Ultrasonic Gas Flow Meters
The Field User's Perspective

Charles W. Derr
DANIEL MEASUREMENT AND CONTROL

Introduction

"New for the sake of new" and "old for the sake of familiarity" may in either case promote the waste of resources. It has now been a number of years since deregulation and the move to open sales, transportation and "hubs" has resulted in fierce competition. Operational cost savings, where practical, are a necessary part of success and indeed, survival. "***Technician"*** is an overly generalized and many times unappreciated title. "Technicians" are the field professionals that really make systems for control, compression, dehydration, odorization, and measurement a success or bad venture and highly influence a gas company's prosperity This document focuses on a "highly proven before release" new technology that offers great savings to gas companies and provides some new challenges to the field professional. Ultrasonic meters are easy to learn and they add some new dimension and value to the user's measurement experience. Gas ultrasonic meters, (USM's), are here to stay.

The Ultrasonic Meter
(*Applications)*

Ultrasonic gas flow meters are used to measure hydrocarbon gases in applications which require wide range (turn-down ratio), very high or low flow, low restriction, high accuracy or any combination of these from low pressure to super-high pressure. The two basic types are ***spooled meter bodies*** or ***hot-tapped*** (in-situ). The spooled types are either ***heavy wall cast*** or ***pipe/sleeve fabricated***. The two types of spooled meter bodies may be path-configured as ***single path*** or ***multi-path***. Multi-path meters may be path configured as ***center-line bounce*** (which requires a calculated profile) or ***parallel straight across paths*** (which section the profile and do not require assumed or calculated profile correction).

Single path spooled body meters are used for check meters, compressor control, system balance, leak detection and receipt or delivery control.

Dual path spooled body meters are used for all the applications of the single path and may under some conditions of controlled flow conditioning and lab. calibration; be used for custody service.

Multi-path spooled body meters (usually three or more paths) are capable of the highest level of accuracy of custody transfer in pipeline gas measurement history. Path techniques should be chosen based upon the application. Heavy wall cast meters have extremely small pressure coefficients compared to "pipe" wall meters. If pressure is constant this would not matter. If pressure varies significantly it may be a major consideration.

Hot-tapped meters are tapped into an existing on-line pipeline. The accuracy results may vary between excellent and several percent, depending upon the tapping and alignment techniques. These need X-Y-Z axis precision tapping positioning during welding to avoid alignment errors which will cost approximately a one percent error per one-half degree angular error. The pipeline tapped will have a relatively thin wall-vs-bore ratio and thereby the errors from growth as a function of temperature or pressure change are a very serious consideration. P & T compensation of the pipe growth and it's effect on the path length and angle can be online compensated on some versions. API 12.2, chapter 4 single wall prover calculations demonstrate the pipe geometry error magnitude if uncorrected. Additive to this is the resultant path elongation or shortening as well as the path bounce angle change. Compensating onboard electronics avoid most of this lost accuracy.

How Ultrasonic Meters Work

Sound energy waves travel or "propagate ", by definition, at Mach-1 or "the speed of sound", (S.O.S.). Sound propagates at different rates in different gas compositions and also propagates at different rates for different temperatures or pressures for any given gas composition. ***RATE*** is, by definition, ***Distance over Time***. We commonly express that relation in feet per second, (fps). Some practical examples are:

Production Gas @ 80-90+% Methane……………………1,150 to 1,400 fps
Gas Plant High Methane Residue………………………1,400 to 1,470 fps

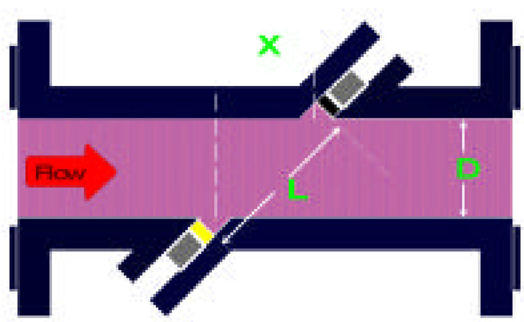
Measuring the time that it takes for a burst of sound waves to travel a fixed and known distance between a pair of sound transducers is referred to as measuring the ***transit time***. The centerline of the sound energy waves as they travel from the transmitting to the receiving transducer is the ***path***. Ultrasonic transducers both transmit and receive sound. They are solid state ***"transceivers***". If you number a pair of ultrasonic transducers as: 1A and 1B; then, they alternate their functions of send and receive in order to clock the ***transit time*** each direction along the ***path***. The sequence of transmitting and receiving or "firing" the transducers would be: 1A (Tx)...1B (Rx), 1B (Tx)…1A (Rx)…..repetitively. If there was no flow and the transducers were placed diagonally across the pipe then it would take exactly the same transit time to go each direction. The ***difference*** in time, or "***Delta",*** would be zero regardless of the total transit time each direction. The actual time in this example would be a function of the ***path length*** and the ***S.O.S.*** As mentioned above any change in gas composition,
temperature or pressure will change the speed of sound. By examining the difference in transit time for the two directions the S.O.S. cancels out. **Calculation example:**

Flow Rate = 0: Path Length = 12.0" S.O.S. = 1,000 fps
At 1,000 feet per second the transit time would be 1/1,000 or 0.001 seconds; which is the same as one millisecond (thousandth of a second) and which is also the same as 1,000 microseconds (millionths of a second).

To avoid working with long strings of decimals the transit time is usually expressed in microseconds. Once again, at zero flow, it would take the same 1,000 microseconds to go each way and the ***transit times***, (T1 and T2), for the 1A to 1B and 1B to 1A transducers are equal to a **“delta-T”** of zero. No ***flow***; no time ***difference***.

Continuing the example: If we measured the ***transit time*** while the sound was traveling the one foot path length **against** the flow and it measured 1,010 microseconds and then we reversed the transducer pair’s transmit/receive functions and measured 990 microseconds **with** the flow; we then observe: The **delta-T** (1,010 – 990) equals 20 microseconds.

Ultrasonic Flow Meter



The upstream “shot” was 10 microseconds slower.
The downstream “shot” was 10 microseconds faster.

The USM’s onboard electronics will then go through several steps to convert that delta-T into flow rate. It will evaluate the velocity by solving: Note: Path Length “L” is used in feet.
The “X” value for this example is: 0.7071 ft. (8.485 inches). The times are in seconds. These dimensions; (feet for lengths and seconds for times) should give the velocity in feet per second, (fps).

$$\text{Velocity (fps)} = \frac{L^2}{2X}\,\frac{(T1-T2)}{(T1*T2)} \quad \text{or} \quad \frac{1}{0.5}\,\frac{(0.001010-0.000990)}{(0.001010*0.000990)}$$

This solves to:

$$\text{Velocity (fps)} = \frac{0.00002}{0.0000005} \quad \text{or} \quad \underline{\textbf{40 fps}}$$

This would be the ***path average velocity*** between transducers. If the transducers were mounted at a 45 degree angle across the pipe the average axial velocity would be the result of the Cosine of the 45 degree angle (0.707) or; the path (at 45 degrees to the flow) would only be observing 70.7% of the axial velocity down the pipe which would thereby be 1.414 times the path velocity or: 40 fps * 1.414 = **56.56 fps.**

Each path represents a certain portion of the total area of the pipe. This portion has a "weight" in the final calculation of the ***average axial velocity*** for the whole cross -sectional area of the meter. For custody transfer it is beneficial to be able to reconstruct the final flow values from the primary time measurements. This equates to reconstructing a flow computer's flow rate by recording D.P., T., P., and gas composition and using independent calculation to prove the imbedded flow calculations. Unpublished weighting information may prohibit reconstruction in case of measurement troubleshooting needs or custody disputes.

After the average path velocities for each path are measured and the path centerline to meter axial centerline angle calculations have been performed, the weighting factor is applied to each path and then all path data is summarized into average axial velocity times the meter area and the actual volume flow rate is calculated and transmitted. Data is transmitted via serial data port, frequency and analog and may additionally be used onboard the advanced ultrasonic meter's transmitter to further calculate and transmit the standard rates and totalized volumes (relative to base conditions). The transmitter may be capable of onboard data logging for reconstruction in the event of loss of flow computer or RTU.

Measured Data Accuracy
(***Percent of Value***)

The designers and field users should recognize that the accuracy statements of the very wide turn-down ultrasonic meters are in percent of flow value or "percent of reading". It is easy to underestimate the performance of this generation of gas meters when you are very familiar with percent of full scale devices. Consider the following example:

USM operating range:	1.0 to 100 fps.
USM accuracy statement:	+/- 0.5 % of reading
Test velocity:	5 fps
Test accuracy:	+/- 0.25 % (Ex. error = one half maximum allowed)

The **error** equals: 0.0025 * 5 = 0.0125 fps

This results in twelve and a half thousandths of one foot per second on a meter that works to 100 fps! Further: 0.0125 fps / 100 fps = an error of 0.000125 of full scale or 0.0125% of full scale or: 1 / 8,000th of full scale! These are realistic numbers for the upper echelon of USMs. Full error allowance means that in this example the meter read the velocity to 1 / 4,000th of full scale.

The following example will evaluate the equivalent accuracy scenario for differential based meters: The assumption will be that the meter is mechanically perfect and only the D.P. error will be considered:

Meter: Perfect differential meter	
Differential transmitter accuracy:	+/- 0.1 % FSD
Transmitter range:	0 to 150 "W.C.
Test differential:	15 " W.C.
Test accuracy:	+/- 0.1 % FSD
Allowed error in " W.C.	(+/- 0.001 * 150) = +/- 0.15 " W.C.
Positive error:	(15 + 0.15 = 15.15 " W.C.) Sq. root of 15.15 = 3.8923 The Sq. root of 15 = 3.8729 3.8923 – 3.8729 = 0.0194 / 3.8729 = 0.005 or +0.5 % of reading

The USM at low flow (5 fps) reads the flow to +/- 1 / 4,000th of full scale.
The differential device at low flow reads the flow to +/- 1 / 200th of full scale.

The accuracy of the ultrasonic meter in this case at 5 % of full scale flow equals the accuracy of the differential device at 31.6 % of full scale flow. Ultrasonic meters achieve accuracy's at low flows that convention technologies reached at higher mid-range flows. Appreciation of the accuracy level helps impose accuracy guidelines for proving and field performance testing.

Calibration

The ultrasonic meter is dry calibrated at the factory. This consists of measurements of the meter body housing and the delay times of the transducer pairs and electronics. The meter is blind flanged and multiple cycle purged with ultra high purity nitrogen. After thermal stabilization, the meter is check for zero flow offset and path speeds of sound –vs- calculated speed of sound for pure nitrogen at a precisely measured temperatures and pressure.
Small residual biases may be flow calibrated and corrected by a meter factor. The quality and test procedure control of the supplier has a great bearing on the relation of dry calibration accuracy to flow calibration accuracy. Manufacturers achieve their stated accuracy's with dry calibrations. When seeking third party proof or attempting to better the dry calibration accuracy, flow calibrating is the user's option.

Piping Considerations

Follow the manufacturer's minimum piping requirement recommendations! Manufacturers have spent large sums of development money determining the minimum piping requirements. A vast amount of background tests have been performed at the premier test facilities of the world. The typical range of meter run piping requirements is 10-20 diameters upstream and 3-5 diameters downstream. This is usually dictated by the number of paths. Flow conditioning may be required in some installations. They are not required in **ALL** installations. Multi-path ultrasonic meters are more tolerant to flow distortions than most meters. Well formed smooth flow is always better than asymmetric flow regardless of the application or meter technology.

Field Verification

The speed of sound is calculated and available from the ultrasonic meter. This value is calculated from the same measured t1 and t2 values by observing the total round trip time (t1 plus t2) and dividing this into two path lengths, (the total round trip distance). By knowing the gas composition from a gas chromatograph and measuring the pressure and temperature; the speed of sound can be precisely calculated and cross-checked. Excellent agreement (to approximately +/- 0.25 % of S.O.S. calculated value) means the meter is working properly. Poor agreement means that either a measurement or data base item is probably wrong. This is an excellent test and does not interfere with metering operation.

The field user should also, at whatever interval that is required for data base check on the other energy system components such as flow computers, etc., check for proper constants and that no diagnostic errors exist.

Ultrasonic meters are surprisingly easy to use. They have rapidly become a friendly measurement component. Take advantage of training programs offered and enjoy working with them.