BASICS OF GAS ULTRASONIC METER DIAGNOSTICS

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ABSTRACT

This paper discusses basic diagnostic features of gas ultrasonic meters (USM), and how capabilities built into today's electronics can identify problems that may have gone undetected in the past. It primarily discusses fiscal-quality, multi-path USMs and does not cover issues that may be different with non-fiscal meters as they are often single path designs. Although USMs basically work the same, the diagnostics for each manufacturer does vary. All brands provide basic features as discussed in AGA 9 [Ref 1]. However, some provide more advanced features that can be used to help identify issues such as blocked flow conditioners and gas compositional errors. This paper focuses on the Westinghouse and British Gas configurations (both being chordal designs) and the information presented here may or may not be applicable to other path designs.

INTRODUCTION

During the past several years there have been numerous papers presented which discuss the basic operation of USMs [Ref 2]. These papers discuss the meaning of the five basic diagnostic features. Following is a summary of the five features available from all USM manufacturers.

- Individual path velocities
- Individual path speed of sound
- Gains for each transducer
- Signal-to-noise (SNR) for each transducer
- Accepted pulses, in percentage, for each transducer pair

Although these features are very important, little has been written on how to interpret them. Part of the reason is analysis varies by manufacturer.

Some manufacturers provide additional diagnostic features such as swirl angle, turbulence, AGA 10 [Ref 3] SOS vs. the meter's reported SOS, and many others.

Graphs shown in this paper are from Excel spreadsheets based on data generated by software that is used to communicate with the meter. Note that these graphs were not individually developed but rather automatically generated from the data collected during calibration or maintenance procedures.

Obviously it is important for users to collect periodic maintenance log files. These log files provide a "snap-shot" of the meter's operation at that point in time. Many utilize some of the data for entry into their company database for tracking over time. However, a large number of users don't perform any tracking or trending of data.

BASIC DESIGNS OF ULTRASONIC METERS

Before discussing diagnostics it might be helpful to review some of the basic designs that are used today. Figure 1 shows 5 types of velocity integration techniques [Ref 4]. The various meter configurations in Figure 1 provide different velocity responses to profiles, and are thus analyzed differently. This is particularly true when trying to perform comparisons on velocity and SOS. Looking at differences in SOS between the various paths may require somewhat different analysis. This is primarily the case when a meter is operated at very low velocities as thermal stratification can occur (more on this later). Analysis in this paper will be applicable to design D in Figure 1.

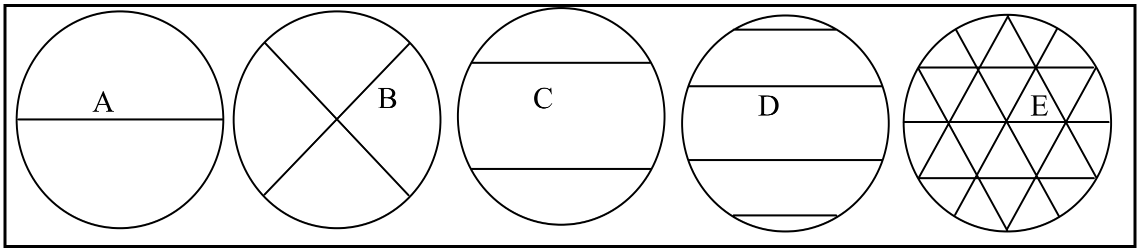

Figure 1 – Ultrasonic Meter Designs

BASIC DIAGNOSTIC INDICATORS

One of the principal attributes of modern ultrasonic meters is the ability to provide several diagnostics that can be used to monitor the meters "health" and thus be used 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 either internal or external diagnostics. Internal diagnostics are those 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. An example of this would be to compute the gas SOS, based upon composition, and compare to the meters' reported SOS.

Gain

One of the simplest indicators of a meter's health is the presence of strong signals on all paths. Today's multipath USMs have automatic gain control on all receiver channels. Transducers typically generate the same level of ultrasonic signal time after time. The increase in gain on any path indicates a weaker signal at the receiving transducer. This can be caused by a variety of problems such as transducer deterioration, fouling of the transducer ports, or liquids in the line. However, other factors that affect signal strength include metering pressure and flow velocity.

Figure 2 shows gains from a 16-inch meter at the time of calibration. These were taken when the meter was operating at approximately 20 fps.

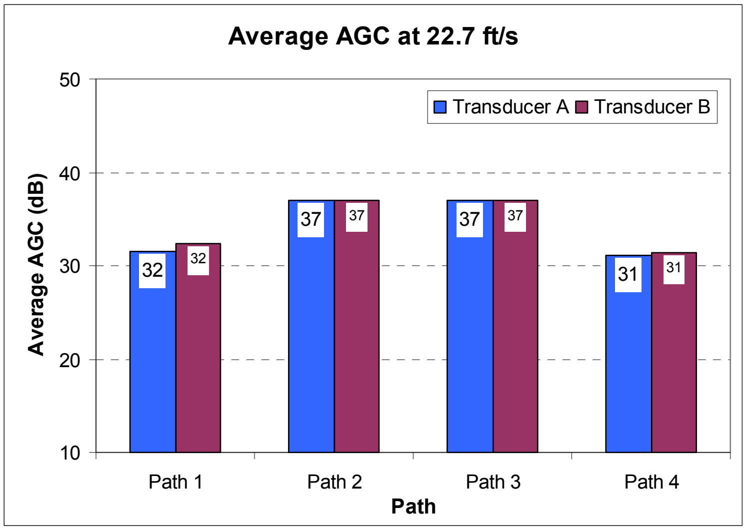

Figure 2 – Gain at 20 fps – 16 inch Meter

Note that the gains on each of the pairs are very similar, and the gains by path are higher in the middle two paths. This is due to the increased path length requiring additional amplification. Figure 3 shows the same meter at 155 fps.

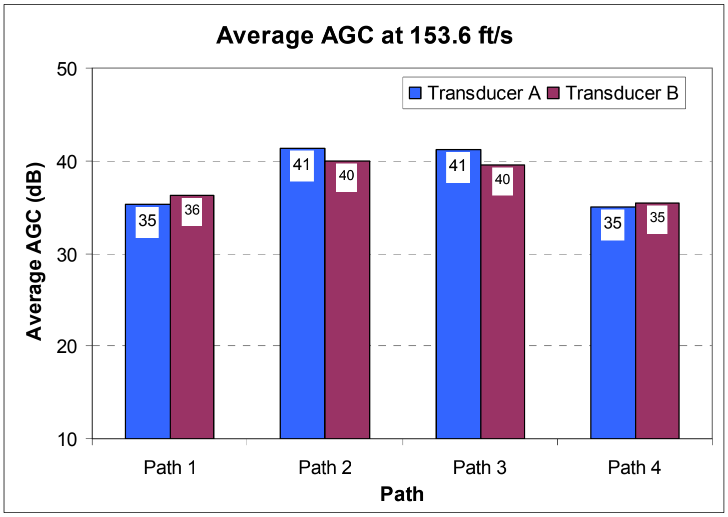

Figure 3 – Gain at 155 fps – 16 inch Meter

Figure 3 shows the gains for all pairs have increased. This is normal when a meter is operating at much higher velocities due to signal attenuation. Gain can also be affected (usually increases) by changes in gas composition (for instance higher than normal CO2), contamination on the face of the sensor, electronics problems and a transducer that has poor connections or failing for one of many reasons.

Signal Quality – Transducer Performance

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 body to the opposing transducer in the pair 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 the received pulse does not meet certain criteria established by the manufacturer. When this happens the electronics rejects the pulse rather than use something of questionable quality that might affect 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. Unless there are other influencing factors, the meter will normally operate at 100% performance until it reaches the upper limit of its velocity rating. Here the transducer signal becomes more distorted and some of the waveforms will ultimately be eliminated since they don't fit the pulse detection criteria. At this point the meter's performance will decrease from 100% to something less.

Figure 4 shows the performance of a 16-inch meter at a velocity of about 20 fps.

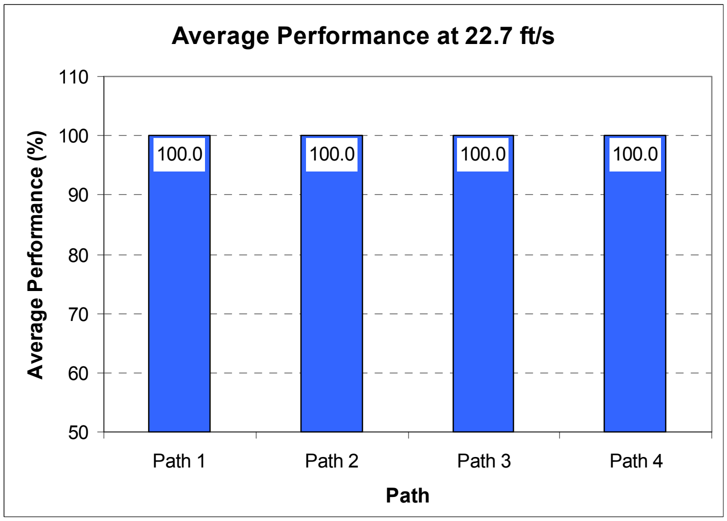

Figure 4 – Transducer Performance at 20 fps

Figure 5 shows the same meter operating at 155 fps. As we can see the performance has fallen from 100 percent on all paths to the 90+% range. This is normal at high velocities as signal distortion will have some impact on waveforms at these high velocities.

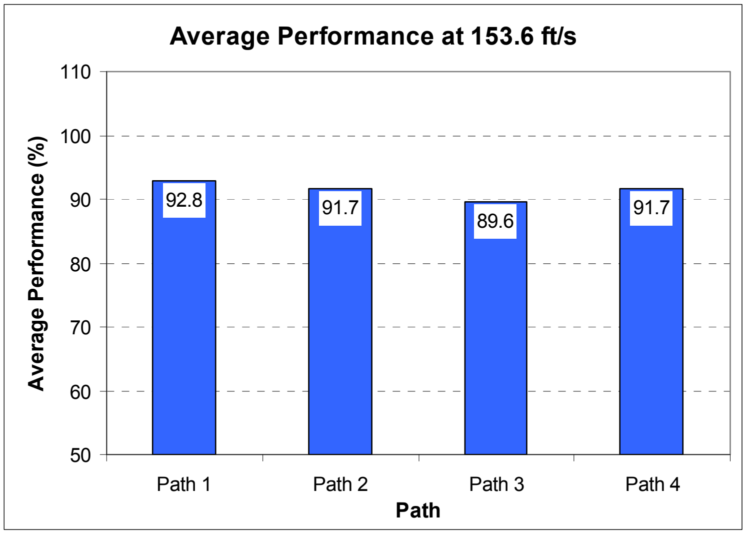

Figure 5 – Transducer Performance at 155 fps

Signal-to-Noise Ratio

Signal-to-noise (SNR) provides information that is also valuable in verifying the meter's health, or alert the user of possible impending problems. Each transducer is capable of receiving noise information from extraneous sources (rather than its opposite transducer). In the interval between receiving pulses, the meter monitors for 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.

The measure of signal strength to the level of "background" noise is called the Signal-to-Noise Ratio, or SNR for short. Typically technicians do not put much emphasis on SNR nearly as much as gains and performance. SNR is generally not an issue unless there is a control valve or other noise generating piping component present. When that occurs, the SNR values will drop. The magnitude of the SNR is a function of the manufacturer's methodology of expressing the value and the ability to handle external ultrasonic noise.

Figure 6 shows the SNR from a 16-inch meter flowing 20 fps at the time of calibration. As can be seen the SNR is about 40 dB.

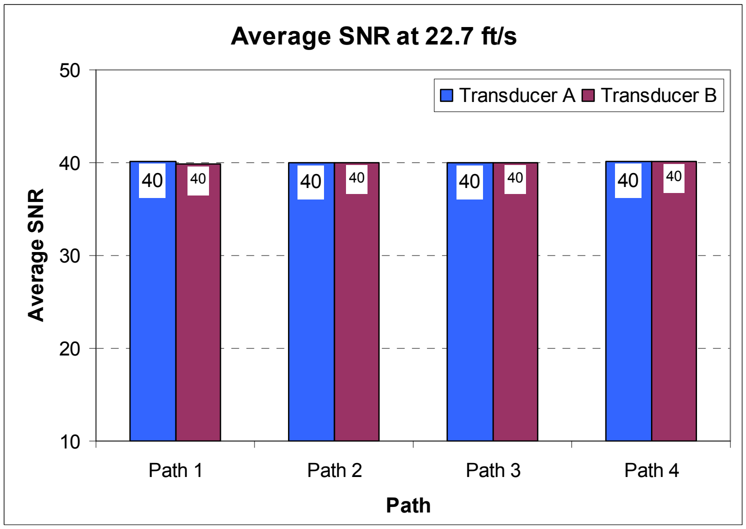

Figure 6 – SNR at 20 fps Meter Velocity

Figure 7 show the same meter at about 155 fps. The SNR values have decreased by about 5-13 dB, depending upon whether they are upstream or downstream. This is due to ultrasonic noise being generated inside the piping due to the gas turbulence and also can be caused by flow conditioners. As the downstream transducers face the upstream direction, the increased level of ultrasonic noise from the higher velocities has more impact on these transducers when compared to the upstream transducers that are facing away from the noise source. Also note that the SNR for the middle pairs has decreased more than the outer pairs. This is due to the path length being longer and thus attenuating the signal more.

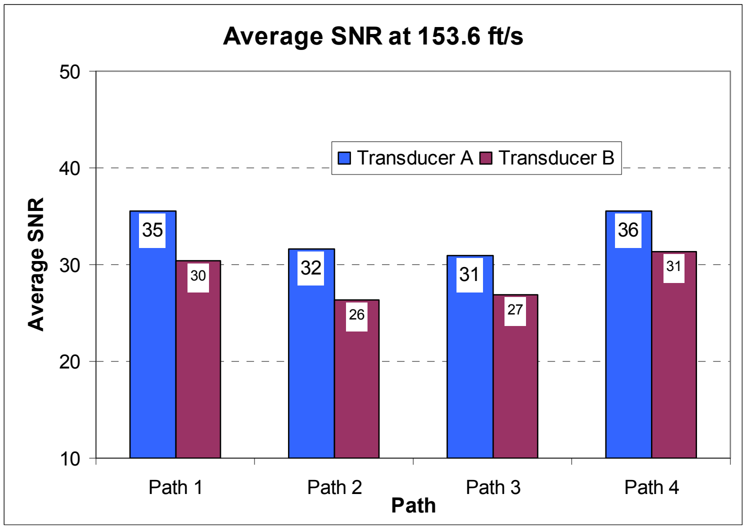

Figure 7 – SNR at 155 fps Meter Velocity

Noise levels can become excessive if a control valve is placed too close to the meter and the pressure differential is too high. When this happens 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, via the SNR, 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.

Today's new generation of transducers can handle significant levels of control valve noise. By using transducers that have a higher frequency, combined with higher efficiency and stronger sound pressure levels, the affects of control valve noise have been significantly reduced as compared to past generations of USMs. Figure 8 shows a picture of a meter and a control valve located immediately downstream of the USM.

Figure 8 – Control Valve near 2-inch USM

In the test shown in Figure 8, the meter was being operated at 600 psig and the regulator was producing about 200 psig differential pressure. The meter's SNR went from a normal of 40 dB to 24 dB. For this meter when the SNR approaches 13 the meter would begin to reject waveforms. Figure 9 shows the waveform during this test. Figure 10 shows the same pair of transducers when there is no regulator noise.

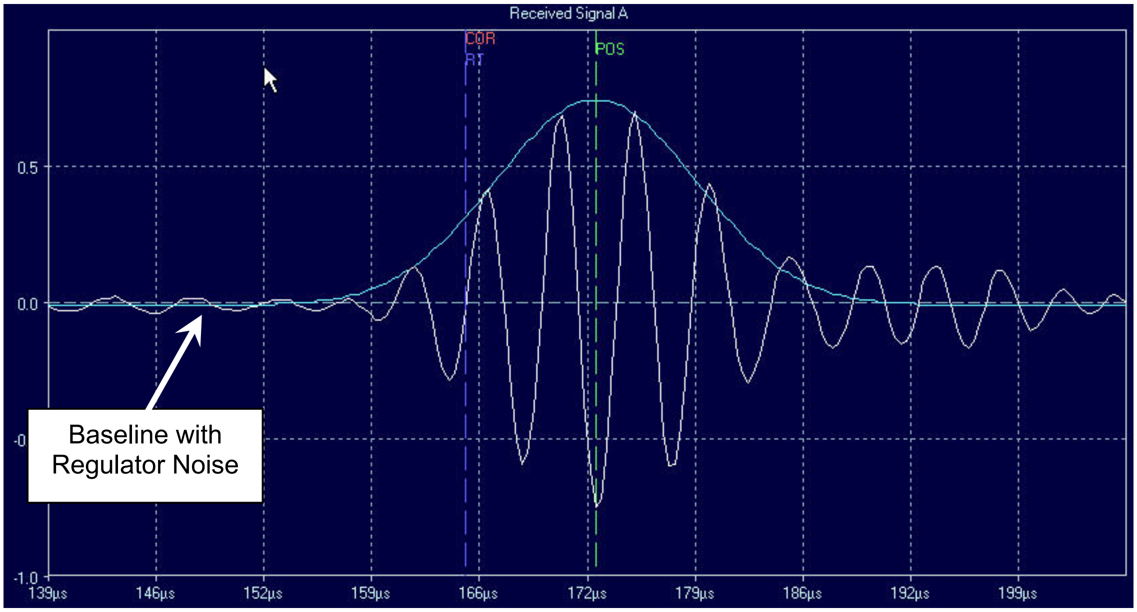

Figure 9 – Waveform with Control Valve Noise

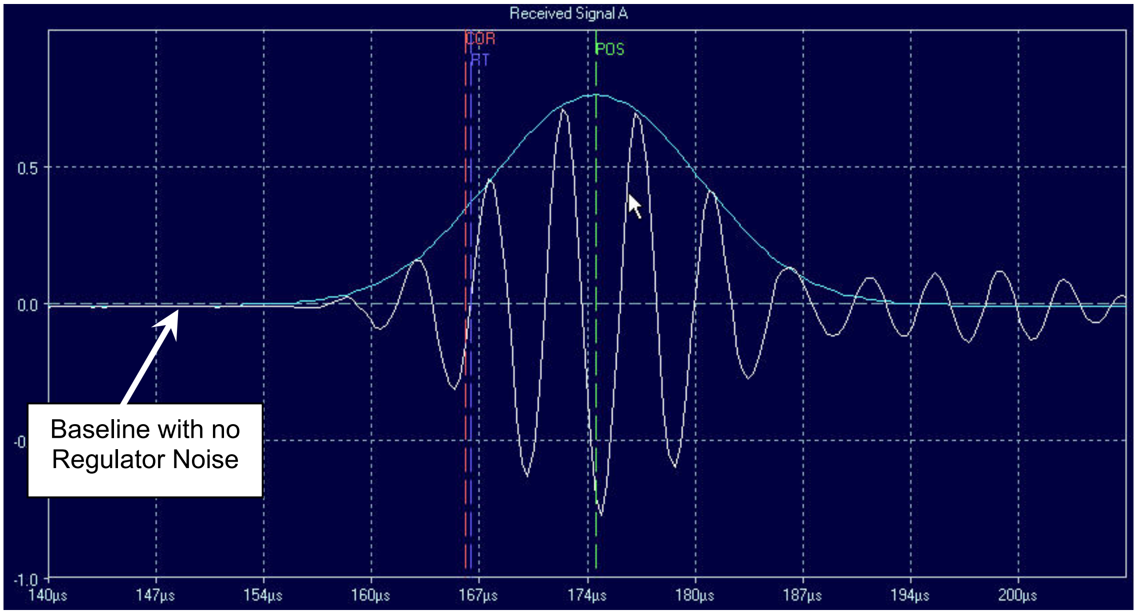

Figure 10 – Waveform with no Control Valve Noise

From Figure 9 we can see there is a little noise on the baseline preceding the major waveform. The baseline in front of the received signal is not perfectly flat as it is in Figure 10. The SNR values are above 24 dB for this condition on the upstream transducers (one that faces the source of the noise). The downstream transducer has a SNR of 30 because it is facing away from the noise source. Figure 10 shows the waveform when there is no noise from the regulator.

SNR can also be low if the electronics has a problem or there is a poor connection between the transducer and the electronics. Figure 11 shows the SNR graphed when there is a problem with the electronics.

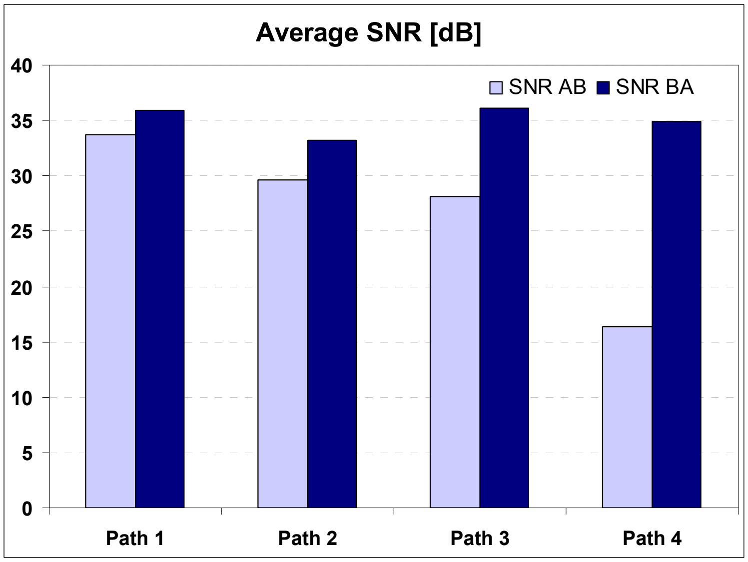

Figure 11 – Poor SNR on Path 4

Here we can see that the SNR from upstream to downstream is not consistent. All of the SNR values of AB are lower than BA. This is due to a problem with the electronics. Figure 12 shows the results of the same meter after the electronics was replaced.

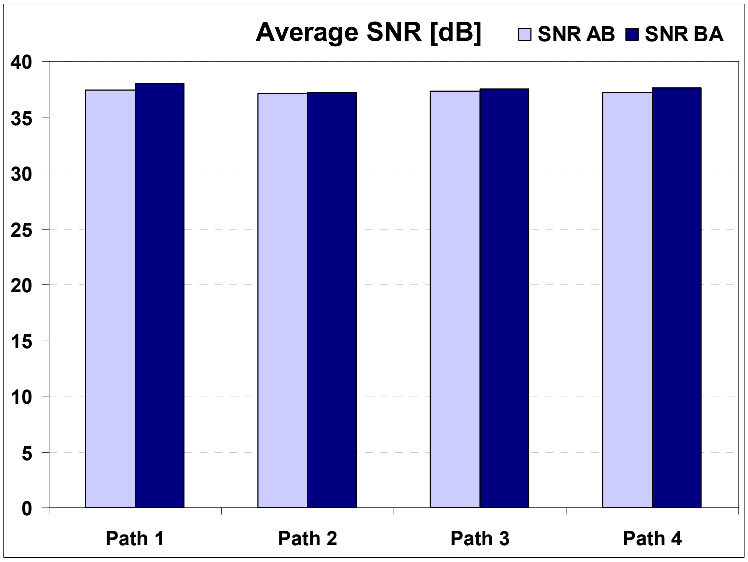

Figure 12 – Good SNR on all Paths

In Figure 12 we can see that all the SNR values are now close to 40 dB. This is the normal for this meter. Even though the SNR was poor in Figure 11, the meter's performance was still 98% and the gains were normal. Thus, it is possible to have low SNR and all other diagnostic indicators are normal.

Speed of Sound

Probably the most discussed and used diagnostic tool of an ultrasonic meter is the speed of sound (SOS). The reader may recall that speed of sound on an individual path is basically the sum of the transit times divided by their product, all then multiplied by one half of the path length. A more detailed discussion on this can be found in a previously presented paper [Ref 5].

There are at least two ways of looking at SOS. The first would be to compare each path's SOS to the average SOS calculated by the meter. Figure 13 shows a graph of the SOS of a 10-inch meter at the time of calibration.

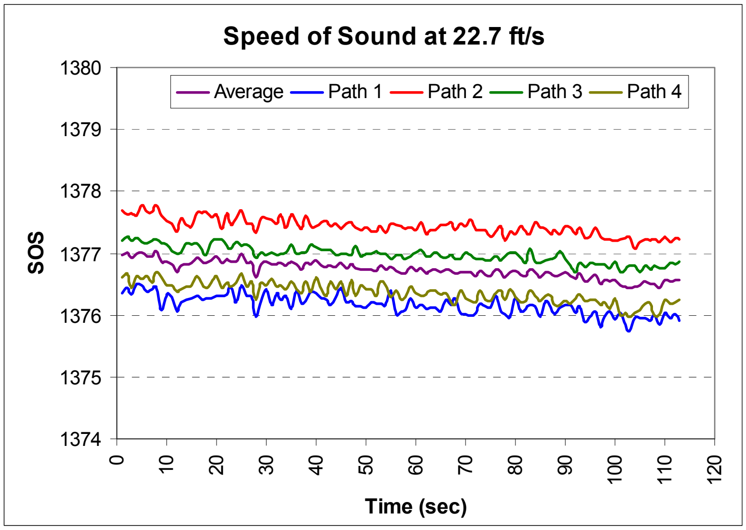

Figure 13 – SOS by Path at Calibration

This data was taken from the meter operating at 23 fps and showing a very stable reading. Here we can see all of the meter's SOS values are very close. But perhaps an easier way of looking at the SOS values is by comparing each paths SOS to the meter's average value. Doing this is makes it easier to spot problems.

Figure 14 shows the percent difference of each path relative to the meter's reported average SOS.

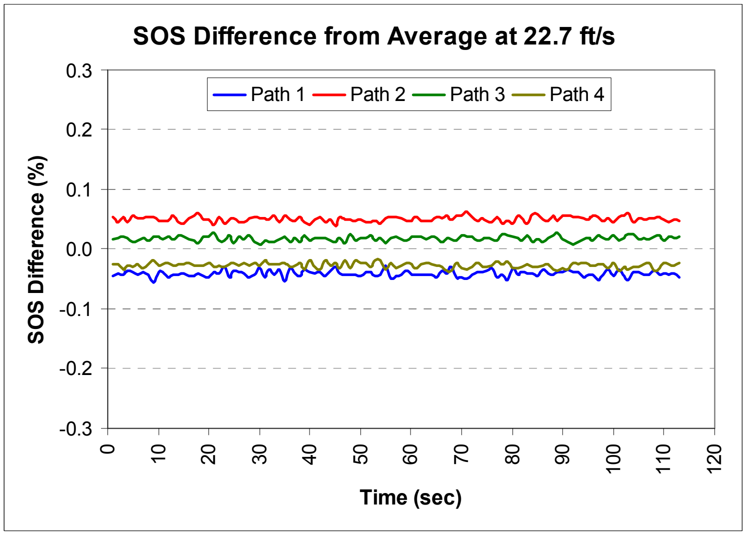

Figure 14 – Path Percent Difference in SOS

Figure 14 shows the SOS by path in percentage difference, relative to the meters' reported SOS. Each of the path's SOS value is within about is ±0.05%. This indicates good correlation between each path and also no temperature stratification within the meter.

When a meter is operated at lower velocities, typically less than 3 fps, and there is a large difference between the gas and atmospheric temperature, heat transfer can occur. As the heat transfer occurs, internal gas temperature gradients can develop (thermal stratification). When this happens the hotter gas inside the pipe rises to the top of the meter. Since the speed of sound in the gas is relatively sensitive to temperature, this will be seen as a SOS difference between the paths. This is often called thermal stratification.

Figure 15 shows the SOS values of the same 10-inch meter when it is operated at 1.8 fps at the calibration lab.

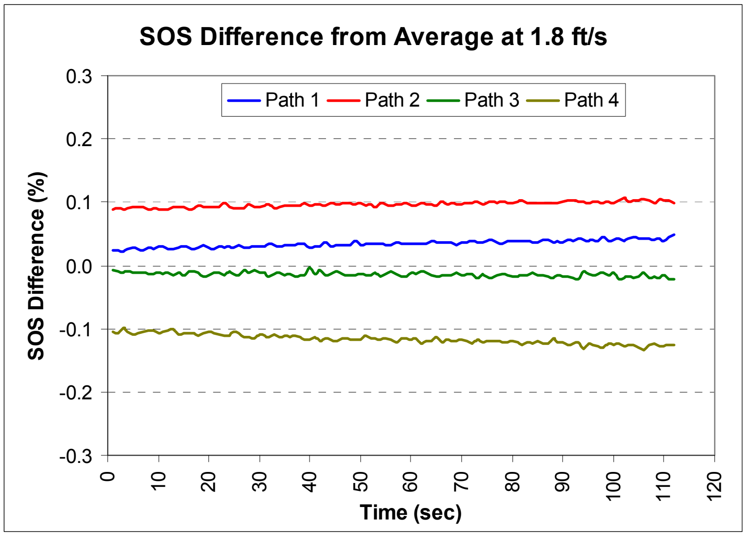

Figure 15 – Thermal Stratification Effects

From Figure 15 it can be seen that the average percent difference in SOS compared to the meter has increased a little. This is due to a slight thermal gradient within the meter. That is the gas at the top of the meter the gas is slightly warmer than that at the bottom. Path 1 color is blue, path 2 is red, path 3 is green and path 4 is gold in color. Figure 15 shows upper paths have increased and the ones at the bottom decreased.

This difference in SOS may be thought to impact the accuracy of the meter. In extreme cases this can occur. However, for this example the impact is virtually non-existent. Figure 16 shows the results of this 10-inch at the time of calibration.

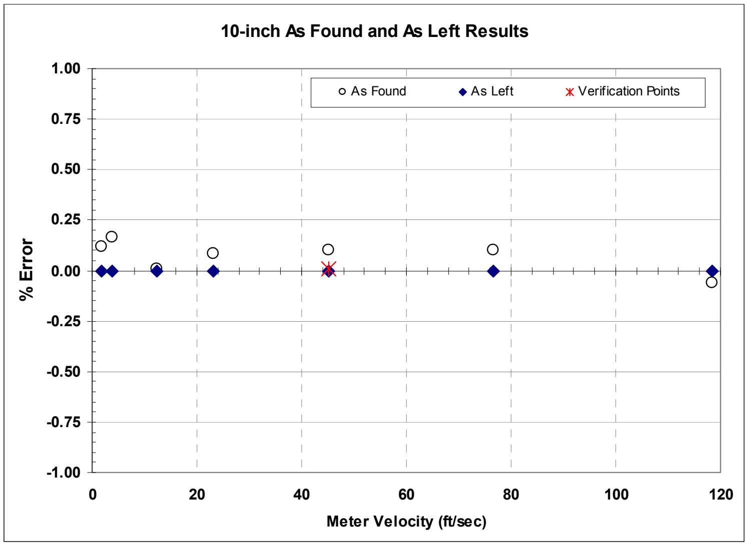

Figure 16 – 10-inch As-Found Calibration Performance

Note that the "as found" error at 20 fps is virtually the same as the "as found" at 1.8 fps. Thus there was very little impact in the performance of the meter even though there was some thermal stratification. The bigger question is "what is the true average gas temperature" since the location of the thermowell is a single-spot measurement?

Velocity Profile

Monitoring the velocity profile is possibly one of the most overlooked and under-used diagnostic tools of today's ultrasonic meter. It can provide many clues as to the condition of the metering system, as well as the meter. AGA Report No. 9 requires a multipath meter provide individual path velocities.

Once the USM is placed in service, it is important to collect a baseline (log file) of the meter. That is, record the path velocities over some reasonable operating range, if possible. These baseline logs can also be obtained at the time of calibration. However, as the piping in the field will likely be different than that at the calibration facility, there could be some minor changes in profile. 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 at a later date.

Figure 17 shows the velocity ratio of each path relative to the meter's average velocity. This ratio is computed by taking each path's average velocity during a period of time and dividing it by the average velocity reported by the meter over the same period of time. The ratio for each path remains essentially constant at all meter velocities. Thus changes in the meter's operation are easier to detect than by looking at the actual velocity on each path.

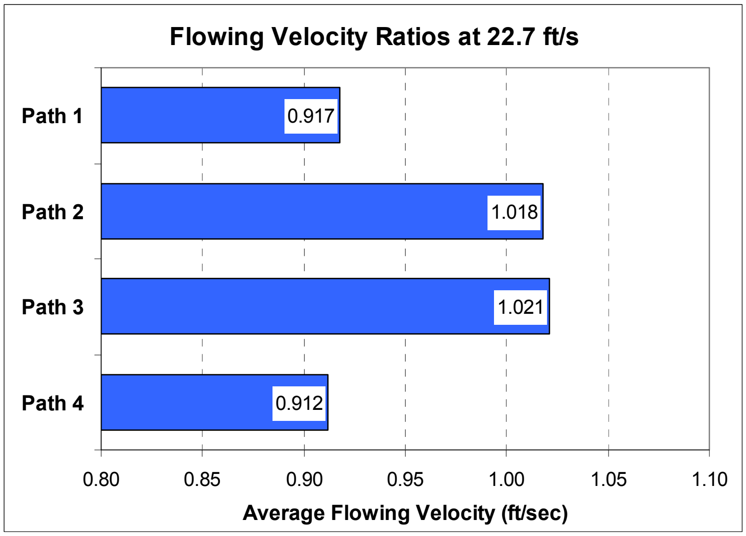

Figure 17 – Path Ratios at 23 fps

Typically the ratio for a chordal design meter is about 91% (ratio = 0.91) for paths 1 and 4, and about 102% (ratio = 1.02) for paths 2 and 3. The difference in ratios is due to the fact that the outer paths are closer to the pipe wall, and thus the velocity of the gas there is less than the gas that is closer to the center of the pipe. When the velocity falls below approximately 3 feet per second, depending upon meter size and station design, the velocity profile may change. Figure 18 shows the same meter's velocity profile when the velocity is at 2.8 fps.

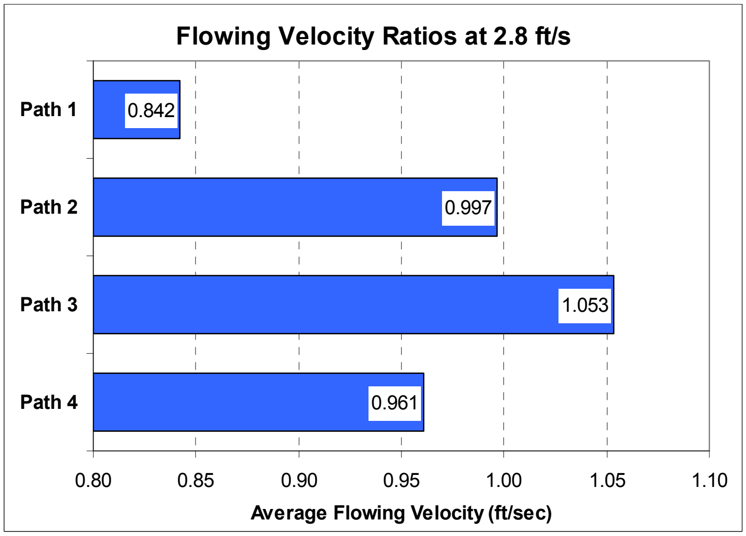

Figure 18 – Path Ratios at 2.8 fps

When comparing Figure 17 and 18 it is very clear that the velocity profiles are very different. Both of these were taken from a 16-inch meter at the time of calibration. Even with the difference in path ratios, the meter's performance was not impacted. Figure 19 shows the meter "as found" data from the calibration.

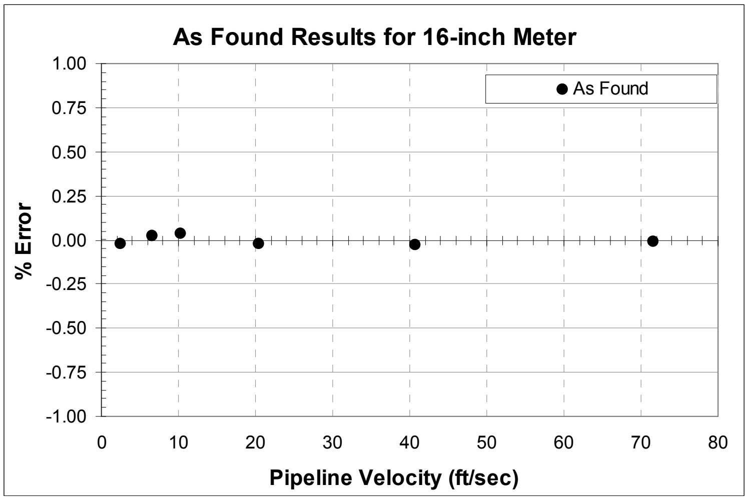

Figure 19 – 16 inch As-Found Results

Figure 19 shows the meters' linearity did not change even though path ratios were different as shown in Figures 17 and 18. This is the same meter discussed earlier that was calibrated to 155 fps, but the x-axis has been adjusted to better show the low velocity performance.

Figures 20 and 21 show velocity profiles for the 10-inch meter discussed earlier at 20 and 1.8 fps respectively. Figure 20 shows the baseline at about 23 fps and the velocity profile is very symmetrical. In Figure 21 the profile has become a little distorted. This is in part due to the minor thermal stratification. However, as figure 16 shows, there was very little impact on the meters' as-found linearity (open circles).

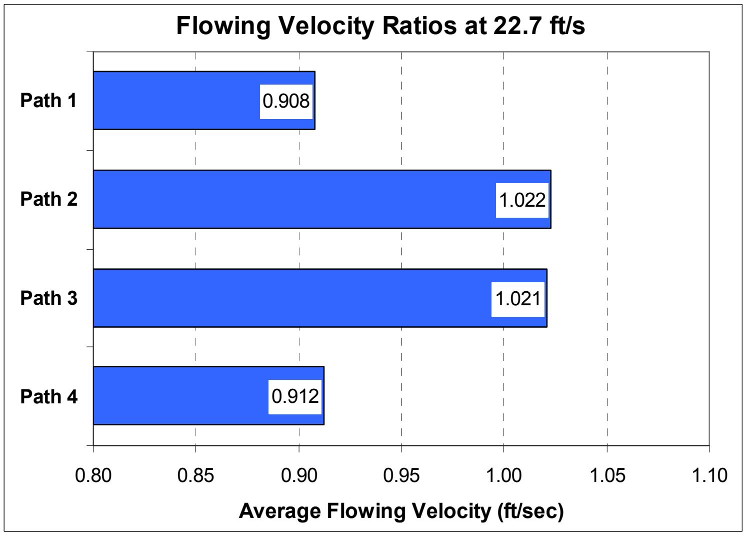

Figure 20 – 10-inch 20 fps Path Ratios

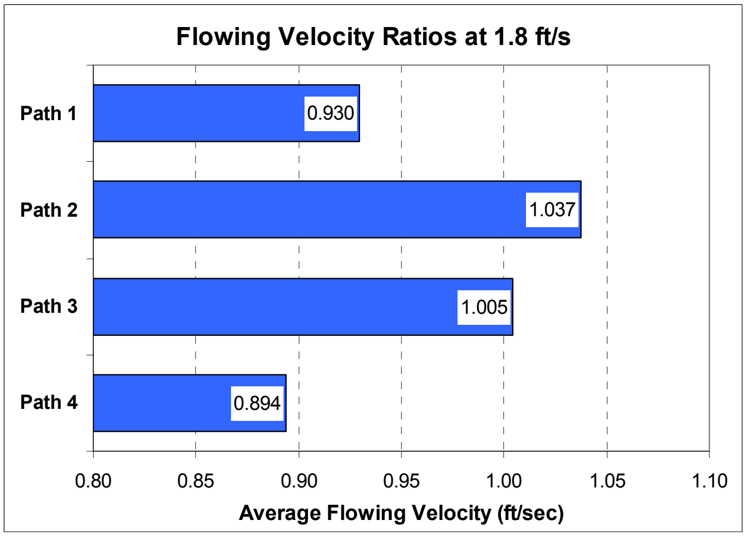

Figure 21 – 10-inch 1.8 fps Path Ratios

Even though this meter had some thermal stratification, the velocity profile didn't change significantly. There is a difference, but once again it is not as significant as the blocked flow conditioner example in Figure 26.

CONCLUSIONS

During the past several years the industry has learned a lot about USM operational issues. The traditional 5 diagnostic features, Gain, signal-to-noise (SNR), Performance, Path Velocities and Path SOS have helped the industry monitor the USMs' performance (accuracy). These 5 features provide a lot of information about the meter's health. Getting an initial baseline on the meter at the time of installation, and monitoring these features on a routine basis can generally identify metering problems in advance of failure.

The industry has learned a great deal more about how to benefit from USMs' diagnostics. Being able to identify when conditions change in the pipeline are one of the many key strengths of today's technology.

REFERENCES

1. AGA Report No. 9, *Measurement of Gas by Multipath Ultrasonic Meters*, April 2007, American Gas Association, 1515 Wilson Boulevard, Arlington, VA 22209
2. John Lansing, *Basics of Ultrasonic Flow Meters*, American School of Gas Measurement Technology, 2000, Houston, Texas
3. AGA Report No 10, *Speed of Sound in Natural Gas and Other Related Hydrocarbon Gases*, July 2002, American Gas Association, 1515 Wilson Boulevard, Arlington, VA 22209
4. BSI 7965:2000, Guide to the Selection, Installation, Operation & Calibration of Transit Time Ultrasonic Flowmeters for Industrial Gas Applications
5. Klaus Zanker, *Diagnostic Ability of the Daniel Four-Path Ultrasonic Flow Meter*, Southeast Asia Flow Measurement Workshop, 2003, Kuala Lumpur, Malaysia
6. John Lansing, *How Today's USM diagnostics Solve Metering Problems*, North Sea Flow Measurement Workshop, 2005, Tonsberg, Norway