered the standard in many of those applications. Although the accuracy and reliability of these devices can be very good, today's averaging pitot tube (APT) can offer some significant advantages in both cost and operation without sacrificing the accuracy of the more traditional DP meters.

Typically, traditional DP meters listed above require pipe flange connections which can add significantly to the cost of installation for these meters. In addition, these meters produce large permanent pressure losses due to their relatively small throat diameters which can result in increased pump or compressor operating costs. These limitations of traditional DP meters led to the development of the averaging pitot tube (APT) sensor some 40 years ago. These devices have found wide application in many industries, including the gas industry, since their introduction. They offer several advantages, including extremely low permanent pressure loss and very low installation costs when compared to other DP meters.

Theory of Operation

The APT is similar to the conventional single point pitot tube in operation, but differs in construction. Instead of a single measuring port, it consists of a bluff body or probe of constant cross-section that spans the diameter of the pipe. The probe has ports that sense the pressure on both the front side and at the rear (or sometimes side) of the probe. The sensed pressures are averaged in the internal passages or plenums in the probe and brought to the exterior of the assembly, where there are connections to a DP transmitter.

The DP signal consists of the difference of two basic measurements- the impact (high) pressure and the reference (low) pressure. (Please refer to Figure 1). On an APT, the impact pressure is sensed on the front of the device as the flow is brought to rest (stagnated) by the bluff body. The standard pitot tube only measures the impact pressure of the velocity flow profile at a single point. However, fluid velocity is not constant across the pipe cross-section. As reflected in the cross section of a flow profile shown in Figure 1, the velocity is typically higher in the middle than on the edges due to viscosity and pipe friction effects. With these changes in the flow profile, gaging the true velocity of the fluid with a single point can cause significant measurement errors. The multiple ports on the front side of the APT allow the instrument to average the individual pressures resulting from the flow profile and give a more accurate measurement of the true flow rate.

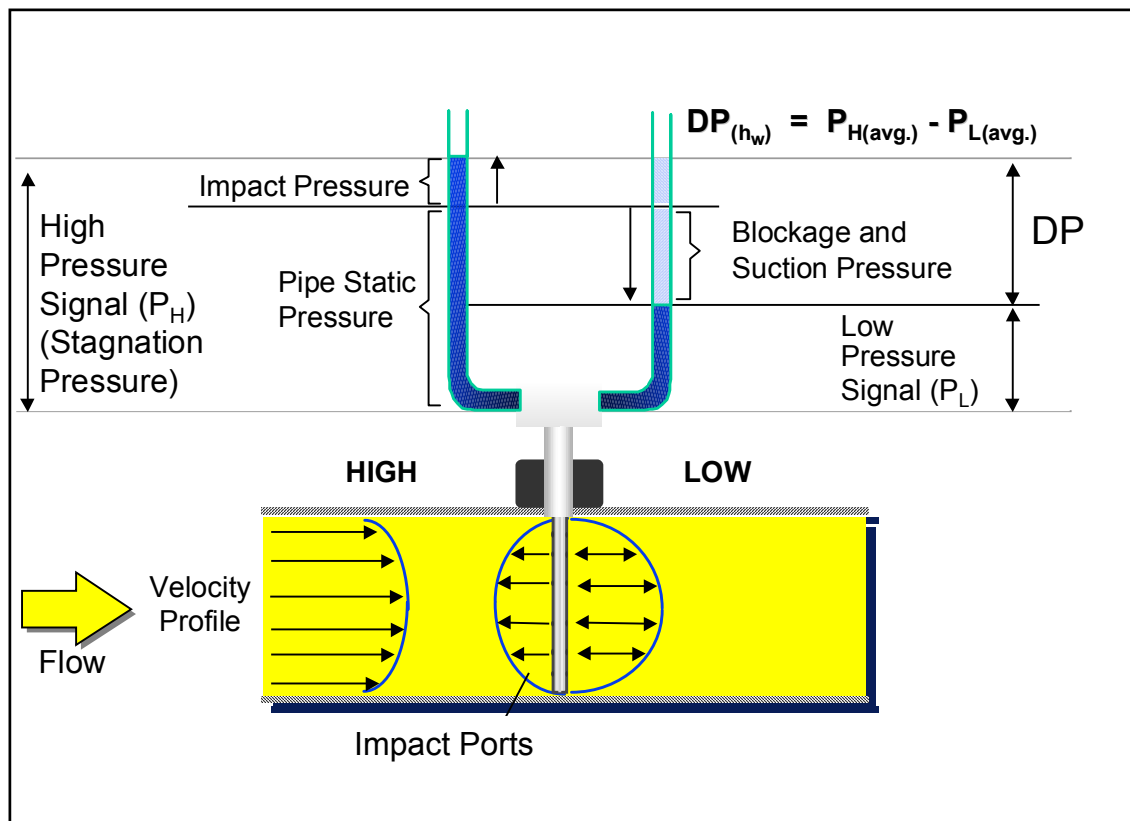


Fig. 1- Design Principles of an APT

The second major component in the APT's DP signal is the reference pressure. This pressure is typically sensed on the back or on the side of the APT. Depending on the shape of the APT sensor and the location of the reference pressure sensing ports, this measurement may comprise up to 60 percent of the overall DP signal. Many APT shapes exist which offer a variety of performance advantages. The cross-sectional shape of the APT is the prime factor in determining the level and stability of the DP signal and therefore the accuracy

with which the flow rate can be related to the DP signal. The location of the sensing ports is also a key factor in determining the level of the reference pressure and therefore has implications for overall strength of the differential pressure signal from the averaging pitot primary element at a given flow rate.

Although it is actually a pressure, the Bernoulli theorem allows the APT signal to be related to the average velocity across the length of the APT probe. Flow rate is calculated by multiplying this velocity by the cross-sectional area of the pipe. Since it plays such a key role in the flow rate calculation, the area of the pipe, and so the diameter of the pipe, must be precisely measured for accurate flow measurement. The flow rate is calculated by the equation:

$$q_v = V \times A$$

where: $A = \frac{\pi D^2}{4}$ = area of the pipe

V = average velocity of the fluid
 q_v = volumetric flow rate

The equations relating flow rate to the DP signal are (SI units):

$$q_v = \frac{\pi}{4} K \epsilon D^2 \frac{\sqrt{2\Delta p}}{\rho_f}$$

and

$$q_m = \frac{\pi}{4} K \epsilon D^2 \sqrt{2\Delta p \rho_f}$$

where:

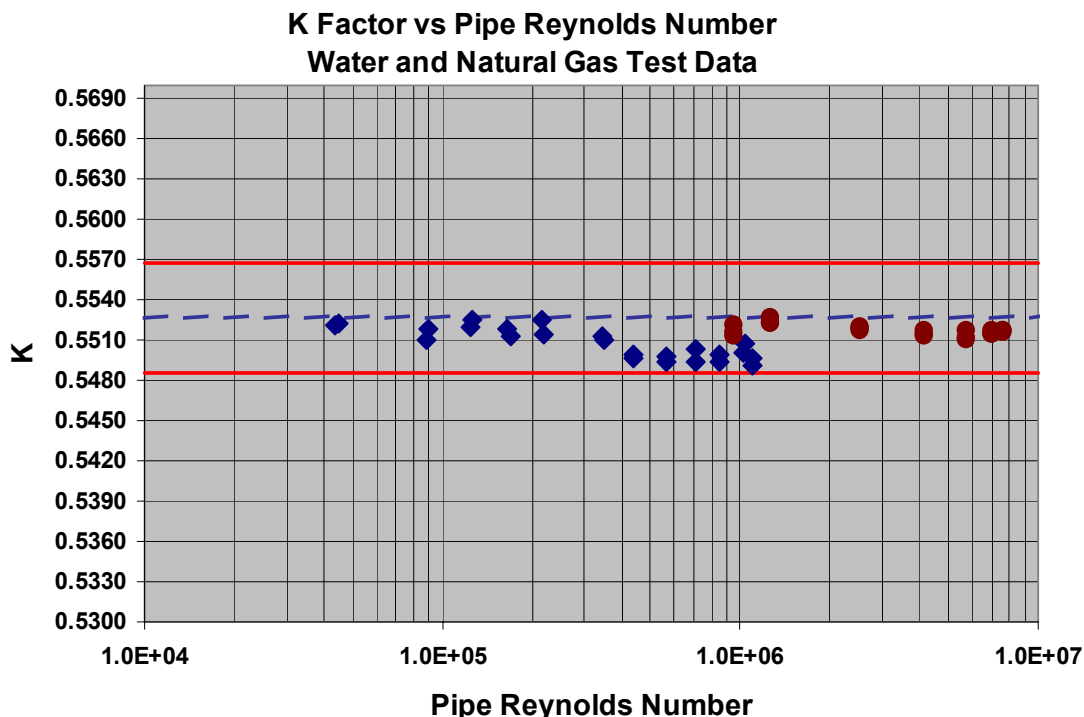
q_v	= volumetric flow rate
q_m	= mass flow rate
ρ_f	= flowing density
Δp	= differential pressure
D	= pipe diameter
K	= APT flow coefficient
ϵ	= gas expansion factor (=1 for liquids)

The accuracy of an APT is directly related to the flow coefficient (K), which is defined as the ratio of the actual flow rate to the theoretically calculated flow rate. The flow coefficient is determined by testing a representative sample of flowmeters to establish the relationship between flow rate and the DP induced across the primary element. For APT's, flow coefficients are usually defined as a function of meter's pipe blockage i.e., the ratio of the projected area of the APT shape to the cross-sectional area of the pipe.

Accuracy

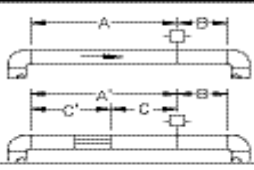
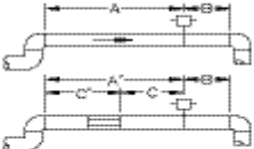
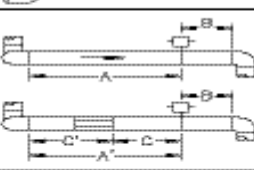

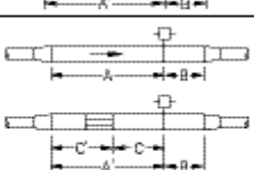
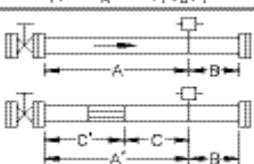
As with any other meter, the APT's accuracy is only as good as its flow coefficient (K). The most accurate way to determine a meter's flow coefficient is to test that meter in the application for which it was intended by reproducing the flowing conditions in a flow laboratory, matching piping conditions, Reynolds Numbers, fluid densities, temperatures, pressures, and installation. Although this method is accurate, it is impractical and expensive to empirically test every flow meter for every application. In lieu of testing every meter for the application for which it was intended, APT manufacturers will test a representative sample of their meters in a sampling of line sizes and Reynolds Numbers. This base line data and curve fitting techniques are used to develop the flow coefficients in untested line sizes and untested Reynolds Number ranges. The curve-fit equation becomes the basis for a manufacturer's published flow coefficients. These published flow coefficients are used for flowmeters in nearly all untested conditions and vary by design of the averaging pitot tube, which includes bar size, shape and mechanism used for "averaging" of the velocity flow profile.

The uncertainty of the averaging pitot tube is a function of the design of the probe, including shape and upstream sampling ability. Typical accuracies on the K-factor are between ± 0.75 and $\pm 1\%$ of rate. It is also important to understand if the K-factor supplied is independent of Reynolds number and over how broad a flow range this independence can be maintained. Again, this ability is tied to the probe's shape and the ability of the APT's design to take a representative average.



The uncertainty of the flowmeter employing an averaging pitot tube as a primary element can be determined by root-sum square method of combining the primary and DP transmitter uncertainties. Although averaging pitot tube uncertainties are typically stated as a % of reading, DP transmitter accuracy is typically stated as a % of span. To convert a % of span accuracy to a % of reading requires multiplying the % of span specification by a differential pressure turndown factor. Due to the square root relationship governing operation, this factor becomes the square of the flow turndown factor. For example, a transmitter that features 0.075% of span accuracy becomes a $\pm 1.875\%$ of flow rate accuracy at a 5:1 flow turndown (25:1 DP turndown). Assuming an averaging pitot tube uncertainty of $\pm 1\%$ of rate, the flowmeter would have an uncertainty of $\pm 2.35\%$ of rate.

The use of higher performing transmitters combined with higher performing averaging pitot tubes ($\pm 0.75\%$ of rate) can significantly improve upon the accuracy. Transmitters that are designed to maximize performance as a percent of reading result in greater accuracy over a wider range. An accuracy of $\pm 0.5\%$ of reading of up to 14:1 flow (200:1 DP) turndown is possible. This would result in averaging pitot tube flowmeter performance of $\pm 0.8\%$ of flow rate over 14:1 flow turndown.

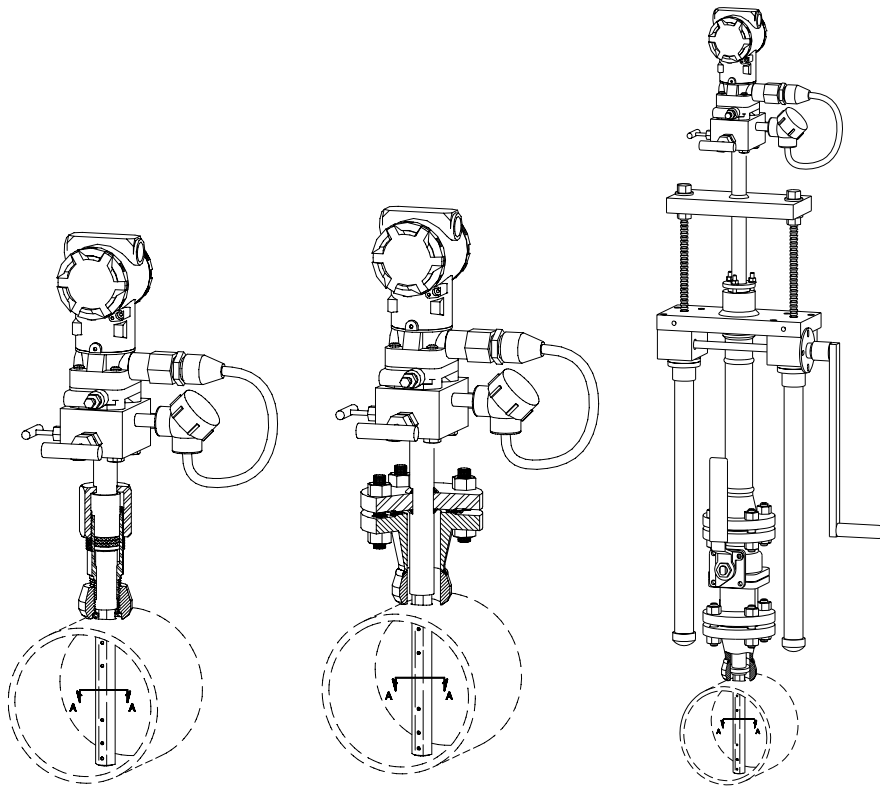
		Upstream Dimensions					Downstream Dimensions
		Without Vanes		With Vanes			
		In Plane A	Out of Plane A	A'	C	C'	
1		8	10	8	4	4	4
2		11	16	8	4	4	4
3		23	28	8	4	4	4
4		12	12	8	4	4	4
5		18	18	8	4	4	4
6		30	30	8	4	4	4

The K-factor for a given APT flowmeter can be affected by anything that alters the flow profile. The flow measurement may be affected by a number of factors; such as piping configurations, upstream pipe fittings and valves, etc. The flow coefficient for an averaging pitot tube assumes a fully developed turbulent flow profile. Given a long enough distance between the flow disturbance and the primary element, the viscous forces in the fluid will overcome the inertia of the swirl or profile asymmetry and cause the velocity profile to become fully-developed. A flow straightener or straightening vanes may be used to reduce the length of straight run required. These are available in several configurations from many piping supply houses. The table at the left shows some typical minimum straight run requirements both with and without the use of vanes or flow straighteners.

In many cases flow disturbances such as valves, elbows, reducers, etc. cause relatively small and predictable shifts in the meter output. Even though the flow profile may not be fully-developed, testing indicates that it is possible for an averaging pitot tube to be located inside the recommended straight pipe distance with no effect on the repeatability and linearity of the meter and predictable effects on the accuracy. In order to predict this shift in K-factor, testing specific to the averaging pitot tube design is required.

Mounting Options

A variety of mounting options are available from most APT manufacturers. Several styles of ferrule or compression-type mounting options exist. In addition, most APT's can be installed with a wide range of flanged connections which can meet almost all recognized pressure and piping codes and standards. Also, many APT's can be installed in the pipe without the need for process shutdown by means of hot-tap or wet-tap methods. In these installations, the APT can be installed and later retracted from the process without any process interruptions. All of these mounting configurations offer the user a significant reduction in installation costs over the alternative of sectioning the pipe and installing flanged or pipe connections for other meter types. The installation of an APT flow measurement point requires only minimal disruption of the piping compared with that required for other technologies. Installed cost savings of more than \$1000 are typical for most line sizes and can be as high as \$20,000.



Application Range

APT's are used in nearly every process requiring fluid flow measurement. APT's have been applied in temperatures ranging from cryogenic (as low as -300°F) to superheated steam, to gases with temperatures in excess of 1000°F . They are typically constructed of stainless steel or other corrosion resistant materials so can be installed in a wide range of liquids and gases. APT's also come in a range of sizes which make them adaptable to pipe or duct sizes from 2 inch to several feet.

Flowmeter Options

The averaging pitot tube is a primary element. Compatibility with the secondary element, the differential pressure transmitter, involves a mechanical interface between the two. Traditional design of an averaging pitot tube flow point utilizes impulse lines to connect the two. This traditional design allows the secondary element to be located at grade to help ease access for purposes of routine maintenance and allows the assembly to handle higher temperatures. The trade-off to this methodology is that the long impulse lines employed become a source of maintenance themselves. Impulse lines tend to plug and are a source of measurement inaccuracy if the hydrostatic heads they create are not kept in balance (liquids) or if moisture is allowed to accumulate (gases).

The use of high performing differential pressure transmitters featuring stability specifications of up to ten years and the ability of these devices to handle higher temperatures allow the secondary element to be direct mounted in a flowmeter configuration. These features can significantly reduce routine maintenance needs. Pressure transmitters that feature the ability to provide a remote display and interface allow interrogation electronically for the purposes of maintenance and diagnostics.

MV Technology

Multivariable transmitters measure pressure and temperature as well as the differential pressure across the primary element to dynamically compensate for density changes. The impact of not making this compensation can be significant. Since gas density is a function of absolute pressure and absolute temperature, the changes in density are proportional to the change in pressure and temperature. For this reason and specifically for gas and steam measurement, line pressure and temperature should be measured and used to compensate the flow output. For example:

1. Gas flow measurement at 75 psig line pressure that varies by 3 psi.

$$\Delta\rho_{\text{pressure}} = \frac{\pm 3\text{psia}}{(75 + 14.7)\text{psia}} = \pm 3.34\%$$

2. Gas flow measurement at 20°C that varies by 5°C .

$$\Delta\rho_{temperature} = \frac{\pm 5K}{(20 + 273.15)K} = \pm 1.71\%$$

The total change in density due to a 3 psi changes in pressure and a 5°C change in temperature is $\pm 3.8\%$ (root-sum of the squares).

Many APT's offer the option of an integral temperature measurement with an RTD mounted in the probe. When coupled with the multivariable transmitter, the customer has the opportunity to measure differential pressure, temperature, and pressure through a single penetration of the pipe wall and also make a fully compensated flow rate calculation. Previously, this sort of compensated flow measurement would have required three separate transmitters (DP, P, T) and a flow computer or some other device to perform the flow rate calculation. The combination of multivariable technology and the cost benefits of the APT can provide both high accuracy, compensated gas flow measurement and substantial cost benefits to the user.

Conclusion

The many innovations and technical developments among APT manufacturers are changing the image of the APT from a niche-type product into one that is finding more widespread acceptance as an accurate, reliable and cost effective flow measurement device. Accuracies that are on a par with both other DP-based devices and other flow technologies are attainable. APT technology can be applied in a wide range of sizes and fluid conditions. It can be installed in a number of different mounting configurations to meet the needs of a range of process industry applications. It uses proven well accepted and widely understood DP flow technology and provides the user with the opportunities for substantial installed and operating cost savings.