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SMART MONITORING & DIAGNOSTICS FOR ULTRASONIC GAS METERS

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1 ABSTRACT

This paper discusses routine maintenance issues relative to multipath ultrasonic meters used in natural gas for fiscal measurement. A basic review of an ultrasonic meter's operation is presented to understand the typical parameters that are monitored. The meter's diagnostic data, along with other operational parameters such as gas composition, pressure and temperature, can be used to help verify proper meter performance. Diagnostic information, obtained from the meter, can also be used to monitor gas velocity profiles and help predict unusual behavior due to obstructions, pipe wall contamination or other performance deteriorating conditions. Intelligent monitoring of the meter's data will be discussed, and examples provided, to show how diagnostic data from an ultrasonic meter can be instrumental in determining a metering facility's health.

2 INTRODUCTION

During the past several years, the use of ultrasonic flow meters for natural gas custody transfer applications has grown significantly. The publication of AGA Report No. 9, *Measurement of Gas by Multipath Ultrasonic Meters* [Ref 1] in June 1998, has further accelerated the installation of ultrasonic flow meters (UFMs). Today virtually every natural gas transmission company is using this technology, either for custody transfer, or for operational applications.

Since the mid-1990s the installed base of UFMs has grown by approximately 50% per year. There are many reasons why ultrasonic metering is enjoying such healthy sales. 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 in both directions with comparable performance.
- **Tolerant of Wet Gas**: Important for production applications.
- **Non-Intrusive:** No pressure drop.
- **Low Maintenance:** No moving parts means reduced maintenance.
- **Fault Tolerance:** Meters remain relatively accurate even if one or more sensors fail.
- **Integral Diagnostics:** Data for determining the meter's health is readily available.

It is clear to many that there are many benefits to using UFMs. Although the first several benefits are important, the most significant may turn out to be the ability to diagnose the meter's health. The primary purpose of this paper will be to discuss basic gas ultrasonic meter diagnostics, review the fundamentals of field maintenance, and show how today's technology can monitor these parameters to provide enhanced reporting on the meter, and ultimately the facilities health.

3 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. If the technician doesn't understand the basics of operation when performing maintenance, at best they can only be considered a "parts changer." In today's world of increasingly complex devices, and productivity demands on everyone, companies can no longer afford this type of service.

Fortunately, 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.

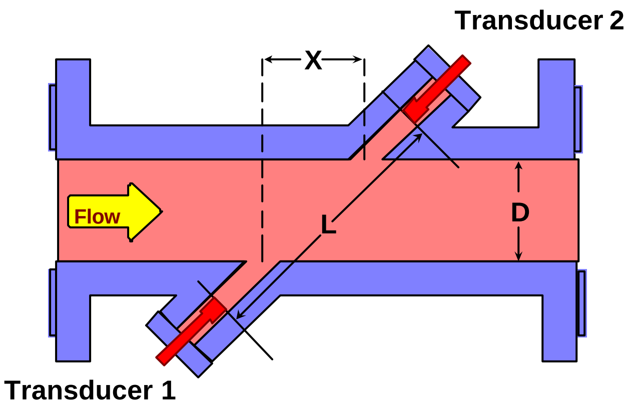

Figure 1 - Ultrasonic Meter

Ultrasonic meters are by nature velocity meters. 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.

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 travelling against the flow is measured (from Transducer 2 to Transducer 1). The transit time of the signal travelling with the flow will be less than that of the signal travelling against the flow due to the velocity of the gas within the meter.

Let us take a moment and 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 (SOS) 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 apply for each path.

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

and

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

Solving for gas velocity yields the following:

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

Solving for the speed of sound (*C*) in the meter yields the following equation:

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

Thus, by measuring dimensions X & L and transit times T_{12} & T_{21}, we can compute both the gas velocity and speed of sound 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 dependent). Consider a 300 mm 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 period. 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, whereas 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 know 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 manufacturers 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.

$$Q = \overline{V} * A \qquad (5)$$

This output (Q) is actually a flow rate based on volume-per-hour, 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 (X 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.

4 INTEGRAL DIAGNOSTICS OF ULTRASONIC METERS

One of the principal attributes of today's ultrasonic gas flow meter is the ability to monitor its own health, and to provide some diagnostics if any problems occur. Multipath meters are unique in this regard, as they can compare certain measurements between different paths, as well as checking each path individually.

The meter's data that can be used in this online "health checking" can be classed as internal or external diagnostics. Internal diagnostics are indicators derived only from internal measurements of the meter. External diagnostics are those methods in which measurements from the meter are combined with parameters derived from independent sources to detect and identify fault conditions. Some of the common internal meter diagnostics used are as follows.

4.1 Gain

One of the simplest indicators of a meter's health is the presence of strong signals on all paths. Today's multipath UFMs 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 pressure and flow velocity.

Gain numbers vary from manufacturer to manufacturer. Thus, recommendations may also differ. 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 was taken at 4,000 kPa, when the meter was placed into service, and subsequent readings taken at 6,000 kPa, one would expect to see a change. This change in reading (assuming gain values are linear, not in dB) would decrease by the ratio of pressures (4,000/6,000). 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 10 m/s. Using velocities in excess of 10 m/s 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 1.25 mm (0.05 inches) of an oily, greasy, and/or gritty substance, today's UFMs will continue to operate. Of course this buildup will generally also coat the inside of the meter, and may impact overall accuracy.

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 0.63 mm (0.025 inches) on each face, and the path length is 406 mm (16 inches). Also, assume the speed of sound through the contamination is twice that of the typical gas application (792 m/s (2,600 fps) vs. 396 m/s (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 (more on that later). 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, 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%. This amount of buildup is abnormal, and not typical of most meter installations.

Concluding the discussion on gain readings, UFMs 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.

4.2 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, the received pulse signal is sometimes distorted, too weak, or otherwise does not meet certain criteria established by the manufacturer. When this happens, the electronics reject 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 frequency range where 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 at 110+% of rated capacity).

Concluding the discussion on performance, this parameter should be monitored periodically, because poor performance on a path may be an indication of impending failure. Lower than expected performance can be caused by several factors. Besides excessive gas velocity, contamination on the transducer face can reduce signal quality. However, by monitoring gains, this condition can be easily identified before it becomes a problem. If excessive extraneous ultrasonic noise is reducing signal quality, this can also be easily identified. Thus, whenever signal quality decreases, the meter generally provides adequate information to assist the user in determining the probable cause.

4.3 Signal-to-Noise Ratio

This parameter is another variable that provides information valuable in verifying the meter's health, or alert of impending problems. Each transducer is capable of receiving noise information from extraneous sources (rather than its mated 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 UFM designs can handle more than others. The important thing to remember is the best time to deal with control valve noise is during the piping design phase. Today's technology has improved significantly in dealing with extraneous noise, but reducing it to manageable levels with a good design is always the best choice.

Other sources can cause reduced signal-to-noise values. Typically they include 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 own 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 1,400 kPa) across a control valve may cause interference with the UFM'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 (although all would be affected to some degree).

4.4 Velocity Profile

The ability to monitoring the velocity profile is possibly one of the most overlooked features of today's ultrasonic meter. It can provide many clues as to the condition of the metering system, not just as a monitor of the meter. AGA Report No 9 requires a multipath meter to provide individual path velocities. As mentioned previously, the output used by the flow computer is an average of these individual readings.

Once the UFM is placed in service, it is important to collect a baseline (log file) of the meter. That is, record path velocities over some reasonable operating range, if possible. Good meter station designs produce a relatively uniform velocity profile within the meter The baseline log file may be helpful in the event the meter's performance is questioned later.

Many customers choose to use a "high performance flow conditioner" with their meter. This conditioner is intended to isolate any upstream piping effects on gas profile. In reality, they don't totally isolate the disturbance, but do provide a reasonably repeatable profile. The important issue here is the velocity profile is relatively repeatable. Once a baseline has been established, should something happen to the flow conditioner, it can be identified quickly by comparing path velocities with the baseline. Many conditions can occur that will impact the original velocity profile. Velocity profile changes can be caused by such things as:

- Partial blockage of the flow conditioner,
- damage to the flow conditioner, or
- upstream piping affects, such as a change in a valve position.

Of course, something could have also occurred with the meter to cause a significant profile change. Generally speaking, this is unlikely as all components are securely mounted. However, the velocity of a given path could be affected by other problems. When considering that only *X* and *L* dimensions, and transit times impact path velocity, it is relatively easy to eliminate these. If a problem develops within the meter that impacts only one or more paths, other performance indicators, such as gain, path performance, and speed of sound will also be indicating problems.

Concluding this discussion on path velocities, most good installations produce somewhat symmetrical velocities within the meter. Depending upon the UFM design, comparing each path's velocity with the average, and sometimes to other paths, can give the user confidence the profile has not significantly changed. Today's UFM can handle some relatively high levels of asymmetry within the meter. It should *not* be assumed that the meter's accuracy is significantly impacted just because the velocity profile has changed. It is usually an indication, however, that something within the metering facility, other than the meter itself, is probably causing the effect. Careful review of other diagnostic parameters can determine if the meter is at fault, or not.

4.5 Speed of Sound

Probably the most discussed and used diagnostic tool is the meter's reported 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. Thus, it is important to periodically verify that the meter's reported speed of sound is within some reasonable agreement to an independently computed value.

Modern UFMs use high frequency clocks to accurately perform transit time measurements. In a typical 300-mm meter, the average transit time may be on the order of one millisecond. When there is no flow within the meter, the difference between T_{12} and T_{21} will be zero. As flow rate increases, the difference will be detected, and a resulting flow rate computed. To obtain a perspective on this differential time, values start out in the 10s of nanoseconds and typically increase to maybe 100 microseconds at the highest velocities.

Accurate meter performance requires consistent, repeatable transit time measurements. Comparing the SOS to computed values is one method of verifying this timing. This procedure would be considered an external diagnostic technique. Let's examine the affects (or uncertainties) on computing speed of sound in the field.

4.5.1 Pressure & Temperature Effects

The speed of sound in gas can be easily computed in the field. There are several programs used for this purpose (like SonicWare™) and they are generally based upon the equation of state provided in AGA Report No 8, *Compressibility and Supercompressibility for Natural Gas and Other Hydrocarbon Gases* [Ref 2]. However, computation of the speed of sound has some inherent uncertainties associated with it.

It is important to realize that the speed of sound is more sensitive to temperature and gas composition than pressure. For example, a 0.55 degree C (1.0 °F) error in temperature at 5,170 kPa (750 psig), with typical pipeline gas, can create an error of 0.13%, or about 0.52 m/s (1.7 fps). An error of 35 kPa (5 psig) at 5,170 kPa (750 psig) and 15.5 degrees C (60°F) only contributes 0.01% error. Thus, it is extremely important to obtain accurate temperature information.

Knowing that temperature errors contribute significantly in computing SOS is important. However, if the temperature is in error by the amount in the previous example, a more significant question might be "what error is this causing in the volumetric measurement?" A quick calculation shows a one degree F error will cause the corrected volumetric calculation to be incorrect by about 0.28%. Having a history of calculated SOS vs. measured may actually be a good "health check" on the stations temperature measurement!

4.5.2 Gas Composition Effects

Sensitivity to gas composition is a bit more difficult to quantify as there are an infinite number of sample analyses to draw from. Let's assume a typical gas composition with about 90% methane. If the chromatograph was in error on methane by 0.5%, and the remaining components were normalized to account for this error, the resulting effect on speed of sound would be 0.03%. Thus, for relatively lean samples, minor errors in gas composition may not contribute significantly to the uncertainty.

Next, let's look at another example gas with approximately 95% methane. Suppose the methane reading is low by 0.5%, and this time the propane reading was high by that amount, the error in computed speed of sound would be 0.67% (2.65 m/s!). Certainly one could argue this may not be a "typical" error. There are many scenarios that can be discussed and each one would have a different effect on the result. The uncertainty that gas composition contributes to the speed of sound calculation remains the most elusive to quantify, and, depending upon gas composition, may prove to be the most significant.

A typical question is "What difference can be expected between the value determined by the meter, and that computed by independent means?" It has been shown [Ref. 3] that the expected uncertainties (two standard deviations) in speed of sound, for a typical pipeline gas operating below 10,200 kPa are:

- UFM measurement: $\pm$ 0.17%
- Calculated (AGA 8): $\pm$ 0.12%

Since the UFM's output is independent of the calculation process, a root-mean-square (RMS) method can be used to determine the system uncertainty. Thus, when using lean natural gas below 10,200 kPa (1,480 psig), it is expected that 95% of readings agree within 0.21% (or about 0.82 m/s). Therefore, it may be somewhat unrealistic to assume the meter will agree within 0.3 m/s under typical operating conditions.

4.5.3 Importance of SOS Verification

As was discussed earlier, SOS verification helps insure the meter is operating correctly. What other changes in a meter can affect the reading? From the previous discussion on gain, we see that buildup on the face of a transducer will affect the speed of sound. Thus, if a pair of transducers has a different value, when compared to the average (or to other paths, depending upon meter's design), this might be an indication of contamination.

One thing to remember is that the percent change in speed of sound, given the same buildup, will be greater for a smaller meter than a larger one. As path length increases from say 250 mm to 750 mm (or more), a buildup of 0.62 mm will affect the transit time less. By utilizing gain information along with SOS data for a given path, it can be quickly determined if the change in SOS is due to contamination, or other causes.

Another benefit in monitoring path SOS is to verify proper identification of reception pulses. In the section on signal-to-noise, extraneous noise was noted to potentially interfere with normal meter operation. That is, if ultrasonic noise within the meter (caused by outside sources) becomes too great, meter performance will be impacted.

As the noise level increases, there is the possibility that the circuit detecting the correct pulse will have difficulty. Good meter designs protect against this and reject received pulses that have increased uncertainty regarding their validity. If this scenario occurs, it is unlikely all paths will be affected simultaneously, and by the same amount. Monitoring variations in SOS from path to path will identify this problem and help insure the meter's health is satisfactory.

4.5.4 Proper SOS Computation

As was discussed earlier, obtaining accurate information about the gas properties is essential for quality results. There are several things to keep in mind when performing a comparison of the meter's reported SOS and values computed from pressure, temperature and gas composition.

When comparing computed speed of sound results with that reported by the meter, accuracy will generally be better when performed at low to medium gas velocities. At higher velocities (approaching the meter's capacity), the percentage of accepted pulses will begin to decrease. UFMs generally provide an average of all paths collected for the SOS update. If some of the samples are being rejected, and the path has a slightly different reading when compared to others, the net result will be a slight increase in scatter. This will be significantly reduced if data is averaged over a short interval. Thus, using an average of samples (say 60 seconds), rather than a spot reading of the meter's output, will yield more reliable results.

When averaging the meter's speed of sound, metering pressure and temperature should also be recorded (or at least monitored). Normally these parameters are stable, but it is possible for conditions to change. If changing pressure and temperature values aren't averaged, comparison uncertainties will increase.

Obtaining accurate gas composition during speed of sound comparisons is often more difficult than pressure and temperature data. This occurs because during the test period, analysis data is not reported by the gas chromatograph (GC) for several minutes. The number of minutes depends upon how long the sample takes to travel from sample probe to column. This could be as short a four minutes (if the GC is close to a pressure-reducing sample probe and/or a speed loop is employed), to more than ½ hour if the tubing is long, too large, or sample pressure reduction takes place at the GC.

If gas composition is stable (doesn't significantly vary over several hours), the impact on uncertainty is reduced. For increased accuracy in comparing AGA 8 computed vs. meter SOS, you should obtain gas analysis data that is representative of the composition during the test by considering "sample time." If the amount of "sample time" of the gas can't be easily determined, obtain a gas sample in a cylinder and have it analyzed later.

One frequently overlooked aspect when performing speed of sound calculations is that the uncertainty of any comparison increases significantly if performed when no gas is flowing through the meter. During periods of zero flow, gas temperatures in the pipeline can stratify, especially if solar radiation is present. Difference in temperatures from the top to the bottom of the pipeline can be significant, and will most definitely impact path and average SOS values. More importantly, as the gas stratifies, the temperature reading at the RTD will most assuredly be incorrect. We see from the brief uncertainty analysis in the preceding sections that temperature is probably the most significant factor in obtaining good agreement between the meter and predicted (AGA 8 method) values. Even small temperature measurement errors (>0.3 deg. C) will cause results to exceed acceptable limits.

Concluding this discussion on speed of sound, this "integral diagnostic" feature may be the most powerful tool for the technician. Using the meter's individual path speed of sound output, and comparing it to not only the computed values, but also comparing within the meter itself, is a very important maintenance tool. Caution should be taken when collecting the data to help minimize any uncertainty due to gas composition, pressure and temperature. Additionally, it is extremely important to obtain data only during periods of flow as temperature stratification can cause significant comparison errors. Developing a history of meter SOS, and comparing it with computed values, can also be used as a "health check" for the temperature measurement used to determine corrected volumes.

4.5.5 Typical Speed of Sound Field Results

This section provides some actual data from two meters using the customer's local flow computer. Figures 2 and 3 show trended values covering 2 to 3 hours. Data is shown from the 200-mm meter in Figure 2. It compares the average speed of sound from the four paths with the AGA 8 calculated value.

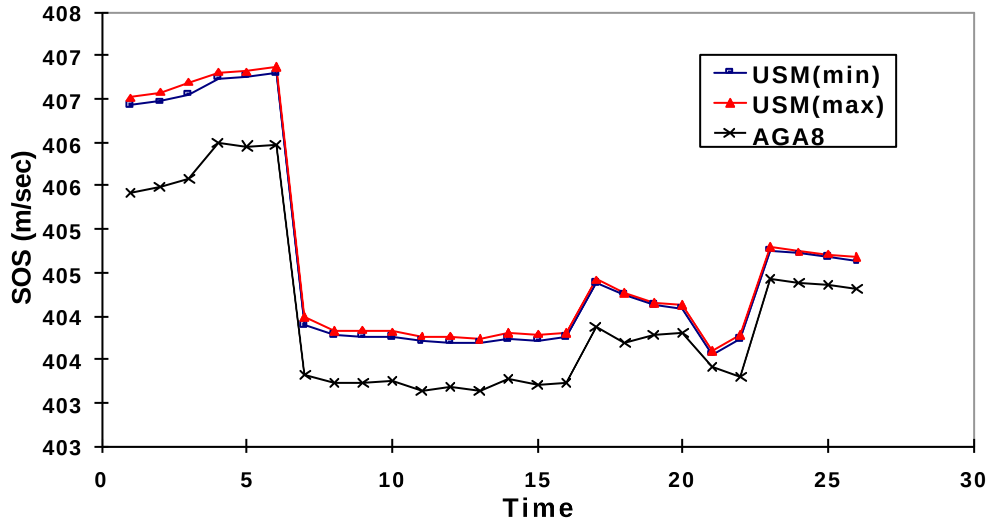

Figure 2 – 200-mm Meter Measured and Calculated SOS

At each measurement point, ten successive values of the ultrasonic meter's SOS were logged. The two curves that show minimum and maximum values in Figure 2 demonstrate repeatability in SOS measurements of better than 0.03%. The difference in the meter's speed of sound vs. computed values are, for most points, less than 0.3%. Note that the difference between computed and reported varies with time. This is most likely caused by delays in gas compositional updates. That is, the meter reports its SOS data several minutes prior to the gas analysis being incorporated in the AGA 8 calculation, increasing uncertainty of the comparison.

Figure 3 shows the AGA 8 calculated speed of sound trended compared to the individual SOS readings from the four paths. Note that in each case the agreement on all chords is roughly as expected (better than 0.3%). In the event of significant contamination on one or more pairs of transducers, this graph would have shown the impact because the speed of sound would have deviated more from the predicted (AGA 8), as well as the other chord's values.

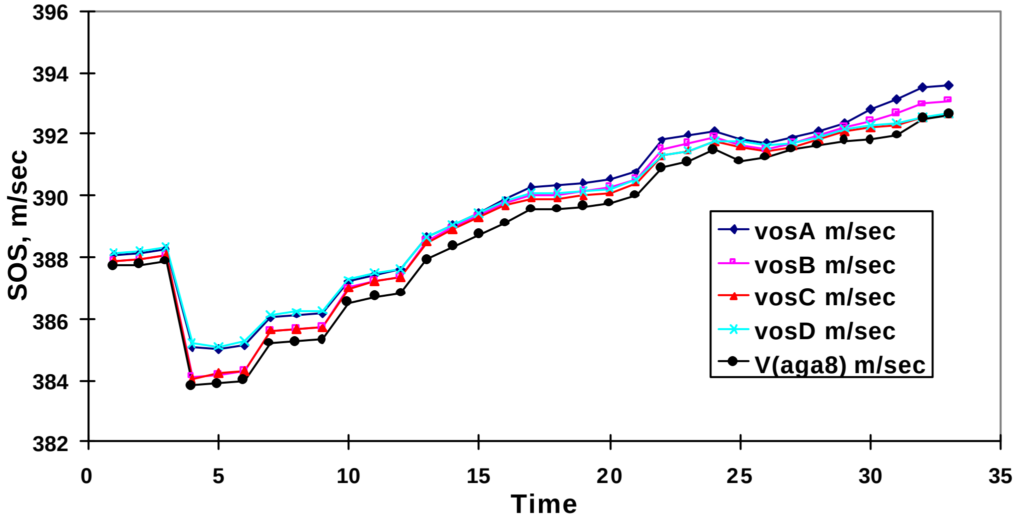

Figure 3 – 250-mm Meter SOS with Four Chords, Measured and Calculated

The previous examples of speed of sound vs. time showed good correlation between the meter's reported value and the theoretical value over the sample range shown. Let's take a look at an example where this is not the case. Figure 4 shows (in red squares) the theoretical vs. reported SOS error relative to time. In the beginning the error is less than -0.10%, but increases to more than -0.40%. At some point in time (around a time of 30), chord differences tend to increase just as the computed vs. reported error also increases. So, what is the cause of this increasing error?

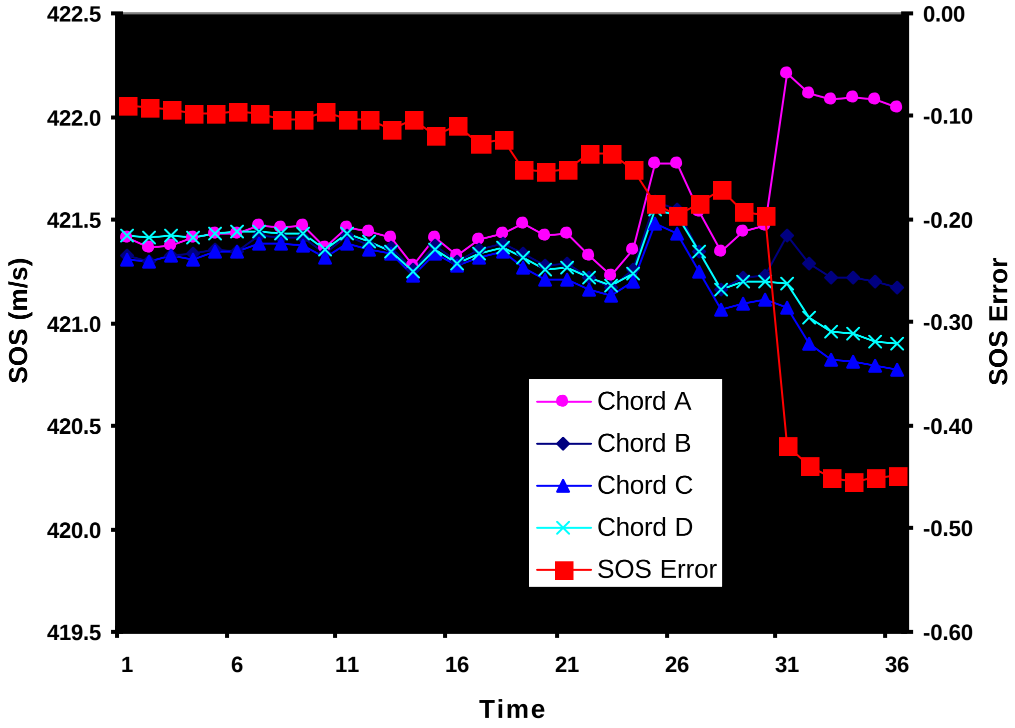

Figure 4 – SOS Values and Average Error

In Section 4.5.1, the importance of accurate temperature measurement, relative to determining the theoretical SOS, was discussed. One thing that wasn't mentioned was the assumption that the temperature was uniform relative to the cross-section of the pipe (and meter). In this example the gas velocity was much lower when the SOS error increased. As the gas velocity decreased to about 1.1 m/s, solar radiation began creating a temperature gradient from top to bottom. This caused temperature stratification within the pipeline, increasing the SOS error. Following is a diagram that shows the chord configuration for the meter used to collect this data.

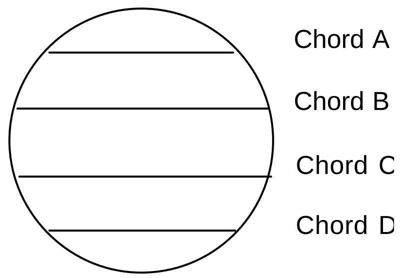

Figure 5 – UFM Chord Layout

Since gas temperature was measured at the top of the pipe, it registered a value higher than the bottom, and was most certainly not the average value seen by the meter. By using this ultrasonic flow meter design (see Figure 5 for the four chordal positions), temperature stratification can be easily determined. By knowing the gas composition and the pressure, the effective temperature at each chord location can be back-calculated, and a theoretical average temperature can be computed. Thus, in this example, measurement errors were not incurred by the meter, but by incorrect temperature measurement that was used for computing corrected volumes.

To demonstrate this error, let's compute what the average temperature should have been based solely on differences in SOS. The following tabled values were recorded at the point where SOS deviations were the most significant. The assumption is that when the meter was operating at higher velocity, the temperature measurement was correct. The amount of error (SOS) at this condition was computed to be -0.094 percent. This will be normalized for the computations that follow. That is, we will correct the errors reported at the low flow rate by this amount prior to reverse-computing the temperature.

Initial conditions are as follows: Pressure is 56.018 bar, temperature is 22.544 °C, the AGA 8 SOS was computed to be 423.18 m/s and the meter reported a SOS of 421.30 m/s, and gas velocity was 1.06 m/s. The "Error" column of Table 1 shows results of each chord relative to the computed AGA 8 value (at the velocity of 1.06 m/s) using the reported temperature and pressure. The error reported in the "New SOS" column is adjusted to take into consideration the corrected reading based upon the bias determined at the high flow rate of approximately 13 m/s. That is, it eliminates biases between meter and computed SOS (-0.094%) when the average gas temperature throughout the pipe is assumed to be homogeneous.

Table 1 – Summary of Adjusted Temperature

Chord	SOS	Error	New SOS	Temp
A	422.103	-0.25	422.50	21.28
B	421.254	-0.24	421.65	20.94
C	420.863	-0.55	421.29	20.56
D	420.985	-0.52	421.38	20.65

From this "New SOS" a temperature is back-computed from each chord's SOS. Interesting to note is that the upper chord's (A) temperature is less than the reported RTD temperature, showing there is probably some additional influence on the RTD beyond just the gas temperature stratification. Clearly, the temperature at the bottom of the pipe is less than the top (by 0.63 degrees C). If all four inferred temperatures were averaged the result would be 20.94. This average is 1.55 degrees C less than what the RTD was reporting, and would translate into an under-registration of approximately 0.54%!

Concluding this discussion on external calculations, the results demonstrate that multi-path ultrasonic meters show good correlation between the computed speed of sound and the meter's reported speed of sound. Even though there are differences between computed and reported values, these remain relatively constant though out the test period. This also suggests that when performing an on-line comparison of speed of sound, an alarm limit of about ± 0.3% between the meter and computed values, as recommended earlier, may be reasonable.

Figure 4 shows that, for a short interval, during periods of low flow and temperature stratification, the error exceeded 0.3%. Since this situation can occur in the field, safeguards should be implemented to insure gas velocity is above some minimum value, and for a specified time, before alarming occurs. Thus, the use of independent estimates of gas speed of sound, derived from an analysis of the gas composition, can be an effective method of understanding how well an ultrasonic meter is performing, and to some degree, how well the measurement system is performing.

5 SMART MONITORING DEVICE

Ultrasonic flow meters today provide the diagnostic information discussed in Section 4. This information is typically manually collected periodically (monthly or quarterly), analyzed, and then stored for future reference. When operating and meter conditions change, this information, often called log files, is used to determine the meter's health. As companies continue to reduce their workforce, and develop job descriptions that require technicians to service an everincreasing number of devices, the need for automatic diagnostics (smart monitor) for UFMs increases.

A smart monitoring device needs to not only be able to monitor the meter's diagnostic data, but also have the capability of obtaining gas composition, pressure and temperature. With this information, the meter's reported SOS can be compared to the theoretical value on a real-time basis. But, this device should be capable of much more than just SOS calculation and comparisons.

There are many factors that can influence measurement accuracy in the field. Periodic checks are a company's best defense against billing errors. In the case of an ultrasonic meter, technicians are looking for changes in gain that generally indicate contamination within the meter. They are looking for chord performance to insure the meter hasn't lost the operation of a chord. They are looking for speed of sound comparisons and signal-to-noise ratios to further insure accurate and proper operation. In short, they are looking to verify that the meter is operating correctly.

5.1 The Next Generation Device

What if a device could perform all of these operations on a real-time basis, store a variety of additional information relative to the meter's operation, provide alarming in the event a parameter exceeds prescribed limits, be web-based for ease of world-wide access, and even report this information to a pager or an e-mail address automatically? Wouldn't such a device make the UFM meter, and for that matter the entire measurement site, much more intelligent, thus requiring less site visits and reducing operational costs? In fact this is where the industry is going. In the very near future, ancillary products will be capable of all of the aforementioned features, and much more.

Earlier in this paper, examples were shown where customers performed some real-time analysis on SOS using their flow computers. This provided one piece of information to help assure them the UFM was operating correctly. However, it didn't provide any historical information or analysis on the four other areas discussed; (i.e., gains, performance, signal-to-noise and chord velocity profile).

The next evolutionary step in ultrasonic metering will incorporate a product that provides much more than just SOS comparison information. It will:

- be a web-enabled device that also supports dial-up and local connection for locations without a WAN or telephone service,
- monitor multiple UFMs and GCs at a given site on a continuous basis,
- perform real-time analysis of the ultrasonic flow meter and GC operation,
- permit viewing live data from the UFM and GC,
- only require an Internet browser for interface (no proprietary software required),
- be very flexible in assigning alarms to a variety of variables and conditions, both UFM and GC parameters,
- provide for configuration on any number of logs for both the UFM and GC,
- be programmable to transmit alarms to a variety of addresses (both internet and text pagers) in the event of a problem,
- support simultaneous users via the world-wide-web with user name and password protection, and multiple levels of security,
- operate un-attended, will not lose memory in the event of power failure, and be capable of re-starting un-attended,
- be remotely upgradeable for enhanced features in the future, and
- be retrofitable to existing installations and future products.

This next evolution in technology will take existing measurement facilities and enhance the information that is available, but not currently being taken advantage of. It will not only help lessen the possibility of billing errors, it will reduce maintenance, identify potential sources of billing errors (temperature gradients for example), permit remote monitoring (thus also providing for third-party technical support), and, in short, improve a facility's operation.

6 CONCLUSIONS

During the past several years ultrasonic meters have become one of the fastest growing new technologies in the natural gas industry. Their popularity 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.

A reduction in maintenance can be attributed to several factors. First, as there are no moving parts to wear out, reliability is increased. Since UFMs 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.

Much of an ultrasonic meter's diagnostic data is used internally to determine its "health." 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).

There are four common 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 features are SOS and gain. Speed of sound is significant since it helps validate transit time measurement, and gain helps verify clean transducer surfaces. When performing speed of sound calculations in the field, care should be taken to collect data only during periods of flow in the pipeline as temperature gradients can, and will, distort comparison results. Additionally as shown in one of the graphical examples, low-flow limits should be implemented to insure pipeline temperature is uniform and stable before comparing meter speed of sound with computed values from gas composition, pressure and temperature.

One significant benefit in performing online comparisons between the meter's speed of sound and a computed value is to provide a "health check" for the entire system. If a variation outside acceptable limits develops, the *probable cause* will be temperature, pressure, or gas composition measurement error rather than the UFM. In this regard, the UFM is actually providing a "health check" on the measurement system!

As technology continues to advance, manufacturers will strive to provide the user with increased ease in analyzing their product. With increased demands upon everyone in today's competitive environment, taking an existing UFM product and making it easier to use brings more value to an already very successful product.

In the very near future, periodic analysis of UFM diagnostic data will become a thing of the past. Ancillary devices will collect the UFM's information, analyze, store, and report it with a variety of methods long before a problem develops, thus permitting a technician to address the issue before it becomes a billing problem. When this occurs, ultrasonic meters may be considered "maintenance free."

7 REFERENCES

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