Ultrasonic Meter Diagnostics - Basic

Overview of operation and maintenance of wetted-sensor ultrasonic flow meters

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ABSTRACT

This paper discusses fundamental principles of ultrasonic gas flow meters used for measurement of natural gas and the available basic diagnostic capability to assess meter operation and performance. The basic requirements for obtaining good meter performance, when installed in the field, will be reviewed. Most of this information can be generalized to other manufacturer's transit time ultrasonic flow meters however, these examples provided, particularly with respect to some diagnostic features, are based on the Daniel SeniorSonic ultrasonic flow meter. Advanced diagnostic data, in conjunction with gas composition, pressure and temperature, that provides diagnostic benefits beyond that of other primary measurement devices is outside the scope of this paper, though these topics will be covered in the companion paper, Ultrasonic Meter Diagnostics – Advanced.

INTRODUCTION

During the past two decades the use of ultrasonic flow meters for natural gas custody transfer measurement has grown significantly as end users come to understand and accept the technology. Many end users are also utilizing the technology to validate other measurements within a metering system, particularly gas composition and temperature measurement. The publication of AGA Report No. 9, *Measurement of Gas by Multipath Ultrasonic Meters, 2nd edition* in April 2007 and ISO 17089, *Measurement of fluid flow in closed conduits - Ultrasonic meters for gas*, *Part 1: Meters for custody transfer and allocation measurement* in 2009 has greatly accelerated the installation of ultrasonic flow meters worldwide. Today virtually every gas transmission company is using this technology, either for fiscal, or for operational applications.

There are many reasons why ultrasonic metering is gaining such broad acceptance in a traditionally conservative industry. Some of the benefits of this technology include the following:

- **Accuracy:** Can be calibrated to <0.3%, little or no drift.
- **Large Turndown:** Typically 50:1, or more.
- **Naturally Bi-directional:** Measures volumes in both directions with comparable performance.
- **Tolerant of Wet Gas**: Important for production applications.
- **Non-Intrusive:** No pressure drop.
- **Low Maintenance:** No moving parts mean reduced maintenance.
- **Fault Tolerance:** Meters remain relatively accurate even if sensor(s) should fail.
- **Integral Diagnostics:** Data for determining both a meter's health and dynamic online performance is readily available.

It is clear that there are many benefits to using ultrasonic flow meters. Although the first several benefits are important, the most significant often turns out to be the ability to diagnose the meter's dynamic online performance. The primary purpose of this paper is to discuss basic gas ultrasonic meter operation, present the basics of diagnostic information, and review installation considerations to assure best meter performance.

ULTRASONIC METER BASICS

Before looking at the main topic of integral diagnostics, it is important to review the basics of ultrasonic transit time flow measurement. In order to diagnose any device, a relatively thorough understanding is generally required. In today's world of increasingly complex devices, and

productivity demands on everyone, companies rely on a well trained work force and instruments that are increasing capable of self-diagnostics. Without a good grounding in the basics, understanding diagnostic messages can be confusing.

Fortunately for everyone, the basic operation of an ultrasonic meter is relatively simple. Consider the meter design shown in Figure 1. Even though there are several designs of ultrasonic meters on the market today, the principle of operation remains the same.

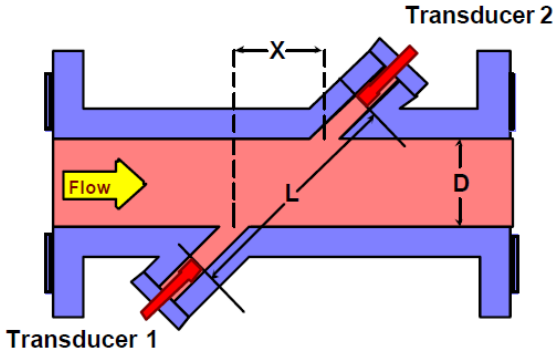


Figure 1 - Ultrasonic flow meter

Ultrasonic meters are velocity meters by nature. That is, they measure the velocity of the gas within the meter body. By knowing the velocity and the cross-sectional area, uncorrected volume can be computed. Let us review the equations needed to compute flow.

The transit time (T_{12}) of an ultrasonic signal traveling with the flow is measured from Transducer 1 to Transducer 2. When this measurement is completed, the transit time (T_{21}) of an ultrasonic signal traveling against the flow is measured (from Transducer 2 to Transducer 1). The transit time of the signal traveling with the flow will be less than that of the signal traveling against the flow due to the velocity of the gas within the meter.

Let's review the basic equations needed to compute volume. Assume L and X are the direct and lateral (along the pipe axis and in the flowing gas), distances between the two transducers, C is the Speed of Sound of the gas, V the gas velocity, and T_{12} and T_{21} are transit times in each direction. The following two equations would then

$$T_{12} = \frac{L}{C+V\cdot\frac{X}{L}} \qquad (1)$$

apply for each path:

and

$$T_{21} = \frac{L}{C-V\cdot\frac{X}{L}} \qquad (2)$$

$$V = \frac{L^2}{2X}\left(\frac{T_{21}-T_{12}}{T_{21}\cdot T_{12}}\right) \qquad (3)$$

Solving for gas velocity yields the following:

Solving for the speed of sound (C) in the meter

$$C = \frac{L}{2}\left(\frac{T_{21}+T_{12}}{T_{21}\cdot T_{12}}\right) \qquad (4)$$

yields the following equation:

Thus, by measuring dimensions X & L and transit times T_{12} & T_{21}, we can compute the gas velocity and the speed of sound (SOS) along each path. The speed of sound for each path will be discussed later and shown to be a very useful parameter in verifying good overall meter performance.

The average transit time, with no gas flowing, is a function of meter size and the speed of sound through the gas (pressure, temperature and gas composition). Consider a 12-inch meter for this example. Typical transit times, in each direction, are on the order of one millisecond (and equal) when there is no flow. The *difference* in transit time during periods of flow, however, is significantly less, and is on the order of several nanoseconds (at low flow rates). Thus, accurate measurement of the transit times is critical if an ultrasonic meter is to meet performance criteria established in AGA Report No. 9.

It is interesting to note in Equation (3) that gas velocity is independent of speed of sound, and to compute speed of sound (Equation (4)), gas velocity is not required. This is true because the transit time measurements T_{12} and T_{21} are

measured within a few milliseconds of each other, and gas composition does not change significantly during this time. Also, note the simplicity of Equations (3) and (4). Observe that only the dimensions *X* and *L*, and the transit times T_{12} and T_{21} are required to yield both the gas velocity and speed of sound along a path. These equations look relatively simple, and they are; the primary difference between computing gas velocity and speed of sound is the *difference* in transit times is used for computing velocity, where as the *sum* of the transit times is used for computing speed of sound.

Unfortunately, determining the correct flow rate within the meter is a bit more difficult than it appears. The velocity shown in Equation (3) refers to the velocity of each individual path. The velocity needed for computing volume flow rate, also known as bulk mean velocity, is the average gas velocity across the meter's area. In the pipeline, gas velocity profiles are not always uniform, and often there is some swirl and asymmetrical flow profile within the meter. This makes computing the average velocity a bit more challenging. Meter manufactures have differing methodologies for computing this average velocity. Some derive the answer by using proprietary algorithms. Others rely on a design that does not require "hidden" computations. Regardless of how the meter determines the bulk average velocity, the following equation is used to compute the uncorrected flow rate.

$$Q = V * A \qquad (5)$$

This output (*Q*) is actually a flow rate based on volume-per-time, and is used to provide input to the flow computer. *A* is the cross-sectional area of the meter. In summary, some key points to keep in mind about the operation of an ultrasonic meter are:

- The measurement of transit time, both upstream and downstream, is the primary function of the electronics.

- All path velocities are averaged to provide a "bulk mean" velocity that is used to compute the meter's output (*Q*).

- Because the electronics can determine which transit time is longer (T_{21} or T_{12}), the meter can determine direction of flow.

- Speed of sound is computed from the same measurements as gas velocity (the "*X"* dimension is not required).

Transit time is the most significant aspect of the meter's operation, and all other inputs to determine gas velocity and speed of sound are essentially fixed geometric (programmed) constants.

INTEGRAL DIAGNOSTICS

One of the principal attributes of modern ultrasonic meters is their ability to monitor their own health, and to diagnose any problems that may occur. Multipath meters are unique in this regard, as they can compare certain measurements between different paths, as well as checking each path individually. Measures that can be used in this online "health checking" can be classed as internal or external (dynamic) diagnostics. Internal diagnostics are those indicators derived only from internal measurements of the meter. External or dynamic diagnostics are those methods in which individual path measurements from the meter are combined in various ratios or with parameters derived from independent sources to detect and identify fault conditions. These topics will be covered in the companion paper, Ultrasonic Meter Diagnostics – Advanced.

Some of the common internal meter diagnostics used are as follows:

Gain

One of the simplest indicators of a meter's health is the presence of strong signals on all paths. Ultrasonic flow meters have automatic gain control on all receiver channels. Any increase in gain on any channel indicates a weaker signal, perhaps due to transducer deterioration, fouling of the transducer ports, or liquids in the line. However, caution must be exercised to account for other factors that affect signal strength, such as operating pressure and flow velocity.

Gain numbers vary from manufacturer to manufacturer. Thus, recommendations may also differ. However, regardless of design or methodology for reporting gain, it is important to obtain readings on all paths under somewhat similar conditions. The significant conditions to

duplicate are metering pressure and gas flow rate.

Gain readings are generally proportional to metering pressure (and to a much lesser extent, temperature). That is, when pressure increases, the amount of gain (amplification) required is reduced. If an initial gain reading were taken at 600 psig, when the meter was placed into service, and subsequent readings taken at 900 psig, one would expect to see a change. Understanding that pressure affects gain readings helps guard against making the false assumption something is wrong.

Fortunately, most applications do not experience a significant variation in metering pressure. If pressure does vary, the observed gain value can be adjusted relatively easily to allow for comparison with baseline values. This method of adjustment varies with manufacturer, so no discussion will be incorporated here.

Gas velocity can also impact the gain level for each path. As the gas velocity increases, the increased turbulence of the gas causes an increase in signal attenuation. This reduction in signal strength will be seen immediately by increased gain readings. These increases are generally small compared to the amount of gain required. Typical increases might be on the order of 10% - 50%, depending upon meter size and design.

Thus, it is always better to "baseline" gain readings when gas velocities are below 30 fps. Using velocities in excess may provide good results, but it is safe to say that lower velocities provide more consistent, repeatable results.

So, what else causes reductions in signal strength (increased gain) you ask? There are many sources other than gas velocity and pressure. For instance, contamination of the transducers (buildup of material on the face) will attenuate the transmitted (and received) signals. The reader might assume that this buildup would cause the meter to fail (inability to receive a pulse). However, this is not generally the case. Even with excessive buildup of more than 0.050 of an inch of an oily, greasy, and/or gritty substance, today's Ultrasonic flow meters will continue to operate.

The reader may wonder what impact on transit time accuracy could be attributed to transducer face contamination. It is true the speed of sound will be different through the contaminated area when compared to the gas. Let us assume a build-up is 0.025 of an inch on each face, and the path length is 16 inches. Also assume the speed of sound through the contamination is twice that of the typical gas application (2,600 fps vs. 1,300 fps).

With no buildup on the transducer, and at zero flow, the average transit time would be 1.025641 milliseconds. With buildup the average transit time would be 1.024038 milliseconds, or a difference of 0.16%. This would be reflected in the meter's reported speed of sound.

However, it is the difference in transit times that determines gas velocity (thus volume). This is the affect that needs to be quantified. Maybe the easiest way to analyze this is assume the transit time measurements in both directions are reduced by 0.16% (from the previous example).

Remembering in Equation (3) that gas velocity is proportional to a constant ($L^2 / 2X$) multiplied by the difference in transit times, all divided by the product of transit times. The decrease in transit times will occur for both directions and this affect will be negated in the numerator. In other words, the Δt will remain the same.

However, the error in both T_{12} and T_{21} will cause the denominator value to decrease, thus producing an error that is twice the percentage of transit time (0.16%), or 0.32%. Thus, the meter's output will increase by 0.32%. However, this amount of buildup is abnormal, and not typical of most meter installations.

Transducer placement can further alleviate this concern, with protruding transducers more subject to this effect than those located at the pipe wall or recessed into the transducer port.

Ultrasonic flow meters all have more than adequate amplification (gain) to overcome even the most severe reductions in signal strength. The amount of buildup required to fail today's high-performance transducers and electronics generally exceeds pipeline operational conditions. Periodic monitoring of this parameter, however, will help insure good performance throughout the life of the meter. Metering accuracy (differences in transit time velocity computation) can be affected, but only when significant buildup of contamination occurs.

Percent Performance (Signal Quality)

This expression is often referred to as performance (but should not be confused with meter accuracy). All ultrasonic meter designs send multiple pulses across the meter to another transducer before updating the output. Ideally, all the pulses sent would be received and used. However, in the real world, sometimes the signal is distorted, too weak, or otherwise the received pulse does not meet certain criteria established by the manufacturer. When this happens the electronics rejects the pulse rather than use something that might distort the results.

The level of acceptance (or rejection) for each path is generally considered as a measure of performance, and is often referred to as signal quality. Meters provide a value describing how good signal detection is for each ultrasonic path. As mentioned above, there are several reasons why pulses can be rejected. Additional causes may include extraneous ultrasonic noise in the same region the transducer operates, distorted waveforms caused by excessive gas velocity, and to some degree, contamination on the face of the transducer.

Typically, the value of acceptance for each path, under normal operating conditions, will be 100%. As gas velocity increases to near the meter's rating, this percentage will begin to decrease. Depending upon design, this percentage may decrease to below 50%. Generally, this reduction in performance will have little impact on meter accuracy. However, if the percentage of accepted pulses is this low, it is safe to say the meter is not operating at top performance, and investigation may be warranted (assuming the meter isn't operating above the rated flow velocity capability).

Gains should be monitored periodically as poor performance on a path may be an indication of possible impending failure. Lower than expected performance can be caused by several factors. Besides excessive gas velocity, contamination on the transducer face and excessive extraneous ultrasonic noise can reduce signal quality. However, by monitoring gains, this condition can be easily identified before it becomes a problem.

Signal-to-Noise Ratio

This parameter is another variable that provides information valuable in verifying the meter's health, or alert of possible impending problems. Each transducer is capable of receiving noise information from extraneous sources (in addition to its paired transducer). In the interval between receiving pulses, meters monitor this noise to provide an indication of the "background" noise. This noise can be in the same ultrasonic frequency spectrum as that transmitted from the transducer itself.

Noise levels can become excessive if a control valve is placed too close and the pressure differential is too high. In this scenario the meter may have difficulty in differentiating the signal from the noise. By monitoring the level of noise, when no pulse is anticipated, the meter can provide information to the user, warning that meter performance (signal quality) may become reduced. In extreme cases, noise from control valves can "swamp" the signal to the point that the meter becomes inoperative.

All meters can handle some degree of noise created from this condition. Some ultrasonic flow meter designs can handle more than others can. The important thing to remember is the best time to deal with control valve noise is during the design of the metering station. Today's technology has improved significantly in dealing with extraneous noise. Reducing it in piping design is always the best choice.

Other sources can cause reduced signal to noise values. Typically they are poor grounding, bad electrical connections between electronics and transducers, extraneous EMI and RFI, cathodic protection interference, transducer contamination and in some instances, the meter's electronic components. However, the major reason for decreased signal to noise ratios remains pressure drop from flow control or pressure reducing valves.

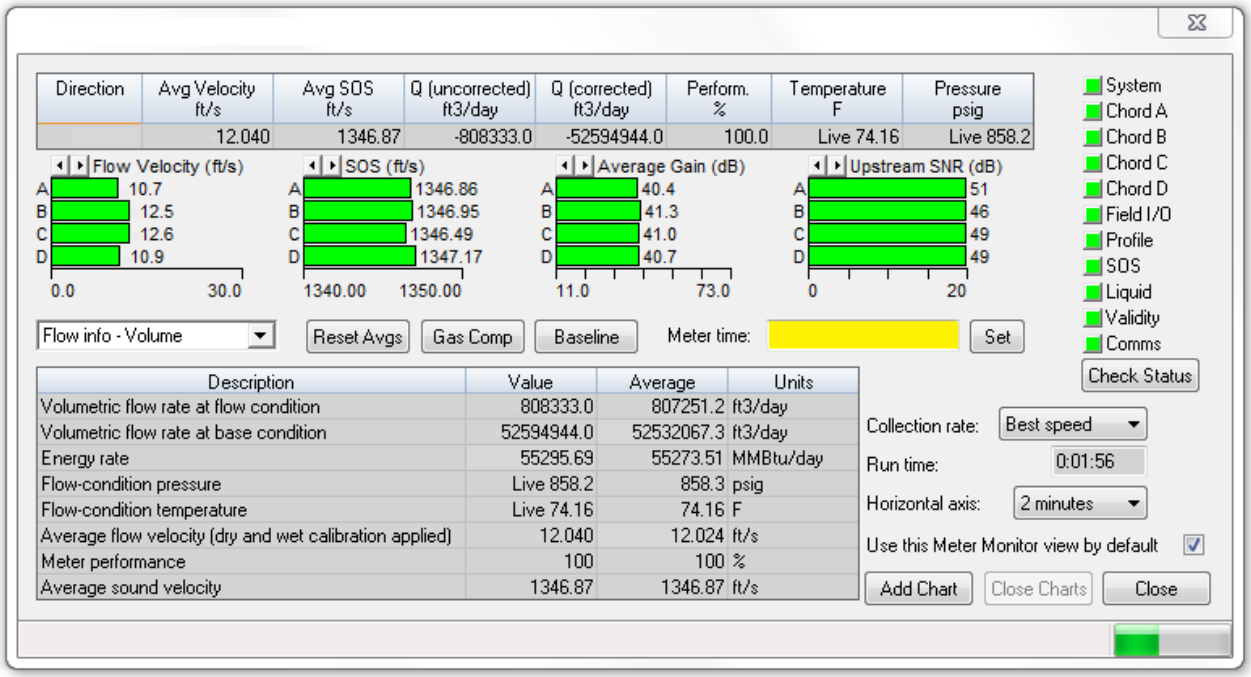
Concluding this discussion on signal to noise, the most important thing to remember is high-pressure drop (generally in excess of 200 psig) across a control valve can cause interference with the meter's operation. If the noise is isolated to a transducer or pair of transducers, the cause is generally not control valve related. Here probable causes are poor component connections or a potential failing component.

Control valve noise usually causes lower signal to noise levels on the transducers that face the noise source (all would be affected).

Speed of Sound

Probably the most discussed and used diagnostic tool is the meter's speed of sound (SOS). The reader may recall that speed of sound is basically the sum of the transit times divided by their product, all then multiplied by the path length (Equation (4)). As was discussed earlier, the primary measurement an ultrasonic meter performs to determine velocity is transit time. If the transit time measurement is incorrect, the meter's output will be incorrect, and so will the speed of sound.

As a fundamental check, the individual path speeds of sound should all agree within 1.5 fps (0.5 m/s) per AGA 9. For example, using a speed of sound of 1346.87 fps per the figure below, each path's speed of sound should be within 1346.12 to 1347.60 fps. If any individual path speed of sound does not read the same as the others, it can be an indication of transducer fouling, impending transducer failure or, at low flows, temperature stratification of the natural gas in the pipe/meter body.



It is important to periodically verify that the meter's reported speed of sound is within some reasonable agreement to an independently computed value. This topic will be covered in the companion paper, Ultrasonic Meter Diagnostics – Advanced.

BASICS OF ULTRASONIC FLOW METER INSTALLATIONS

When installing ultrasonic flow meters, many factors should be taken into consideration to insure accurate and trouble-free performance. Before discussing these issues, let's review the basics of a good installation.

Basic Piping Issues

Ultrasonic meters require adhering to basic installation guidelines just as with any other technology. Primary metering elements, such as orifice and turbine, have adopted recommendations for installation long ago. These are provided through a variety of standards (API, AGA, etc.) to insure accurate performance (within some uncertainty guidelines) when installed. The reason for these guidelines is the meter's accuracy can be affected by profile distortions caused by upstream piping. One of the benefits of today's ultrasonic flow meter is that they can handle a variety of upstream piping designs with less impact on accuracy then other primary devices.

For a discussion of basic diagnostics, though, we are less concerned about installation effects on the meters accuracy and more concerned on installations that affect the meter performance.

With the introduction of vast sources of natural gas coming from both shale gas fields and deep water offshore production, rich, wet gas is being added into the traditional clean, dry gas pipeline systems. Therefore consideration should be given to the installation in terms of low spots which can accumulate liquids produced as a result of rich gas being transported below its dew point.

Ultrasonic meters and their accompanying upstream/downstream meter tubes should be installed whenever possible with the inlet piping feeding the meter vertically upwards or horizontally. Installing the meter and meter tube with a light downward slope from inlet to outlet lets any liquids drain through the meter run.

Another common problem is sag, where the ultrasonic meter is installed lower than the outer ends of the meter tube, essentially allowing liquids to pool in the meter body,

As mentioned earlier, the best time to deal with control valve noise is during the design of the metering station. Today's technology has improved significantly in dealing with extraneous noise, however, reducing it in the initial piping design is always the best choice.

Consideration should also be given to properly grounding the ultrasonic meter electronics as well as isolation of the meter and meter run from any cathodic protection on the pipeline. Improperly grounded meters can potentially be identified by lower signal to noise ratios and/or or higher noise levels on the transit time signals.

CONCLUSIONS

During the past decade ultrasonic meters have become one of the fastest growing new technologies in the natural gas arena. The popularity of these devices has increased because they provide significant value to the customer by reducing the cost of doing business. One of the most significant benefits is the reduction in maintenance over other technologies.

There are several factors that can be attributed to this increased usage. First, as there are no moving parts to wear out, reliability is increased. Since Ultrasonic flow meters create no differential pressure, any sudden over-range will not damage the meter. If the meter encounters excessive liquids, it may cease operation momentarily, but no physical damage will occur, and the meter will return to normal operation once the liquid has cleared.

Most importantly, ultrasonic meters provide a significant amount of diagnostic information within their electronics. Most of an ultrasonic meter's diagnostic data is used to directly interpret its "health." Some additional diagnostics can be performed by using external devices and information (for example, computing speed of sound). This diagnostic data is available on a real-time basis and can be monitored and trended in many of today's remote terminal units (RTUs). Ultrasonic flow meters support remote access and monitoring in the event the RTU can't provide this feature.

There are four commonly used diagnostic features being monitored today. These include speed of sound by path (and the meter's average value), path gain levels, path performance values (percentage of accepted pulses), and signal to noise ratio. By utilizing this information, the user can help insure the proper meter operation.

Probably the most commonly used tools are path speed of sound and gains. Speed of sound is significant since it helps validate transit time measurement, and gains help verify clean transducer surfaces.

Installation of an ultrasonic meter is important if proper operation is to be obtained. The two primary issues relating to a good installation are upstream effects and the potential impact of control valve noise. Upstream effects are much better understood today. Testing conducted by Southwest Research Institute, under the guidance of the measurement community, and funded by the Pipeline Research Council (PRCI) provides much of the information needed to help understand installation effects.

Control valve applications are much better understood today than a few years ago. All manufacturers have methods to deal with this issue, and it varies depending upon design. The manufacturer should be consulted prior to design

to help insure accurate and long-term proper operation.

Today's ultrasonic flow meter is a robust and very reliable device with many fault-tolerant capabilities. It is capable of handling a variety of pipeline conditions including contaminants in the natural gas stream. In the event of transducer failure, the meter will continue to operate, and some ultrasonic flow meter designs maintain excellent accuracy during this situation. When encountering contamination such as oil, valve grease, and other pipeline contaminants, todays' ultrasonic flow meter will continue working and, at the same time, provide enough diagnostic data to alert the operator of possible impending problems.

As ultrasonic metering technology advances, so will the diagnostic features. Today, ultrasonic flow meter diagnostic data has become even more useful (and user friendly) as more intelligence is placed within the meter. They can not only provide diagnostic data, but can identify what the problem is.

Future incarnations of ultrasonic flow meters may be able self-diagnose and correct settings to automatically deal with valve noise issues, or, a much pursued goal, be able to estimate error. With the advances taking place at the current rate the impossible or the implausible may actually become possible.

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