OPERATION AND MAINTENANCE CONSIDERATIONS FOR ULTRASONIC METERS

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ABSTRACT

This paper discusses both basic and advanced diagnostic features of gas ultrasonic meters (USM), and how capabilities built into today's electronics can identify problems that often may not have been identified 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 is based upon the Westinghouse configuration (also knows as a chordal design) and the information presented here may or may not be applicable to other manufacturers.

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 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.

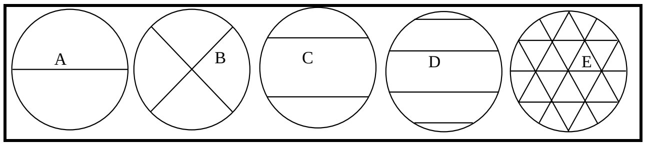


Figure 1 – Ultrasonic Meter Designs

BASIC DIAGNOSTIC INDICATORS

One of the principal attributes of modern ultrasonic meters is the ability to 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 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' measured 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.

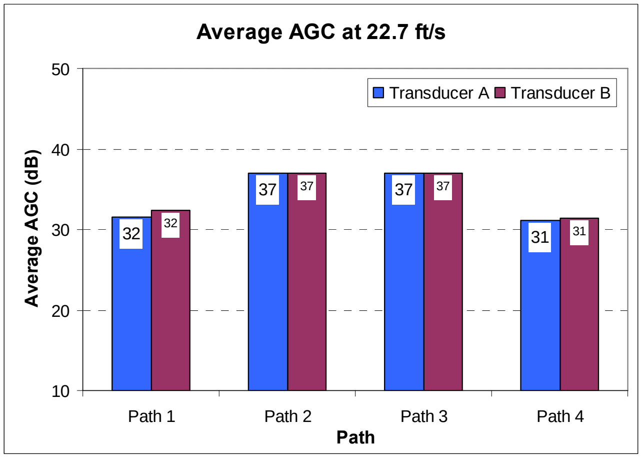


Figure 2 – Gain at 20 fps – 16 inch Meter

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.

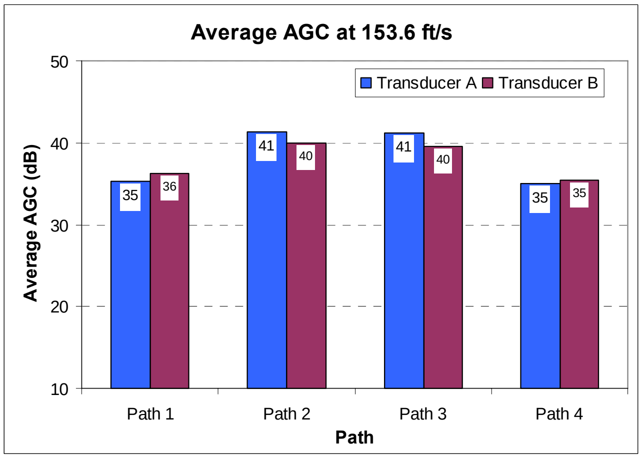


Figure 3 – Gain at 155 fps – 16 inch Meter

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. However, notice both graphs have the same look in that the center pairs have higher gains than the outer ones. Again, this is due to the longer path length.

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 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. Unless there are other influencing factors, the meter will normally operate at 100% performance until it reaches the upper limit of the 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 drop from 100% to something less.

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

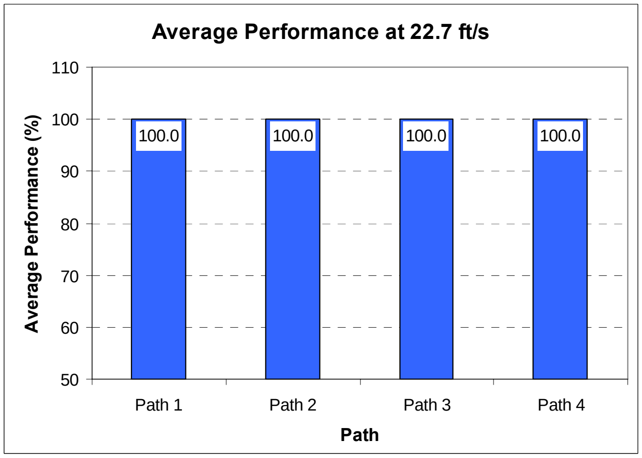


Figure 4 – Transducer Performance at 20 fps

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 for high velocities as signal distortion will have some impact on waveforms at these high velocities.

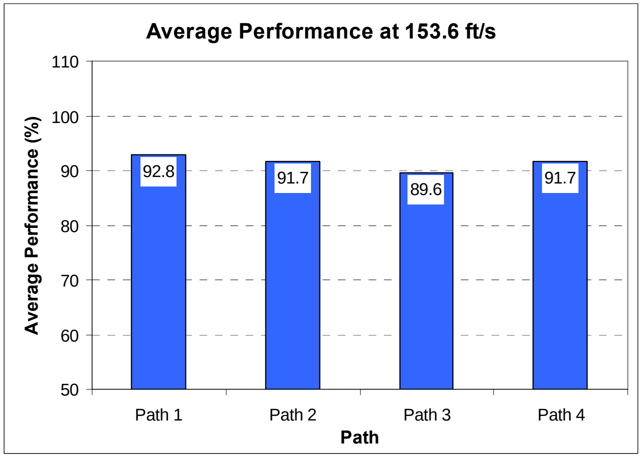


Figure 5 – Transducer Performance at 155 fps

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, 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.

The measure of signal strength to the level of "background" noise is called the Signal to Noise Ratio, or SNR for short. Typically this is not monitored nearly as often 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.

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.

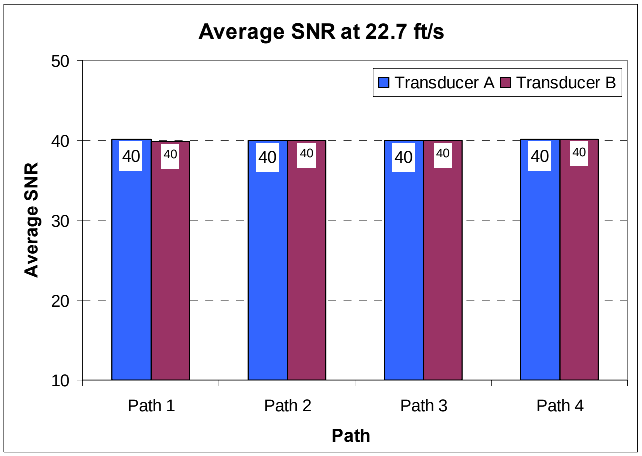


Figure 6 – SNR at 20 fps Meter Velocity

Figure 7 show the same meter at about 155 fps. The SNR values have decreased by about 5-15 dB, depending upon whether they are upstream or downstream. This is due to ultrasonic noise being generated inside the piping. As the downstream transducers face the upstream direction, the increased level of noise has more impact on the downstream transducers. 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.

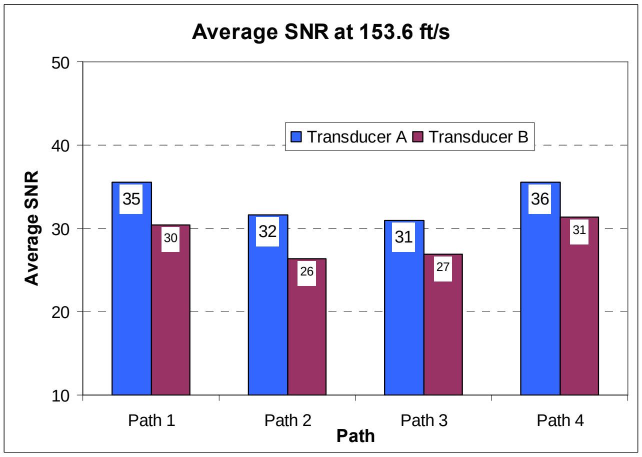


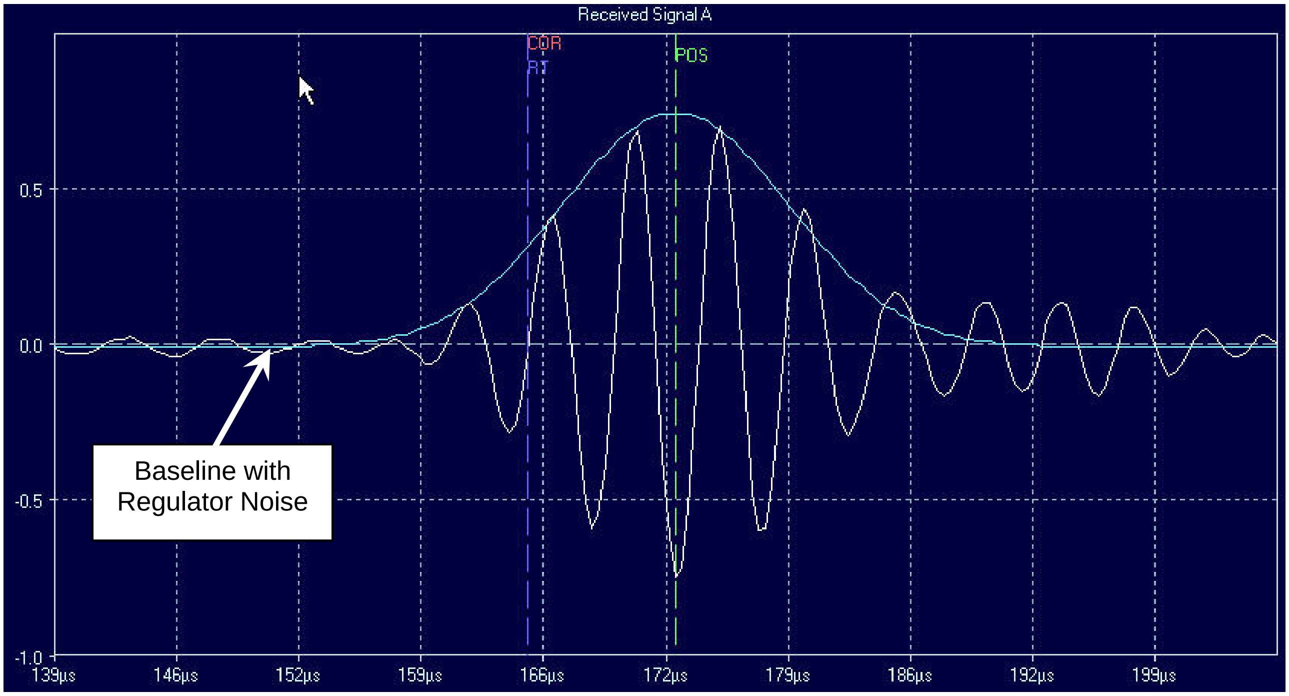
Figure 7 – SNR at 155 fps Meter Velocity

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.

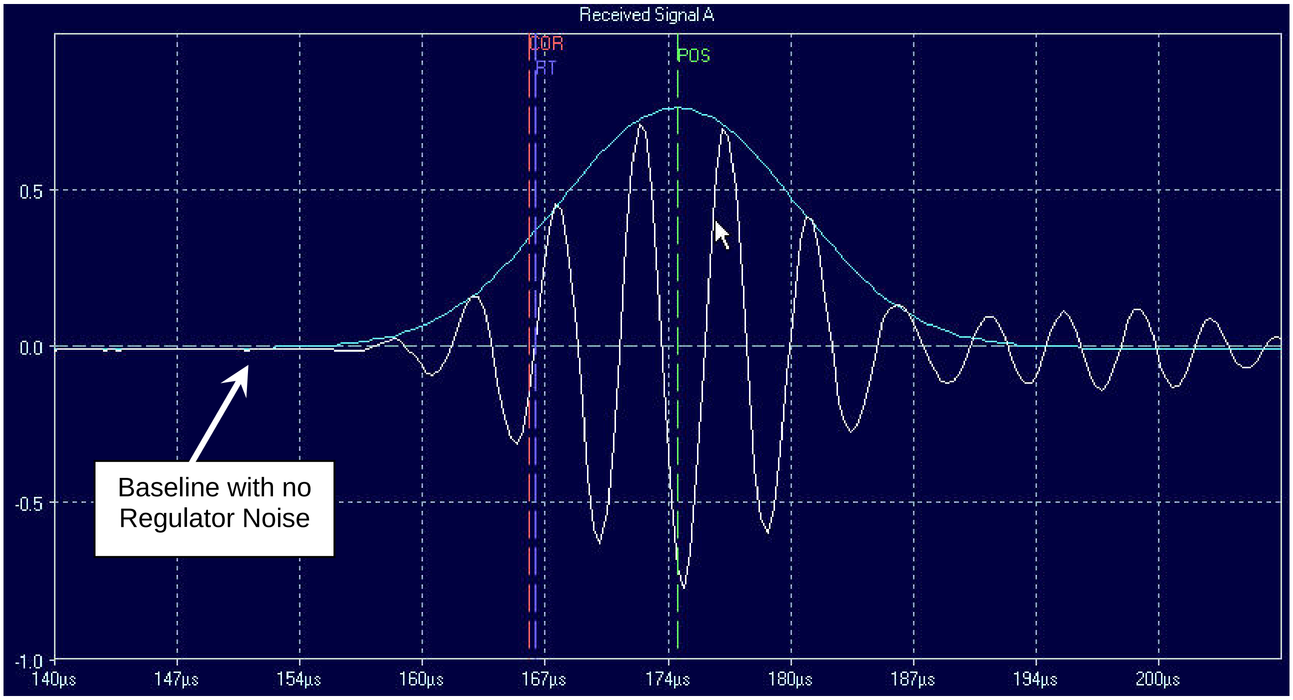
Figure 8 – Control Valve near 2-inch USM

In the test shown in Figure 8, the meter was being operated at 600 psig and the regulator was producing about 200 psig differential. 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.



Baseline with Regulator Noise

Figure 9 – Waveform with Control Valve Noise



Baseline with no Regulator 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.

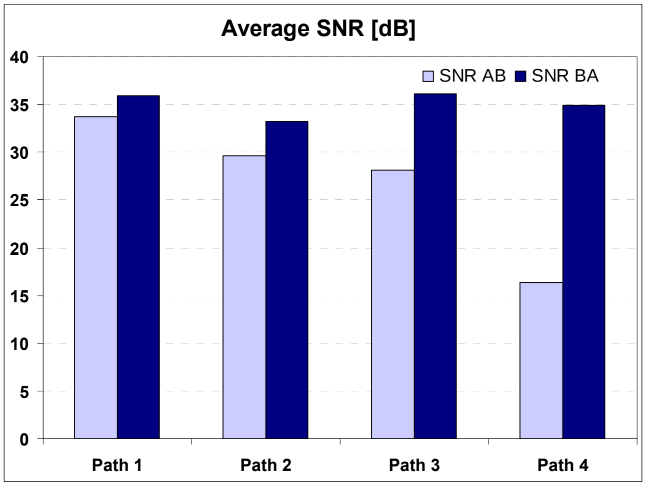


Figure 11 – Poor SNR on Path 4

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.

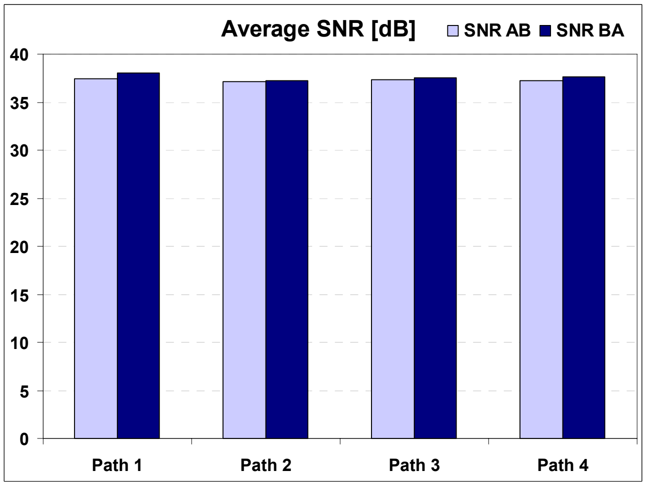


Figure 12 – Good SNR on all Paths

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 be normal.

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 13 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 as reported by the meter over the same period of time. Since the ratio for each path remains essentially constant at all meter velocities, changes in the meter's operation are easier to detect than by looking at the actual velocity on each path.

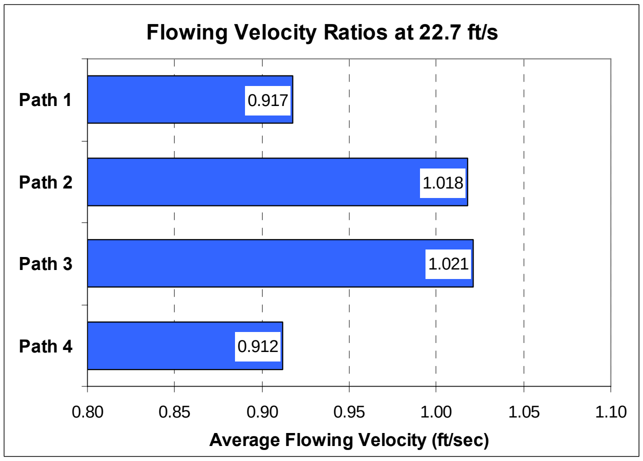


Figure 13 – Path Ratios at 23 fps

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 14 shows the same meter's velocity profile when the velocity is at 2.8 fps.

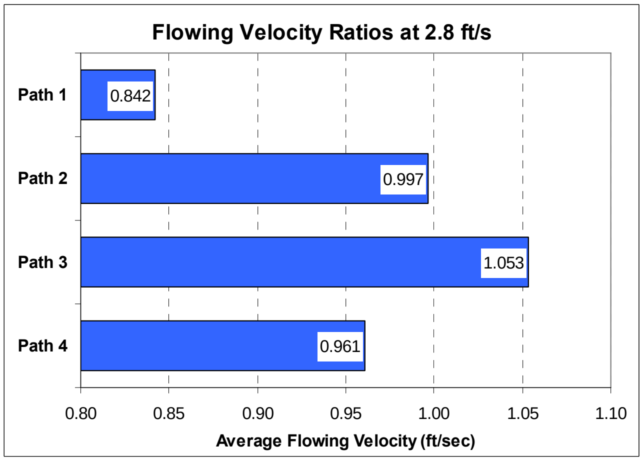


Figure 14 – Path Ratios at 2.8 fps

When comparing Figure 13 and 14 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 15 shows the meter "as found" data from the calibration.

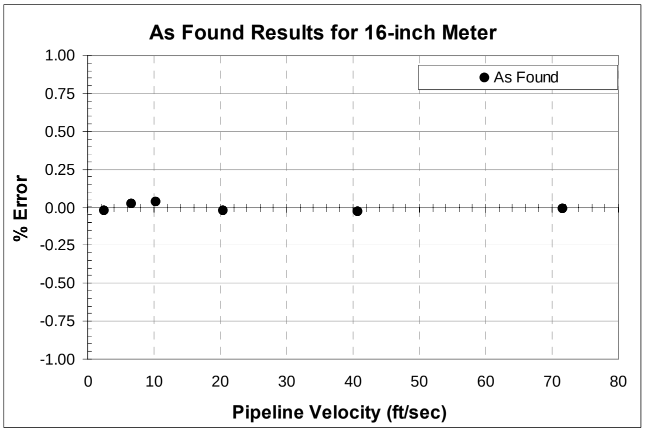


Figure 15 – 16 inch Performance

Figure 15 shows the meter's linearity did not change even though path ratios were different as shown in Figures 13 and 14. 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 end performance.

Looking at four path ratios takes understanding why the velocities are different. Since these can change by small amounts, a simpler method of identifying changes in profile is desired. A single value would be much easier to understand, and also easier to quickly analyze. This value is called Profile Factor.

The Profile Factor is computed by adding the velocity ratios of paths 2 and 3 together and dividing by the sum of the ratio of paths 1 and 4. The equation looks like this: Profile Factor = (2 + 3)/(1 + 4). Assuming that paths 1 and 4 are 0.91 and the path 2 & 3 values are

1.02 the Profile Factor is about 1.12. This value does vary a little from meter to meter due to piping installation effects and to some degree the type of flow conditioner and its distance from the meter.

Another method used to analyze path velocities is to compare the sum of paths 1 & 2 to the sum of paths 3 & 4. This provides a look at the symmetry of the profile from top to bottom. Normally the meter's path velocities will be very symmetrical resulting in a value close to 1.000. Figures 13 and 14 show both the Profile and the Symmetry

In Figure 16, when the meter was flowing at 20 fps, the Profile Factor was 1.115. As the velocity dropped to 2.8 fps (Figure 17) the Profile Factor changed to 1.137. This is about a 2% change in profile when comparing the middle paths to the outer paths.

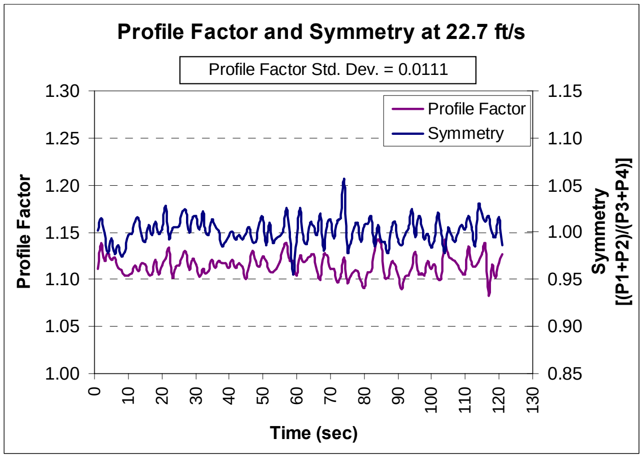


Figure 16 – Profile Factor and Symmetry at 20 fps

The other diagnostic worth reviewing is the Symmetry value. Figure 14 shows a significant change (on the order of 10%) in the Symmetry at the lower velocities, but again there was no significant impact on meter performance. This just indicates there was a change in the meter's profile.

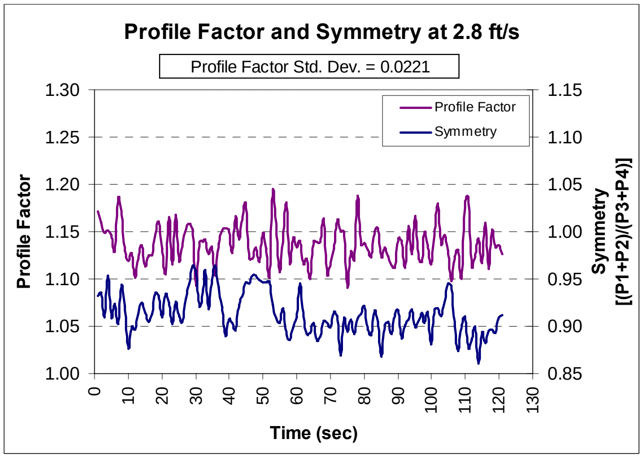


Figure 17 – Profile Factor and Symmetry at 3 fps

The Profile Factor can be a valuable indicator of abnormal flow conditions. The previous discussion showed what happens to the Profile Factor and Symmetry due to low velocity operation. This profile change is typical when the meter is operated at lower velocities.

Figure 18 shows an ideal profile from a 12-inch meter. This was based on the log file collected at the time of calibration. Users have often asked what impact partial blockage of a flow conditioner has on the meter's accuracy. This meter was used to show what happens not only to the profile, but to quantify the change in accuracy.

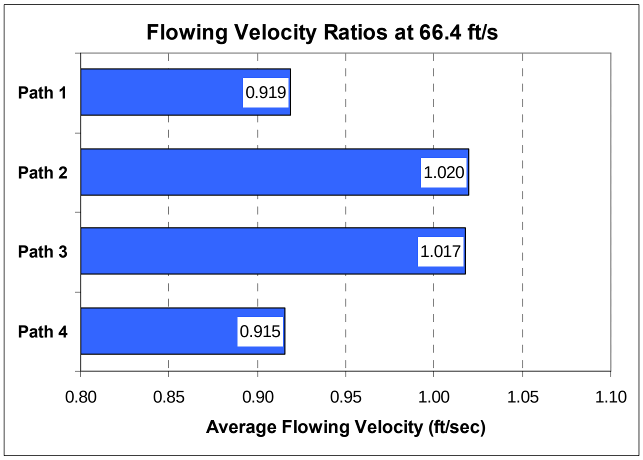


Figure 18 –12-Inch Meter Profile – Normal

The Profile Factor for this meter is 1.118. For the second test, the flow conditioner was modified to have about 40% of the holes blocked with duct tape. Duct tape was used to ensure repeatability. Figure 19 shows the flow conditioner just before it was installed in the pipeline.

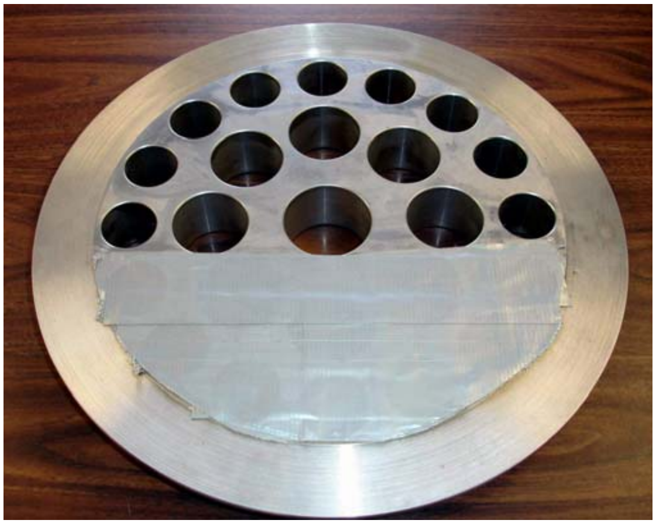


Figure 19 – 40% Blocked Flow Conditioner

Figure 20 shows the velocity ratios during the time the flow conditioner was blocked. This was taken at a velocity of 66 fps. The profile at two other velocities, 22 and 45 fps, looked the same.

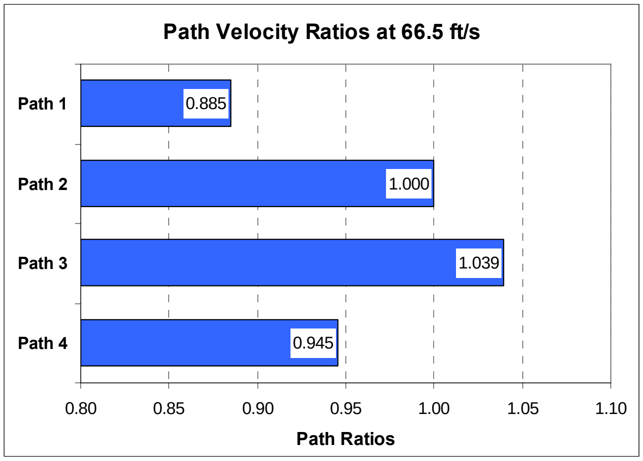


Figure 20 – 12-inch Meter Profile – Blocked

The Profile is obviously distorted with higher-than-normal readings on path 3 and 4, and lower than normal on paths 1 and 2. The flow conditioner was installed with the blockage at the bottom of the pipe. As the gas flowed through the open holes, there was a low-pressure created just downstream of the blocked area causing the gas to then accelerate downward, thus causing the higher velocity at the bottom of the meter.

The Profile Factor for this 12-inch meter, as determined from Figure 20, is 1.061. This difference doesn't seem like much, but it certainly indicates a significant change in profile. After installation in the field a meter typically will generate a Profile Factor that is repeatable to ±0.02. However, this does depend upon the piping, and makes the assumption that there are no other changes like flow conditioner blockage.

The next question is what was the impact on accuracy with this distorted velocity profile? Figure 21 shows the result of the three test velocities and the impact on metering accuracy.

Baseline vs. 40% Blocked CPA	
Velocity (fps)	% Diff. with Blocked CPA
68.4	**-0.02**
45.3	**-0.12**
22.9	**-0.10**

Figure 21 – Blocked CPA Results

As can be seen the meter was affected by an average of about 0.15% for all flow rates. In this case the meter slightly under-registered with this distorted profile. Later in this paper a more advanced diagnostic feature will also show the meter has blockage, but for now one can see the Profile Factor has indicated a significant change.

In the past many have thought that looking at the Profile Factor alone would be a good indication if there was any contamination or flow conditioner blockage. This may not always be true. Figure 22 shows a picture of a flow conditioner with 3 holes blocked at the bottom.

Figure 22 – 3 Holes Blocked Flow Conditioner

In this test the three blocked holes in the flow conditioner were located at the bottom of the meter run. This is the same 12-inch meter and testing as discussed with the 40% blockage. Figure 23 shows a graph of the Path Ratios during this test.

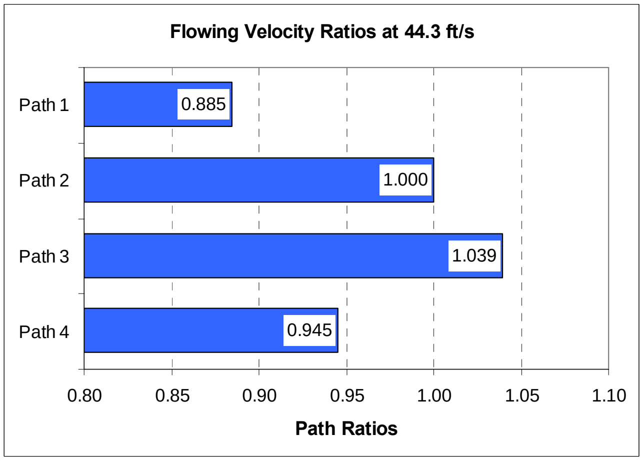


Figure 23 – Path Ratios with 3 Holes Blocked

When we compare Figure 23 with Figure 18 (the normal Path Ratio profile) it is obvious that the two do not look the same. However, when computing the Profile Factor, the average value for Figure 23 is 1.114. This is almost the perfect number for this meter.

Upon further inspection we see in Figure 24 that the Symmetry is not correct.

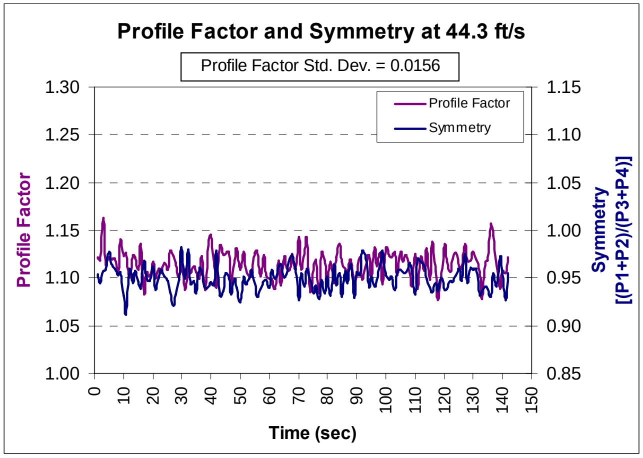


Figure 24 – Profile Factor and Symmetry at 40 fps

In Figure 24 we see the average for the Profile Factor is 1.114 and almost normal, but that the Symmetry value average is 0.95, or about a 5% shift from normal. Thus it is possible for the Profile Factor to be normal, when the velocity profile in the meter is not. The combination of Profile Factor and Symmetry are needed to fully analyze the velocity profile entering the meter.

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 2 ways of looking at SOS. The first would be to compare each path's SOS to the average SOS calculated by the meter. Figure 25 shows a graph of the SOS of a 10 inch meter at the time of calibration.

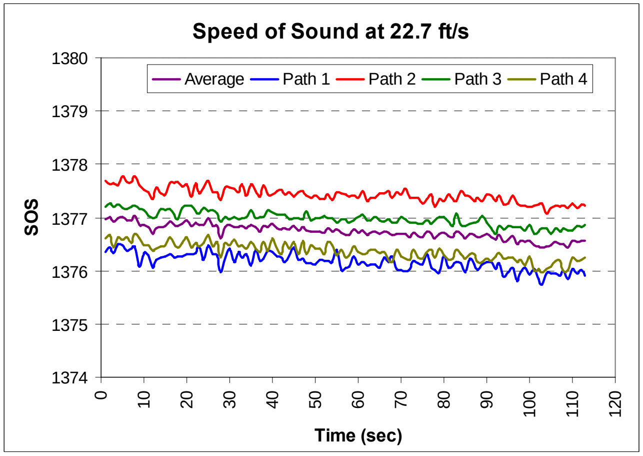


Figure 25 – SOS by Path at Calibration

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

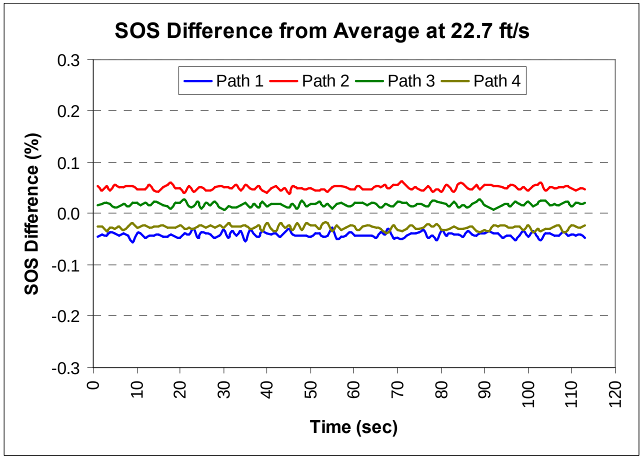


Figure 26 – Path Percent Difference in SOS

Here the difference, in percentage, of each of the path's SOS values is within about 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 temperature gradients can develop. 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 27 shows the SOS values of the same 10 inch meter when it is operated at 1.8 fps at the calibration lab.

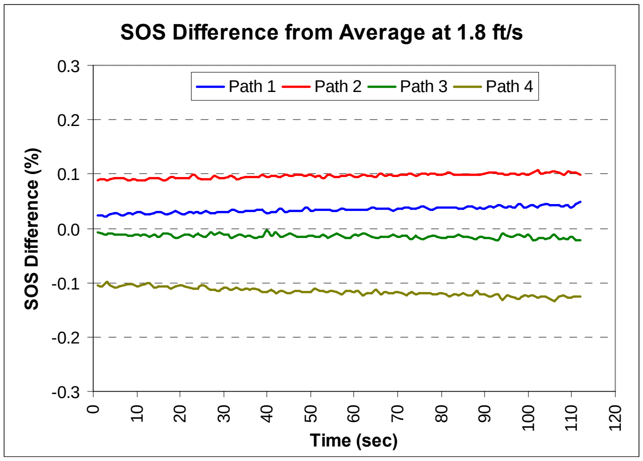


Figure 27 – Thermal Stratification Effects

From Figure 27 we can see 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 is hotter 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 27 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 be the case. However, for this example the impact is virtually on-existent. Figure 28 shows the results of this 10-inch at the time of calibration.

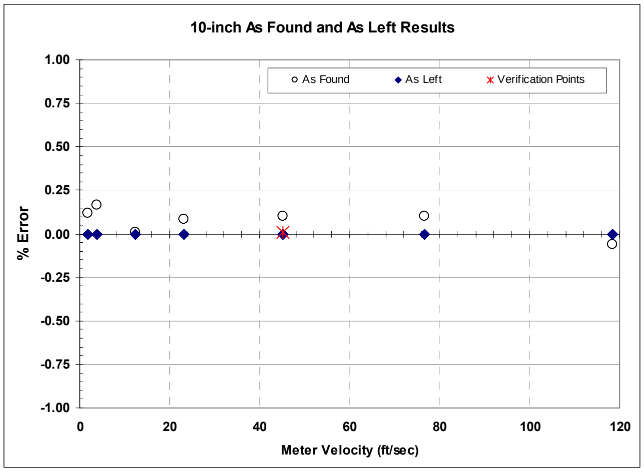


Figure 28 – 10-inch Low-Flow Error

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.

Figures 29 and 30 show profiles for this same 10-inch meter at 20 and 1.8 fps respectively.

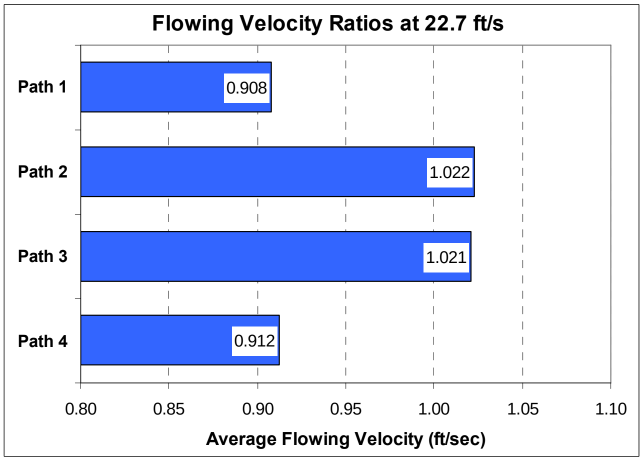


Figure 29 – 10-inch 20 fps Path Ratios

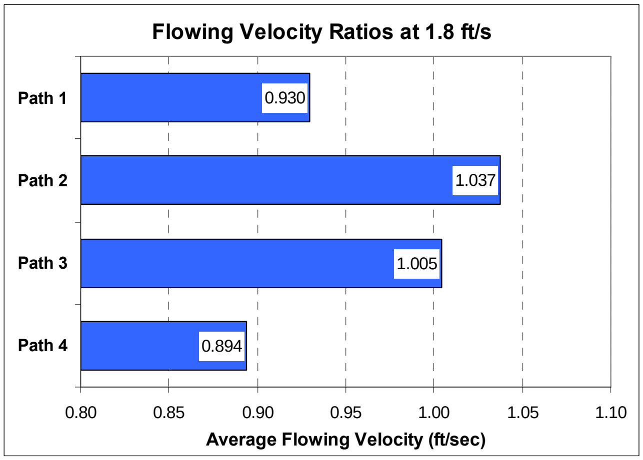


Figure 30 – 10-inch 1.8 fps Path Ratios

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 20.

ADVANCED DIAGNOSTIC INDICATORS

During the past several years an additional diagnostic feature has been studied by Engineering. This feature, called “Turbulence,” is discussed thoroughly in a previous paper [Ref 6]. Essentially Turbulence is a measure of the variability of each path’s velocity readings during the time the meter was sampling, and is provided each time it updates the velocity information. This gives the technician an idea of the steadiness of the flow as seen by the meter.

Typically the level of turbulence on a Westinghouse design shows paths 1 and 4 to have around 4% turbulence, and paths 2 and 3 around 2%. This is based upon the history of many meters. The outer paths 1 and 4, being closer to the pipe wall, always exhibit higher turbulence because they are more affected by the surface friction of the upstream piping.

Turbulence can be computed from the maintenance log file for older meters. With the advent of more advanced electronics, it is now computed real-time in the meter and reported on the maintenance log files. This greatly reduces the time for analysis since it is not only stored in the log file, it is graphed out automatically for quick review.

Recently viewing Turbulence has solved several metering problems. Distorted velocity profiles often cause concern about metering accuracy. If the velocity profile, as shown in Figure 18, now appears like that in Figure 20, the cause needs to be determined. Some might feel this is just due to upstream affects and may not believe there is any object blocking the flow conditioner.

The 12-inch meter in Figure 31 shows a very consistent level of Turbulence during the period of the test. It was collected at the time of calibration and the velocity was about 66 fps.

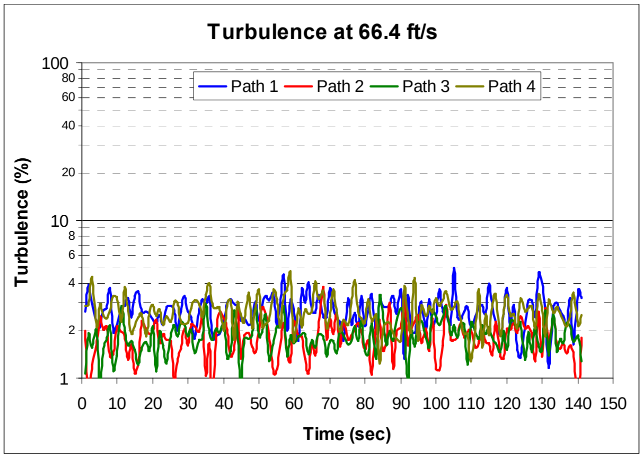


Figure 31 – Normal 12-inch Meter Turbulence

Figure 32 is the same meter with a blocked flow conditioner as shown in Figure 16.

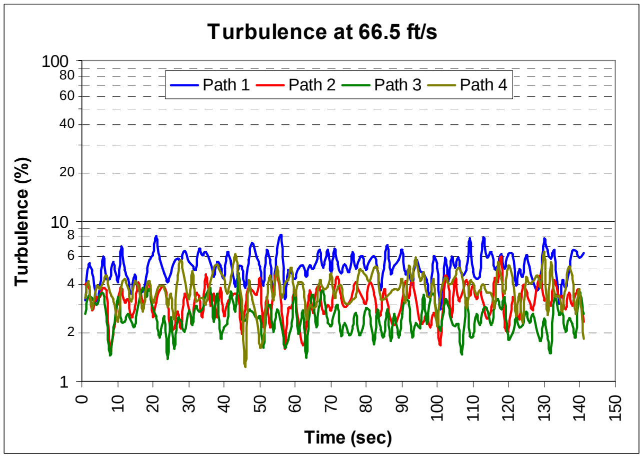


Figure 32 – High 12-inch Meter Turbulence

It is clear that the turbulence in Figure 32 is about 3 times higher. Certainly the velocity profiles for this meter, shown in Figures 18 and 20, look different. Anyone looking at the blocked profile would immediately recognize there is a problem. It is possible, however, to have a complete blockage of a flow conditioner with something like a porous bag and have a relatively symmetrical profile. In this situation the turbulence would be excessive, indicating there is a problem with blockage. This has been observed in the field and without Turbulence it would have gone un-detected.

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, performance, path velocities and SOS have helped the industry monitor the USM. 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.

More advanced diagnostic indicators, such as Turbulence, are paving the way to allow the meter to become virtually maintenance-free. In the future it is likely that a meter will have enough power and intelligence to quickly identify potential measurement problems on a real-time basis.

As the industry learns more about not only the USM, and the operation of their own measurement system, the true value of the ultrasonic meter will be recognized. The USM industry is still relatively young and technology will continue to provide more tools to help solve today’s measurement problems.

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