HOW TODAY'S USM DIAGNOSTICS SOLVE METERING PROBLEMS

JOHN LANSING, Manager, Gas Ultrasonics, Daniel Measurement & Control

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. 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 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 Daniel USM 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 manufacturers' of USMs.

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 that the analysis does vary by manufacturer.

In addition some manufacturers provide additional diagnostics such as swirl angle, turbulence, AGA 10 [Ref 3] SOS vs. the meter's reported SOS, and many others.

This paper will go into more detail on all of the above features and more. It is important to understand that the meters being analyzed in this paper are of the chordal design, and therefore some of the analysis would not apply to other designs.

Graphs shown in this paper are from Excel spreadsheets and were automatically generated by Daniel's CUI (Customer Ultrasonic Interface) software that is used to communicate with the meter. Note that these graphs were not individually developed but rather automatically generated while collecting a "Maintenance Log," or by using a feature called "Trending."

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.

Looking at a single inspection, which may be done either monthly or quarterly, can give the user an indication of the meter's health. However, to truly monitor how a meter is doing over the long-term, a method needs to be employed that "trends" key variables. This is important since many diagnostics change slowly over time. Trending helps identify these changes and makes problems much more obvious than merely viewing a single inspection report.

ULTRASONIC BASIC DESIGNS

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]. As one can see the methods differ and thus responses to different velocity profiles may also differ. This is particularly true when trying to perform comparisons on velocity and SOS. The various meter configurations in Figure 1 provide different velocity responses to profiles, and are thus analyzed differently. Additionally, looking at differences in SOS between the various paths will require analysis somewhat differently. Analysis in this paper will be of design D in Figure 1.

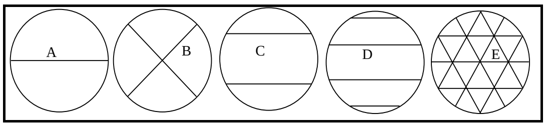


Figure 1 - Ultrasonic Meter Designs

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 using gas composition to compute the gases SOS and comparing it to the meter.

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. Any 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 how gains change with velocity. This example was taken at the time of calibration for a 16-inch meter. A log file was generated for each velocity during the calibration. By using software that "trends" specific features, a summary of gains (left axis) vs. velocity (right axis) can be very easily developed. As can bee seen on the graph this meter was calibrated from 26 to 0.15 m/s.

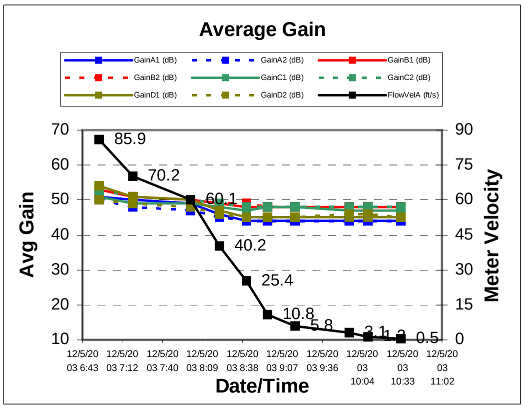


Figure 2 – Gain Changes with Velocity

Figure 2 shows that all chord gains increased about 6 dB, or in other words about doubled at the higher velocities. This is normal since the signal becomes somewhat attenuated by the higher velocity. Thus, in looking at gains alone one should also consider velocity changes when comparing to the gains noted on previous logs.

If this meter was operating at 750 Bar, and then the pressure was reduced to 375 Bar, the gain change would be about the same as this example. Since most pipelines don't typically experience this type of pressure change, generally speaking gain changes will be from velocity or perhaps a transducer contamination.

Figure 3 is an example of a transducer that is failing. This graph was generated from several CUI log files. An Excel file was developed by combining several periodic maintenance logs into several trended graphs. It is clear that chord D has increasing gains far greater than the others. The increase of all transducers about mid-way in time was due to the velocity increasing, and that can be seen on a separate graph in the maintenance log.

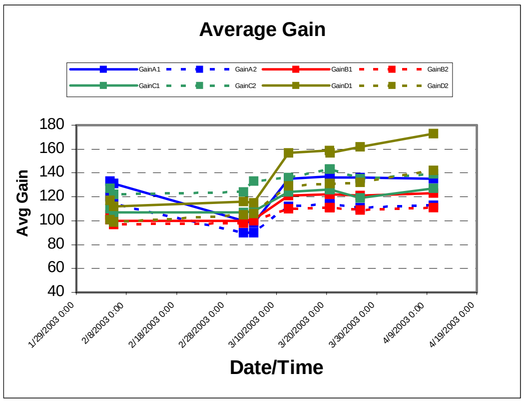


Figure 3 – Gain Increasing on One Chord

This meter had velocities that were typically around 12 m/s and then the operation changed and the meter velocity approached 18 m/s, resulting in the increased gain on all paths. However, Chord D indicated a significantly higher increase in the gain, and then continued to increase while the other chords maintained a relatively stable gain level.

Some may feel the meter's accuracy could be affected with this type of gain increase. In actuality as long as the transit times are being measured correctly then there is virtually no impact on accuracy. By trending gains this customer identified a meter problem before failure, thus avoiding any possible downtime.

Figure 4 shows gains graphed for each transducer during a routine inspection. As can be seen they are relatively consistent. Knowing what is normal for a given meter is more difficult for a technician to keep track because each meter may have somewhat different characteristics due to size and metering pressure. It is important to collect routine maintenance log files, like that shown in Figure 4, so that it's possible to develop the trending graph in Figure 3.

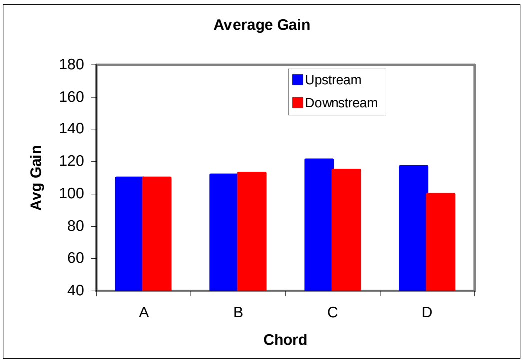


Figure 4 –Transducer Gains - Normal

Figure 5 shows a graph of a meter with a transducer problem. In this case it is quite obvious since the gain levels on chord D are double those of the other chords. The benefit of trending log files to identify gain changes is valuable since it helps identify a potential problem before it becomes significant, allowing the user to be proactive in dealing with the problem rather than reactive.

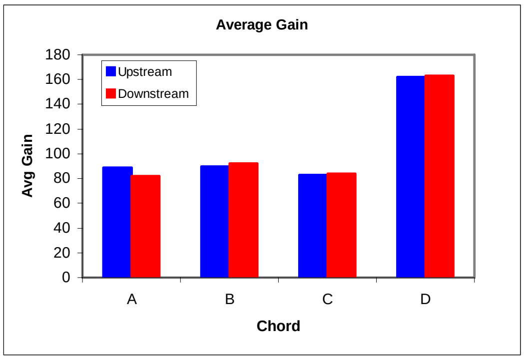


Figure 5 – Transducer Gains - Abnormal

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 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 otherwise the received pulse does not meet certain criteria established by the manufacturer. When this happens the electronics rejects the pulse rather than use something that might distort the results.

The level of acceptance (or rejection) for each path is generally considered as a measure of performance, and is often referred to as signal quality. Unless there are other influencing factors, the meter will normally operate at 100% transducer 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 within the specified tolerance. At this point the meter's performance will drop from 100% to something less.

Typically this will occur on the outer chords (A&D) for the British Gas design meter. Even though the paths are shorter, the chord position is closer to the wall, and thus there is more distortion in the received waveform.

Figure 6 shows the performance of a meter, taken from data obtained during a calibration, and then trended to show what happens at higher velocity.

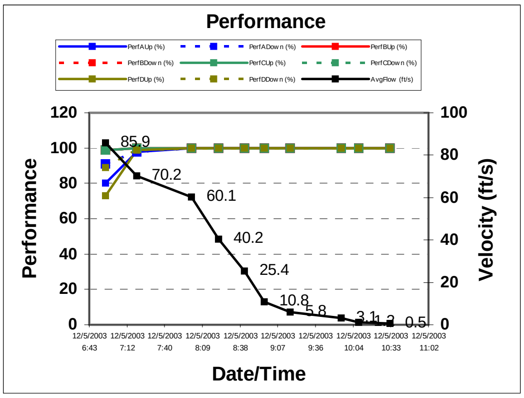


Figure 6 – Performance vs. Velocity

Figure 7 shows the results of a maintenance log file where all transducers are operating at 100% performance. This is what one would expect unless the meter is near maximum velocity.

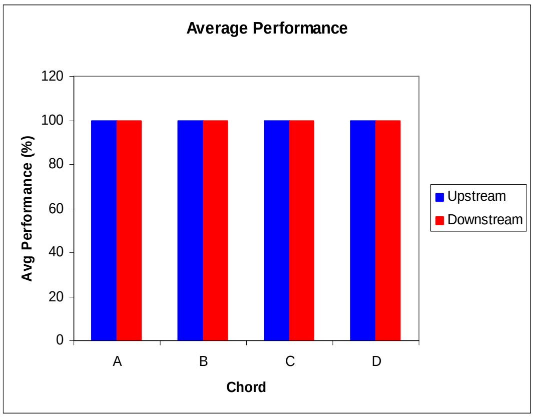


Figure 7 –Transducer Performance Summary

Figure 8 shows the summary from a maintenance log file where Chord D is running less than 100% while all others are at 100%. Although the meter is still most likely operating accurately, this is an indication additional attention is needed to address a problem that may be developing.

As mentioned above, there are several reasons why pulses can be rejected. Additional causes may include extraneous ultrasonic noise in the same region the transducer operates, distorted waveforms caused by excessive gas velocity, and to some degree, contamination on the face of the transducer.

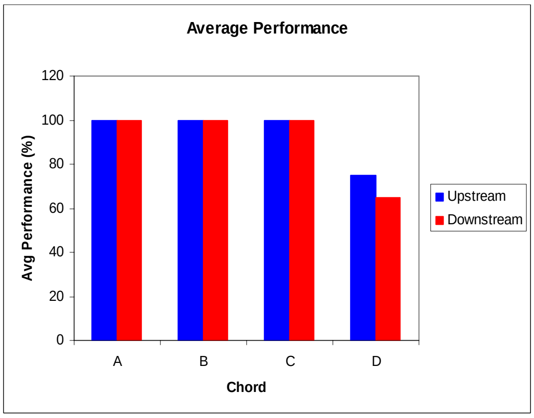


Figure 8 – Transducer Performance Summary

In the example show in Figure 8, the cause can be from a transducer that is either beginning to fail, or it could be from contamination in front of the transducer. This can occur if a large quantity of debris is present, and users have experienced ice partially blocking the transducer port. With performance low on one pair this warrants further investigation.

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 9 shows a trended graph of SNR taken from a meter at the time of calibration. As can be seen the SNR is above 3500 at the lower velocities, and steadily drops to something over 1000 when the meter is at maximum velocity. This is normal due to the increase in signal distortion and gain at higher velocities.

Upon initial inspection of a meter, if it is operating near capacity one might be alarmed to see the SNR for all chords around 1000 rather than the expected value of 2500 to 3000. However, it is important to recognize that the SNR drops at higher meter velocities.

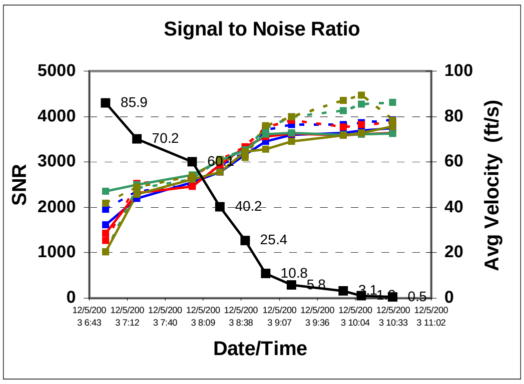


Figure 9 – Trended SNR vs. Meter Velocity

Noise levels can become excessive if a control valve is placed too close 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.

When the ultrasonic noise from a control valve begins to cause the SNR to be too low then action may be warranted. There are several things that can be done to improve SNR. The easiest way to improve SNR is to activate the "Stacking" feature built into the electronics. This feature changes the way transducers are activated.

Normally each transducer is fired once sequentially until all 8 transducers have been fired. This occurs about 31 times per second. When stacking is activated each transducer is fired several times in a row (as opposed to once only). The sum of the waveforms is added up and this effectively filters out the noise that is not synchronous with the transducer waveform. Using this technique can improve the SNR by more than 4 to 1. Figure 10 shows the SNR values of a meter that has stacking turned on. Without stacking this meter would not be operating. With it the meter is running very close to 100% transducer performance.

	Perf (%)	Gain	SNR
Chord A Up	100	44	2292
Chord A Dn	100	43	2533
Chord B Up	100	45	340
Chord B Dn	100	46	329
Chord C Up	100	44	482
Chord C Dn	100	44	498
Chord D Up	100	43	2306
Chord D Dn	100	43	2258
Average Up	100	44	1355
Average Dn	100	44	1404.5

Figure 10 – SNR of Meter with Stacking

The section in yellow shows that the SNR for the middle two chords is below 500, yet this meter was operating with 100% transducer performance. Note that the outer chords have SNR values that exceed 2000. This is partly due to the length being shorter and thus the gain is lower for these. With less gain needed the noise is also amplified less on the outer chords than on the inner accounting for an improved SNR. Also, control valve noise usually causes lower signal to noise levels on the transducers that face the noise source (all would be affected).

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 later.

Figure 11 shows the velocity ratio of each chord relative to the meter's velocity. This ratio is computed by taking each chord velocity average during a period of time and dividing it by the velocity average as reported by the meter. Since the ratio for each chord 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 chord.

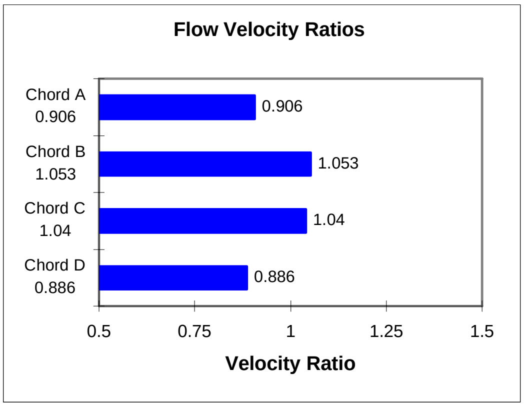


Figure 11 – Chord Ratios at 1 m/s

Typically the ratio for a BG design meter is about 89% (ratio = 0.89) for the A and D chords, and about 104% (ratio = 1.04) for the B and C chords. The difference in ratios is due to the fact that the outer chords 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 something like 1 m/s, depending upon meter size and station design, the velocity profile may change. Figure 12 shows the same meter's velocity profile when the velocity is at 0.3 m/s.

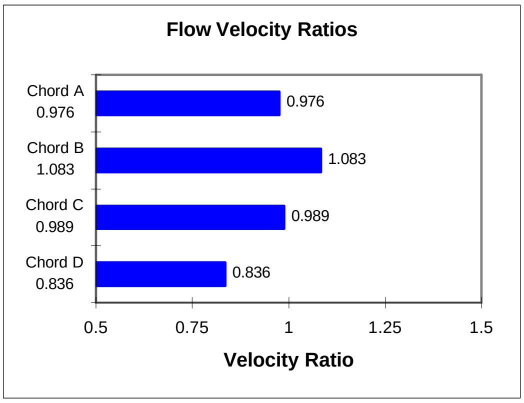


Figure 12 – Chord Ratios at 0.3 m/s

It is clear in Figure 12 and 13 that the velocity profile is very different than that in Figure 11. These were taken from a 16-inch meter at the time of calibration. When one sees this type of "distortion" in the velocity profile, it may be assumed that the meter's accuracy has been affected. Actually this meter's uncorrected reading was within 0.1% at 0.3 m/s when compared to 1 m/s, and within 0.2% at 0.12 m/s compared to the 1 m/s. Thus, just because the velocity profile is distorted, particularly at low velocities, it should not be assumed there is a significant shift in the meter's accuracy.

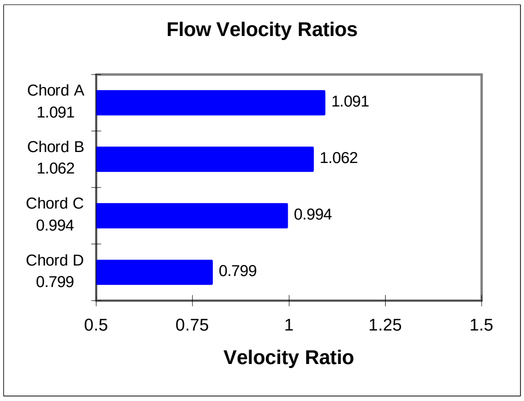


Figure 13 – Chord Ratios at 0.15 m/s

Looking at four chord 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 B & C chord values together and dividing by the sum of the A & D chords. The equation looks like this: Profile Factor = (B+C)/(A+D). Assuming the A & D chords are 0.89 and the B & C chords are 1.04 the Profile Factor then computed to about 1.17. This value does vary from meter to meter due to installation design and to some degree the type of flow conditioner and distance of the flow conditioner from the meter. However, the key aspect of the Profile Factor is to monitor when performing a log file and trend it to compare it to the historical norm for that meter

In Figure 11 when the meter was at 1 m/s the Profile Factor was 1.168. As the velocity dropped to 0.3 m/s (Figure 12) the Profile Factor changed to 1.143 and the Profile Factor was 1.087 in Figure 13. By looking at the Profile Factor it is easier to see that the velocity profile is different in the meter than the typical value. Even with this shift in velocity profile, the accuracy of the meter didn't change by more than 0.2% from 1 m/s to 0.15 m/s Again, a change in profile, particularly at low velocities, does not necessarily suggest a significant change in meter accuracy.

The Profile Factor can be a valuable indicator of abnormal flow conditions. The previous discussion showed what happens to the velocity ratios and Profile Factor due to low velocity operation. This profile change is typical when the meter is operated at these lower velocities. Figure 14 shows an ideal profile from a 12-inch meter. This was based on the log file collected at the time of calibration [Ref 5]. Customers 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.

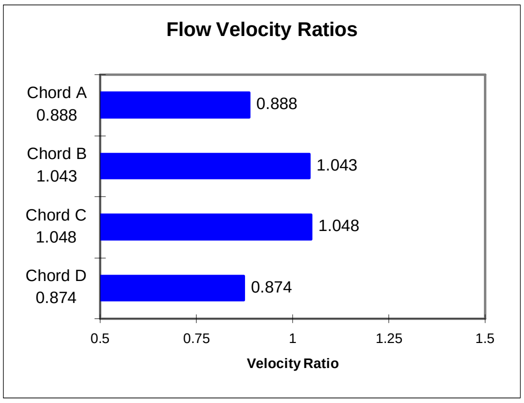


Figure 14 – Normal 12-Inch Meter Profile

The Profile Factor for this meter is 1.187. 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 15 shows the flow conditioner after it was removed.

Figure 15 – Blocked Flow Conditioner

Figure 16 shows the velocity profile during the time the flow conditioner was blocked. This was taken at a velocity of 12 m/s. The profile at two other velocities, 6 and 18 m/s, looked the same.

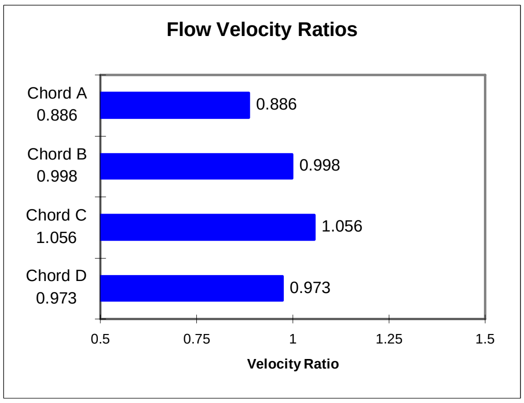


Figure 16 – 12-inch Meter Profile – Blocked

The Profile is obviously distorted with higher-than-normal readings on Chords C & D. 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 16, is 1.105. This difference doesn't seem like much, but it certainly indicates a significant change in profile. Typically a meter will generate a Profile Factor, after installation in the field, that is repeatable to ±0.02, but that depends 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 17 shows the result of the three tests velocities and the impact on metering accuracy.

Velocity (m/s)	% Error
18	0.22
12	0.19
6	0.17

Figure 17 – Blocked Flow Conditioner Results

As can be seen the meter was affected by about +0.2% for all flow rates. In this case the meter slightly over-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.

Monitoring the profile factor is a very valuable tool to identify a variety of problems. The previous example shows a change that most would say is relatively easy to understand. One of the questions many users have is "How can I determine if my meter is dirty?"

As contamination collects on the pipe wall, and of course on the inside of the meter, the profile will also change. This was discussed in a paper presented in 2004 summarizing the results of several dirty meters that were tested at a calibration facility both dirty and clean [Ref 6 & 7].

The method of determining the meter's condition is relatively simple. The profile tends to change such that the velocities on Chords B & C become higher relative to Chords A & D. This is due to the surface roughness of the upstream piping causing the velocity along the pipe wall to be lower. Thus, for a given amount of volumetric flow, if the velocity along the wall is lower, then the center will have to be higher to make up for it.

In order to determine this change, which typically occurs over time, it would be helpful to "trend" the Profile Factor. The USM software has this feature built-in so that the technician doesn't need to develop these manually. By using several periodic maintenance log files the software will develop a graphical representation of the profile factor, and several other diagnostic graphs as well. Figure 18 shows a 10-inch meter with a normal "trended" Profile Factor.

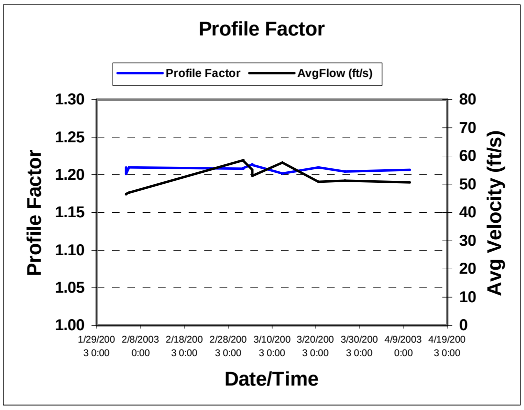


Figure 18 – Trended Profile Factor – Normal

The Profile Factor, which is in blue, to be running about 1.208 for this period of time (approximately 8 months).

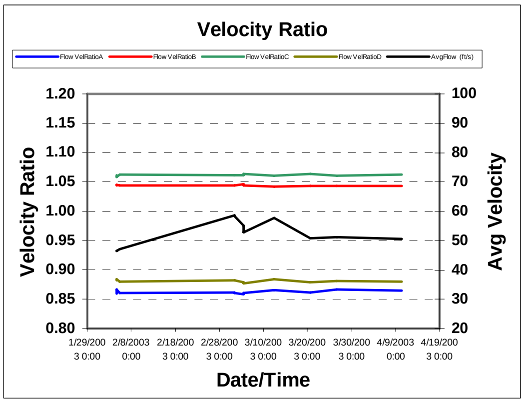


Figure 19 – Chord Ratios of Clean meter

Figure 19 shows the chord velocity ratios for this clean meter over the same period. Notice how the chord ratios remain very stable over these several months.

Figure 20 shows a meter that has some change in the Profile Factor over time. The Profile factor starts out at about 1.198 and gradually increased to about 1.270 after about 9 months. After the first 9 months the Profile Factor basically remains the same, indicating additional contamination is probably not occurring. This meter had been cleaned just prior to the collection of these log files.

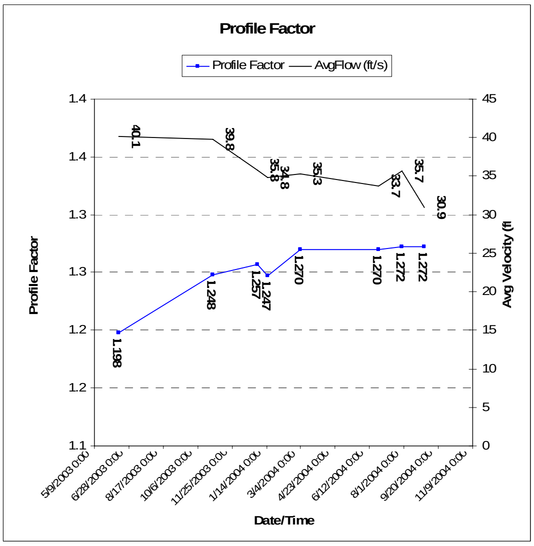


Figure 20 – Trended Profile Factor – Dirty

Figure 21 shows how the chord ratios for this dirty meter were also changing over time. Of course one would expect this since the Profile Factor is developed from all four chords.

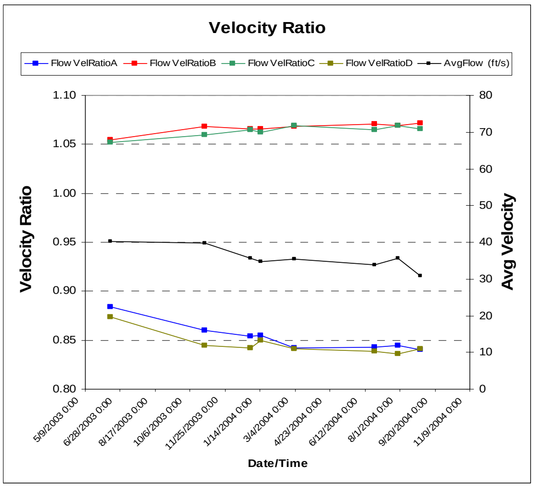


Figure 21 – Chord Ratios of Dirty Meter

As expected the inner chords (B&C) from Figure 21 begin registering faster relative to the meter's average, and the outers (A&D) are now reading lower. Notice how consistent the change is from the beginning to the end of the trend file. Both inners change about the same, and both outers also track each other very closely. This may not always be the case depending upon how uniform the coating inside the meter is.

Figures 22 and 23 show the inside of the dirty meter tube and the meter prior to cleaning. The buildup is relatively thin. As the transducers do not protrude beyond the edge of the meter, the transducer have not contamination on them.

Figure 22 –Dirty Upstream Meter Tube

Although the chord ratio change is subtle, it is apparent when trended and then used to develop the Profile Factor. It is clear change is occurring in this meter. Trending makes it very easy to see that something is happening to this meter. It might not be obvious that change is occurring if the technician were to only look at the monthly maintenance log file. Without periodic collection of maintenance log files, identifying this condition would be more difficult.

Figure 23 –Dirty 10-inch Meter

When a meter becomes dirty one question that is often asked is "how does this affect the meters' accuracy?" Several papers have been published on this issue [Ref 6, 7, 8 & 9]. Figure 22 shows the error results from this 10-inch meter calibrated dirty and clean.

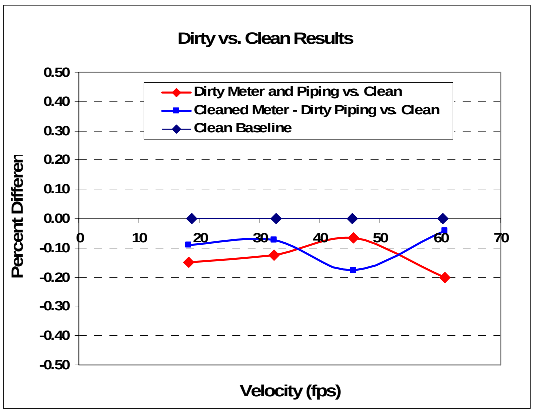


Figure 24 – 10-inch Dirty vs. Clean Results

Figure 24 shows this 10-inch meter registered about -0.14% FWME (slow) when dirty as compared to clean (red line). The blue line represents the meter clean and the piping still dirty. In this case the meter registered approximately -0.093% (slow). This test shows simply cleaning the meter body does not restore the meter's accuracy.

Registering slightly slow has been seen in other sized chordal meters when they become dirty. There is no guarantee that all meters will under-register when dirty, but certainly several results that have been published show this trend.

Figure 26 shows how the Profile Factor shifted back to normal on this meter after being cleaned. Additional flow rate data points were included as the meter was calibrated throughout the range of normal operation.

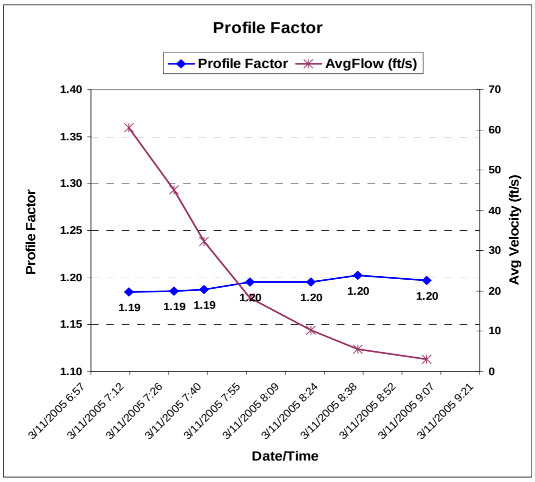


Figure 25 – Profile Factor After Cleaning

This 10-inch meter exhibited an approximately change of approximately 0.074 in the Profile Factor and registered slightly slow when dirty compared to its clean condition. Additional data is required to determine if there is a correlation between Profile Factor change and meter error. If such a correlation exists, then it may be possible to someday predict error based upon Profile Factor change.

Speed of Sound

Probably the most discussed and used diagnostic tool is of an ultrasonic meter is the speed of sound (SOS). The reader may recall that speed of sound on an individual chord is basically the sum of the transit times divided by their product, all then multiplied by the path length. A more detailed discussion on this can be found in a previously presented paper [Ref 10}.

There are at least 2 ways of looking at SOS. The first would be to compare each path's SOS to the meter, or to the other paths. Typically the agreement with today's technology is within ±0.3 m/s during normal operation. At lower and higher velocities there can be some variance from this norm.

Figure 26 shows a trend graph of each chords SOS relative to the meter over a period of several months. This is a very easy way to compare them rather than looking at the absolute value of each chord.

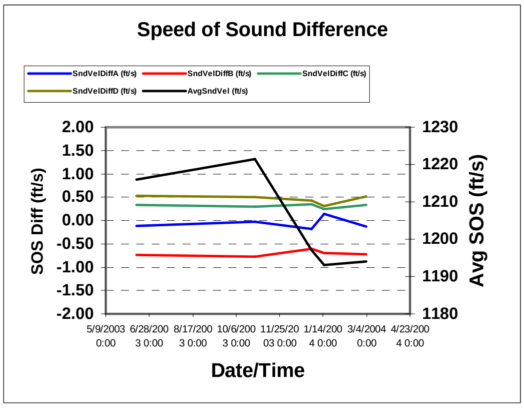


Figure 26 – SOS Difference Over Time

One of the important features about looking at SOS difference is identifying potential buildup on the face of the transducer. If grease or a combination of oils and mill-scale coated the transducer face, one or more of the chords would be changing. Figure 25 shows a meter with a significant difference in SOS between Chord D and the remaining.

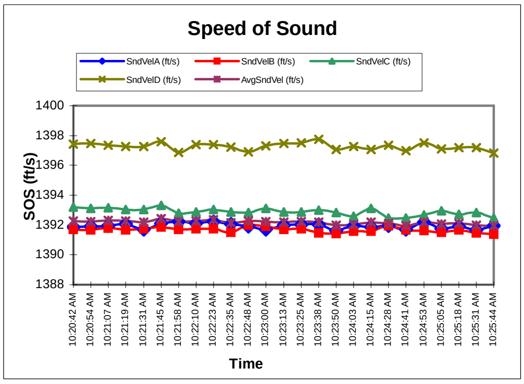


Figure 27 – Chord D Contaminated

Figure 27 was taken from a monthly maintenance inspection log file. This graph shows the actual reading of SOS for each chord, and it clearly shows a SOS difference in Chord D relative to all other chords. Typically all SOS values will be within 1 m/s maximum spread, but here there is about 2 m/s difference in Chord D relative to all others.

Looking at the SOS difference chart, shown in Figure 28, shows how different this chord's reading relative to the others.

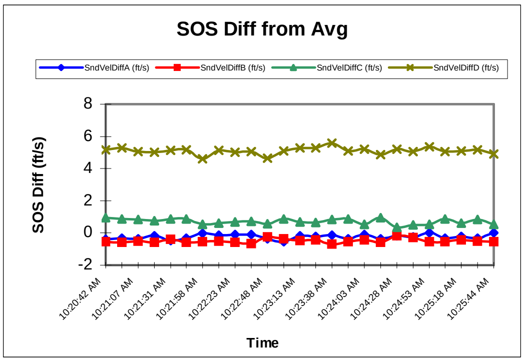


Figure 28 – SOS Difference - Contamination

This SOS difference is graphed at the same time as the graph showing all the meter's reported chord SOS values. Each graph clearly shows a problem, but when the difference between the chords is small, the SOS difference graph makes it easier to see there is a problem.

If the meter is being subjected to significant levels of ultrasonic noise from a control valve, prior to total failure of the meter one might see an occasional pulse detection error. This is also known as a peak switch. This may occur intermittently as shown in Figure 29, or it may be a permanent switch that would continuously show a difference of several fps in SOS.

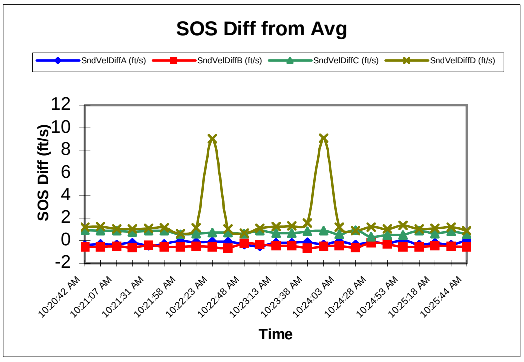


Figure 29 –Intermittent Peak Switch Problem

When this condition occurs the meter will provide an alarm indicating there is a problem. This is a configurable value that is typically set to 0.5% of the meters' SOS reading. This helps identify this condition and it is also logged in the event log, including the date and time it occurred. Once the SOS returns to normal (something less than the 0.5% difference), the alarm will clear.

When a meter is operated at lower velocities, typically less than 1 m/s, and there is a significant 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. Since the speed of sound in the gas is relatively sensitive to temperature, this will be seen as a SOS difference between the chords. This is often called thermal stratification.

Figure 30 shows an example of a 16-inch meter at the calibration lab. The temperature of the gas is quite a bit higher than the ambient, so at lower velocities there is some stratification inside the pipe. If the gas and ambient temperatures were the same, then no stratification would occur.

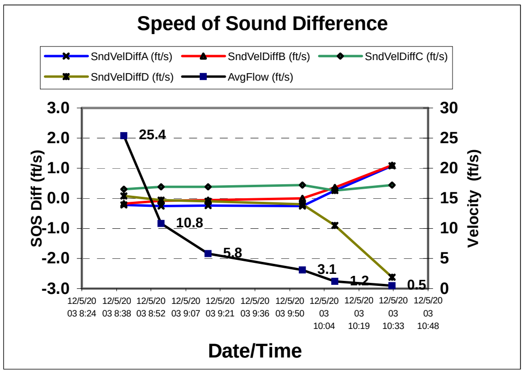


Figure 30 – Thermal Stratification

From this example it appears that somewhere around 1 m/s there is a possibility that thermal stratification can occur. This will cause some increase in measurement uncertainty for at least two reasons. First, the temperature reading by the RTD will most likely not be representative of the average gas temperature. This will lead to errors when converting from uncorrected to corrected volumes. Second, as illustrated in Figures 12 & 13, the velocity profile is also affected. This can cause the uncorrected reading of the meter to be in error if it were different than at the time of flow calibration.

This difference in profile is probably not more than a very few tenths of a percent under most conditions and is supported by the results in Figure 31.

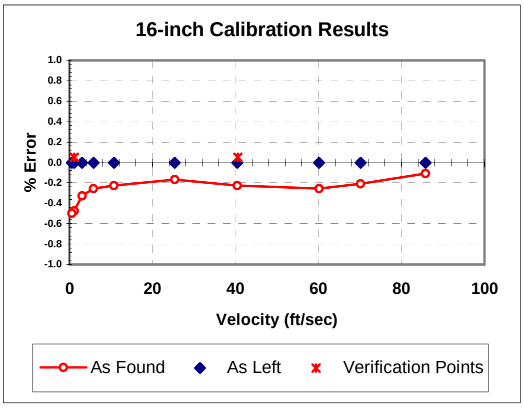


Figure 31 – 16-inch Low-Flow Error

This meter was calibrated to 0.15 and 0.3 m/s. Both error points are virtually the same making it look as though only one data point was taken. The error difference between the 0.15 and 0.3 m/s is less than 0.03%. Thus, even with the chord velocities looking very ‘skewed” at the time of flow calibration, as shown in Figures 12 & 13, the metering accuracy is not significantly affected.

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 10]. Essentially Turbulence is a measure of the variability of each chords’ 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 BG design shows the A & D Chords have 2-4%, and the B & C Chords have 1-2%. This is based upon the history of hundreds of meters. The outer Chords A & D, being closer to the pipe wall, always exhibit higher turbulence by about a factor of 2.

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 14, now appears like that in Figure 16, 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.

Figure 32 shows the turbulence level for this 12-inch meter is normal. It was collected at the time of calibration and the velocity was about 12 m/s.

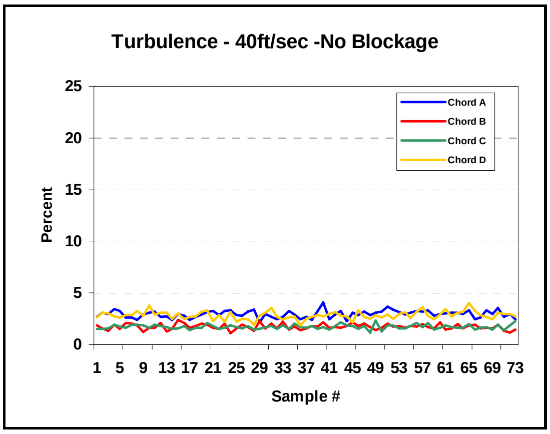


Figure 32 – Normal Turbulence

The 12-inch meter in Figure 32 shows a very consistent level of Turbulence during the period of the test. Figure 33 is the same meter with a blocked flow conditioner as shown in Figure 15.

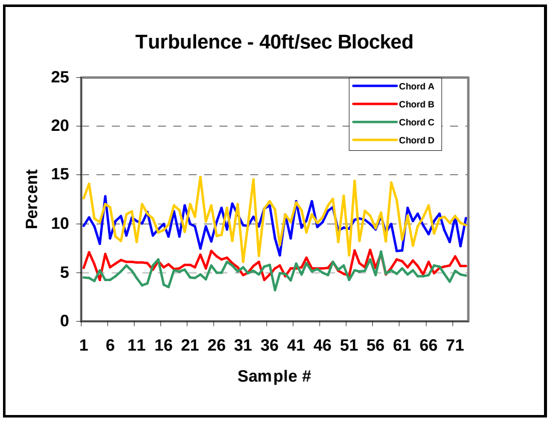


Figure 33 – High Turbulence of 12-inch Meter

It is clear that the turbulence in Figure 31 is about 3 times higher. Certainly the velocity profiles for this meter, shown in Figures 14 and 16, 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.

Figure 34 is an example of turbulence is from a 12-inch meter. This meter is installed with a single-bounce meter downstream for checking. This customer uses the single-bounce meter to help insure measurement accuracy. When a deviation is observed, the metering system is investigated. Such a deviation occurred recently and one can also see the elevated turbulence at this time.

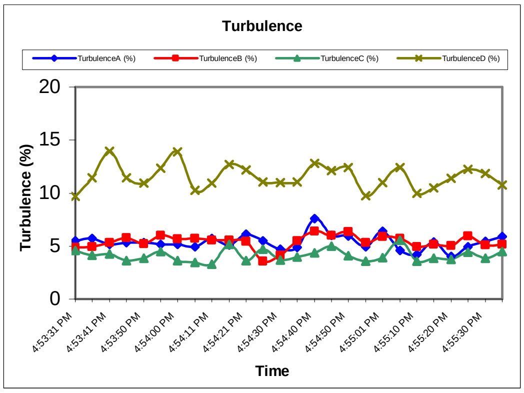


Figure 34 – High Turbulence on 12-inch Meter

This meter is equipped with an older generation of electronics. In order to determine the turbulence it must be manually computed from the log files. Newer generation electronics automatically computes the turbulence and stores it in the hourly archive logs. In this way it is possible to identify to within 1 hour when the blockage occurred.

Figure 35 – 12-Inch Meter Blockage

Figure 35 shows the reason for the shift in meter performance between the 4-path chordal meter and the single-bounce meter. This blockage was just upstream of the flow conditioner.

When looking at the chord ratios with the blockage it is very clear that something has distorted the profile. Figure 36 shows the velocity profile is very non-symmetrical with much higher velocities at the top of the pipe.

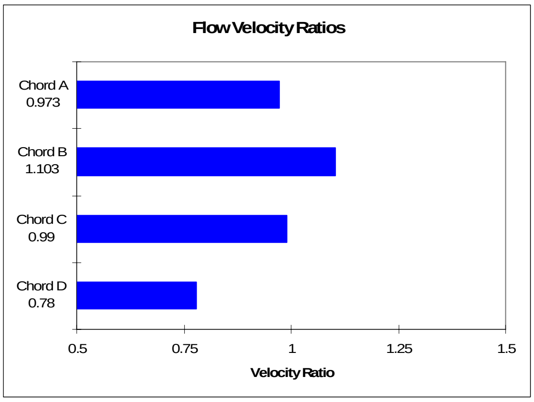


Figure 36 – Chord Ratios of 12-Inch Meter

Figure 37 shows the chord ratios after the blockage is removed. This is the look of a normal profile.

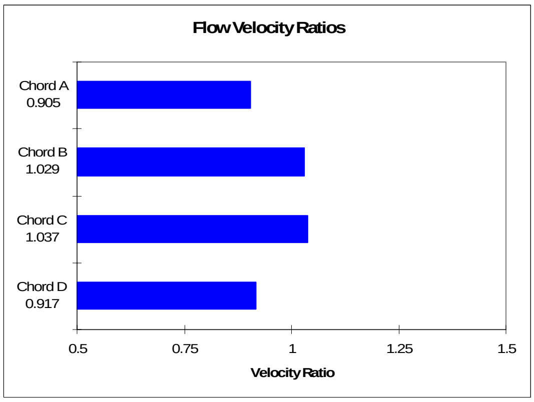


Figure 37 – Chord Ratios of 12-Inch Meter

After the blockage is removed the turbulence levels return back to a more normal value of 2-4% for the A and D chords and 1-2% for the B and C chords, as shown in Figure 38.

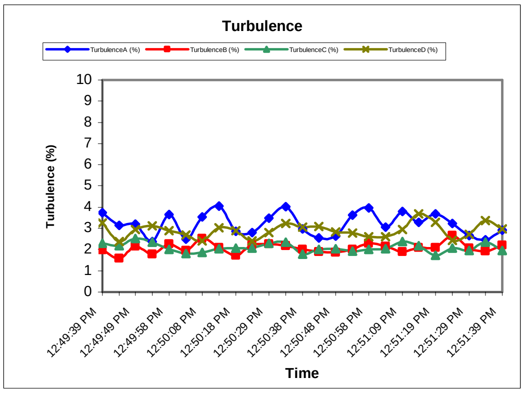


Figure 38 – Chord Ratios of 12-Inch Meter

Another way of looking at distorted velocity profiles is to compare the sum of Chord A & B with the sum of Chords C & D. This is discussed in detail by a paper presented by Klaus Zanker [Ref 10]. He defines this as Symmetry. Figure 39 graphs the Symmetry, and we see that there is a significant shift from the normal.

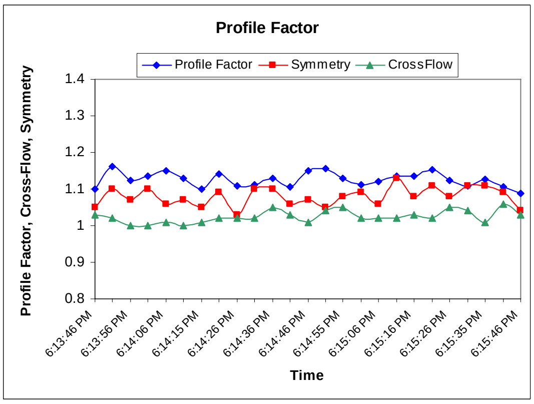


Figure 39 – Symmetry of 12-Inch Meter

Figure 39 is a graph not only of the profile factor (blue line), but the red line represents symmetry and the green is Crossflow. Crossflow is also defined in Klaus' paper as Chords (A+C)/(B+D). Note the Profile Factor is not very steady, indicating a very turbulent, changing flow pattern. Normally both Crossflow and Symmetry will be very close to 1.00, but as we can see the Symmetry is closer to 1.10. Figure 40 show the same graph after the obstruction is removed.

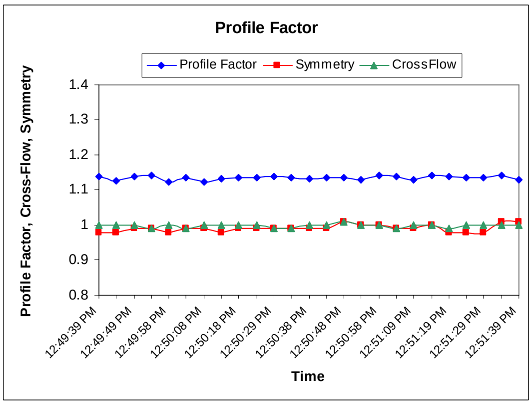
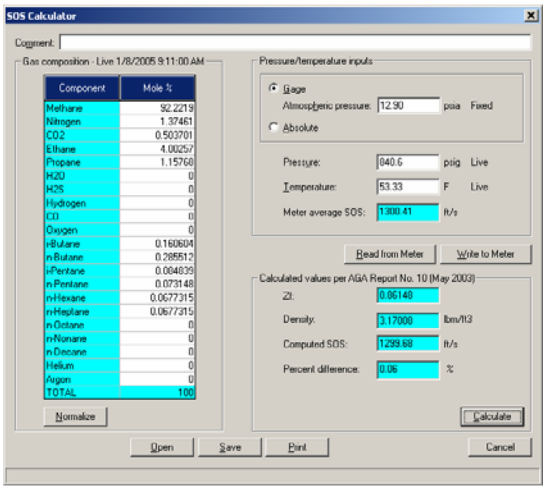


Figure 40 – Symmetry of 12-Inch Meter

With the obstruction removed the Symmetry and Crossflow both return to normal (approximately 1.00), and the Profile Factor is more consistent.

Another diagnostic tool is comparing the computed SOS to that reported by the meter. This has been done for years by using an external program and reporting the difference on the inspection report. This is one good method for identifying if the metering system has a problem. Figure 41 shows such a calculator.



Gas composition - Live 1/8/2005 9:11:00 AM

Component	Mole %
Methane	92.2219
Nitrogen	1.37461
CO2	0.503701
Ethane	4.00257
Propane	1.15760
H2O	0
H2S	0
Hydrogen	0
CO	0
Oxygen	0
i-Butane	0.160604
n Butane	0.285512
i-Pentane	0.084839
n Pentane	0.073148
n-Hexane	0.0677315
n-Heptane	0.0677315
n Octane	0
n-Nonane	0
n Decane	0
Helium	0
Argon	0
TOTAL	100

Pressure/temperature inputs

● Gage
Atmospheric pressure: 12.90 psia Fixed
○ Absolute
Pressure: 840.6 psig Live
Temperature: 53.33 F Live
Meter average SOS: 1300.41 ft/s

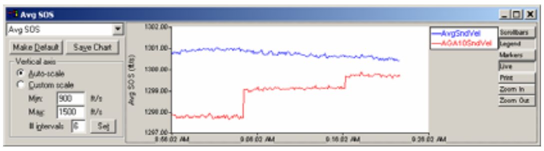
Calculated values per AGA Report No. 10 (May 2003)

Zf: 0.86140
Density: 3.17000 lbm/ft3
Computed SOS: 1299.68 ft/s
Percent difference: 0.06 %

Figure 41 – Actual SOS vs. AGA 10 SOS

The problem with doing this only at the time of inspection is that there can be an intermittent problem that would go undetected. The latest generation of ultrasonic electronics can now perform this on a real-time basis and also store on the hourly log files. This permits a more thorough monitoring of not only the meter, but the gas chromatograph as well.

Figure 42 shows a graph of the meter's reported SOS and that from the meters' computed SOS using the AGA 10 algorithm.



● Auto-scale
○ Custom scale
Min: 900 ft/s
Max: 1500 ft/s
intervals: 6

Figure 42 – Actual SOS vs. AGA 10 SOS

This example shows how the SOS, in red, moves closer to the meters' reported SOS (in blue). The cause of this is most likely a delay in the gas sampling process. In this case the GC has a 12-minute update interval (two-stream GC). By seeing how the computed SOS trails the meter's SOS one can see the impact having the sample updated in the GC quicker to insure more timely computation.

Generally if the computed AGA 10 SOS does not agree with the meter's reported SOS, more often than not the problem is with the temperature measurement or the gas chromatograph. The big benefit for computing SOS on a real-time basis is to help insure meter station health.

If the meter and AGA 10 SOS agree it should not be assumed the meter's accuracy has not changed. The AGA 10 SOS comparison shown in the 10-inch dirty meter example did not show any deviation over time. Since there was no contamination on the transducers, the meter's path length was unaffected, and thus the meter's SOS registered correctly.

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, chord 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 identified in advance of failure.

One major benefit to the USM is that it provides information that can also be used to diagnose the entire metering facility. By looking at the AGA 10 SOS vs. the meter's reported SOS, potential problems with gas analysis or temperature can be spotted. However, as powerful as the basic diagnostic indicators are, new features are being developed.

These more advanced diagnostic indicators, such as Turbulence, Symmetry, Crossflow and real-time SOS computation 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 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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