UNDERSTANDING GAS ULTRASONIC METER DIAGNOSTICS – ADVANCED

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ABSTRACT

This paper discusses advanced diagnostic features of gas ultrasonic meters (USMs), and how capabilities built into today's electronics can identify problems that may have gone undetected in the past. It primarily discusses fiscal-quality, multipath 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 Report No. 9 [Ref 1], also known as AGA 9. However, some provide more advanced features that can be used to help identify issues such as blocked flow conditioners, liquids, and gas compositional errors. This paper focuses on the Westinghouse and British Gas configurations (both being four-path 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. Gas ultrasonic meter diagnostics basics are not presented in this paper, but rather just advanced features that are common in today's USMs.

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.

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, many users don't perform any tracking or trending of data. Thus, one of the most powerful features of the gas USM is often not used.

BASIC ULTRASONIC METER DESIGNS

Before discussing diagnostics, it might be helpful to review some of the basic designs that are used today. Figure 1 shows five types of velocity integration techniques as shown in a British document BSI 7965:2000 [Ref 4], additional meter designs are now available, and thus this table doesn't reflect all that are currently on the market. 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). Most analysis in this paper will be applicable to design D in Figure 1.

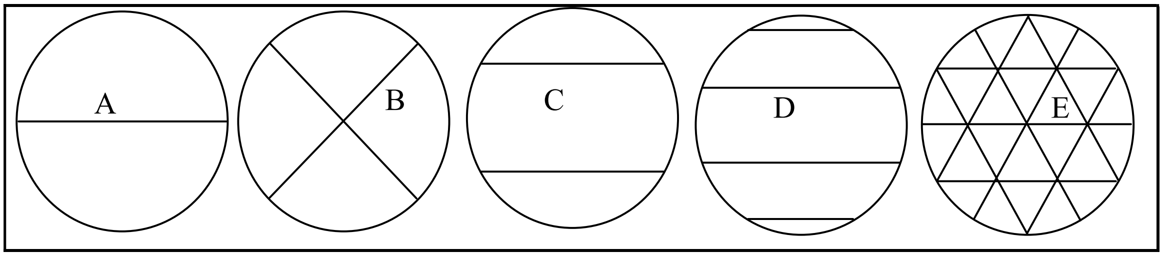


Figure 1 – Ultrasonic Meter Designs

ADVANCED DIAGNOSTIC INDICATORS

The basic diagnostic parameters that are provided by today's USMs have been discussed in other papers [Ref 2 & 5]. They are gain, performance, signal-to-noise ratio (SNR), speed of sound (SOS) and velocity profile. Of these the most difficult for most to understand is the Velocity Profile. This is due in part to the various USM path configurations and different methods of presenting path velocity information by the manufacturers.

For the chordal type of meter, most manufacturers talk about path velocity ratios. This method of displaying the path velocity is easier to understand because these individual path ratios don't change significantly over most velocities the USM is operated.

However, there are easier ways to analyze the various profiles that can occur in the field. These variations occur due to the wide range up upstream piping conditioners. Today's flow conditioner can significantly reduce gas profiles distortions arriving at the meter, but sometimes can't create a totally symmetrical, non-swirling profile. Even though the USM can handle a wide range of distortion with minimal impact on accuracy, the ideal situation is to reduce the "installation affects" (distortion of the gas velocity profile) to an absolute minimum.

To understand if the velocity profile has changed over time, enhanced methods of diagnosing the USM have been developed. Since the velocity profile is the most difficult, due to the wide range of possible scenarios, a simpler method of summarizing these profiles would be beneficial.

Profile Factor and Symmetry

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. One of these methods is called **Profile Factor**.

The Profile Factor is computed by adding the path ratios (or velocities) for 2 and 3 together, and then dividing this value by the sum of paths 1 and 4. The equation is: Profile Factor = (2 + 3)/(1 + 4). If 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 and is called **Symmetry**. Normally the meter's path velocities will be very symmetrical resulting in a value close to 1.000. Figures 2 and 3 show both the Profile and the Symmetry in a single graph.

A third method of analyzing the path velocity profile in the British Gas design (also known as the BG design) is **Crossflow**. Here the equation is similar but different. Crossflow is = (1 + 3)/(2 + 4).

In Figure 2, when the meter was flowing at 23 fps, the Profile Factor was 1.115 (average of the magenta-colored line). As the velocity dropped to 2.8 fps (Figure 3) the Profile Factor increased to 1.137. This is about a 2% change in profile when compared to the Profile Factor at 23 fps.

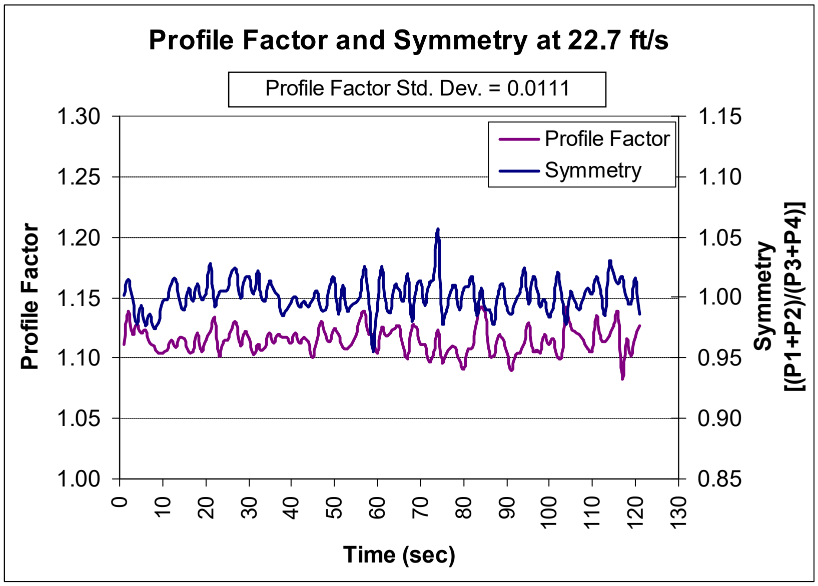


Figure 2 – Profile Factor and Symmetry at 22.7 fps

The other diagnostic worth reviewing is the Symmetry value. Figure 3 shows a significant change (on the order of 10%) in the Symmetry at the lower velocities. This can be seen by comparing the blue line if Figure 2 to the blue line in Figure 3. However, there was no significant impact on meter performance at the time of calibration. These graphs indicate there was a change in the meter's profile and this is to be expected at lower gas velocities.

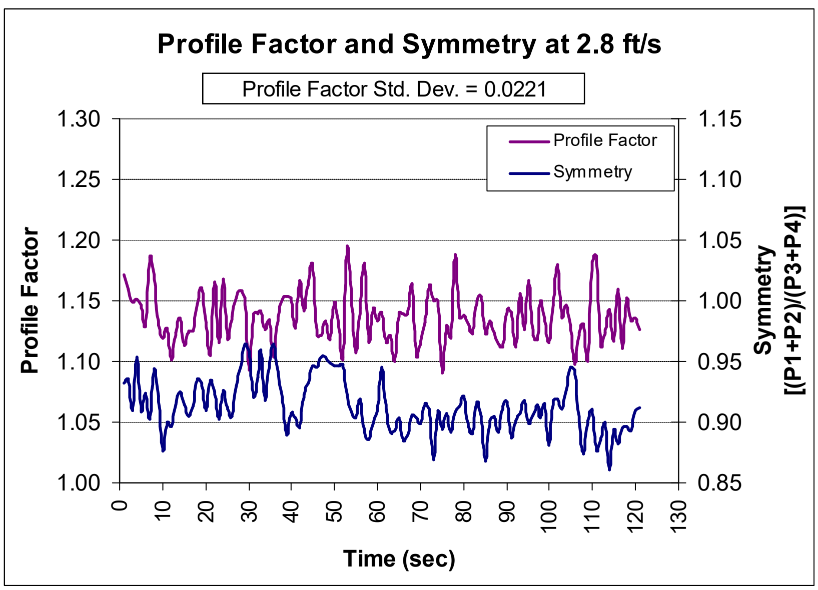


Figure 3 – Profile Factor and Symmetry at 2.8 fps

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 4 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.

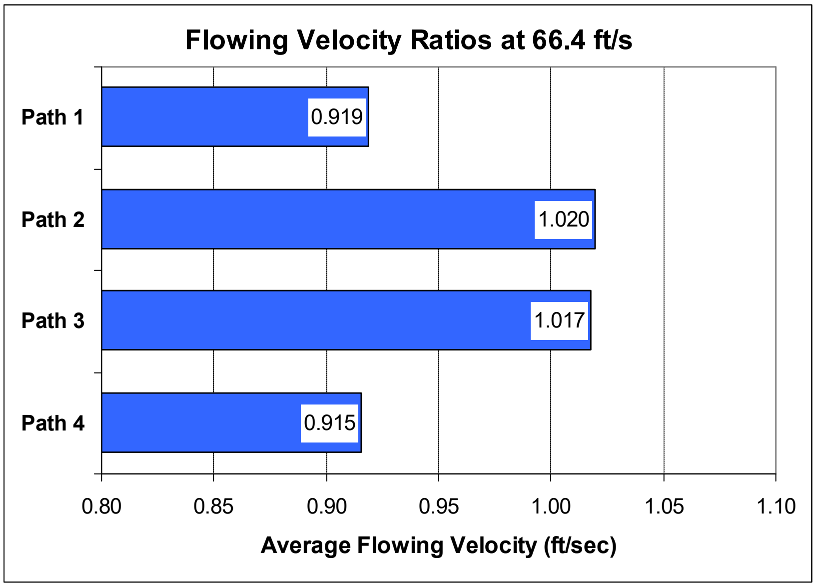


Figure 4 –12-Inch Meter Profile – Normal

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 5 shows the flow conditioner just before it was installed in the pipeline.

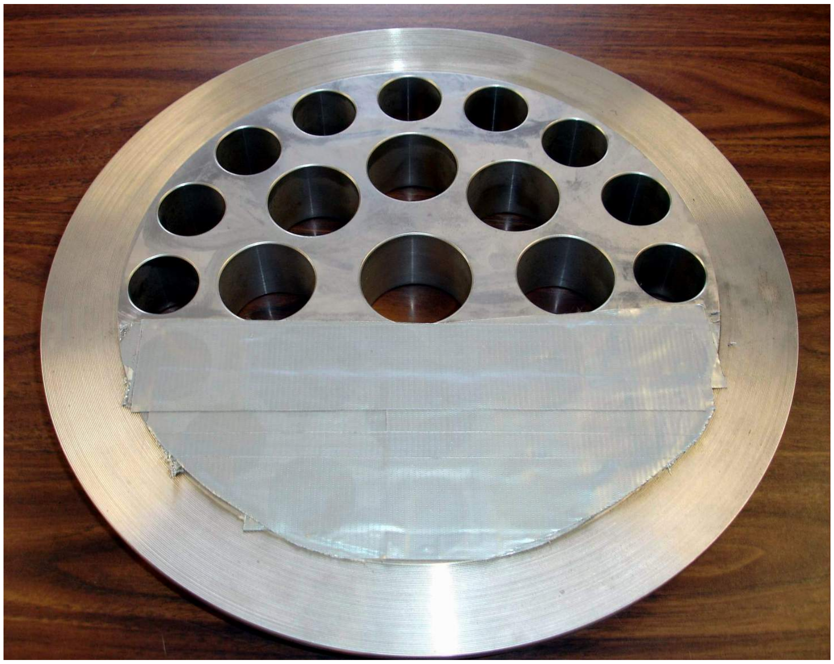


Figure 5 – 40% Blocked Flow Conditioner

Figure 6 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.

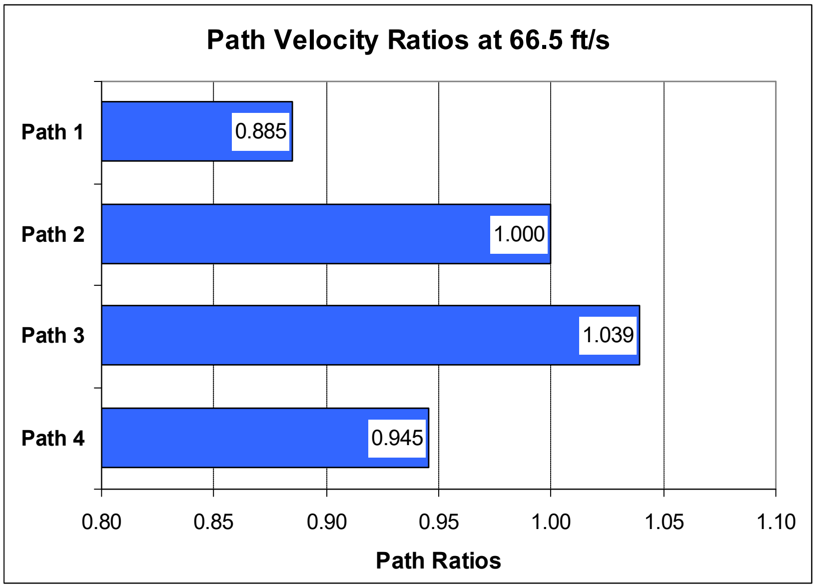


Figure 6 – 12-inch Meter Profile – 40% Blocked

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 than at the top.

Figure 7 shows the graphical results of the Profile Factor and Symmetry with no blockage.

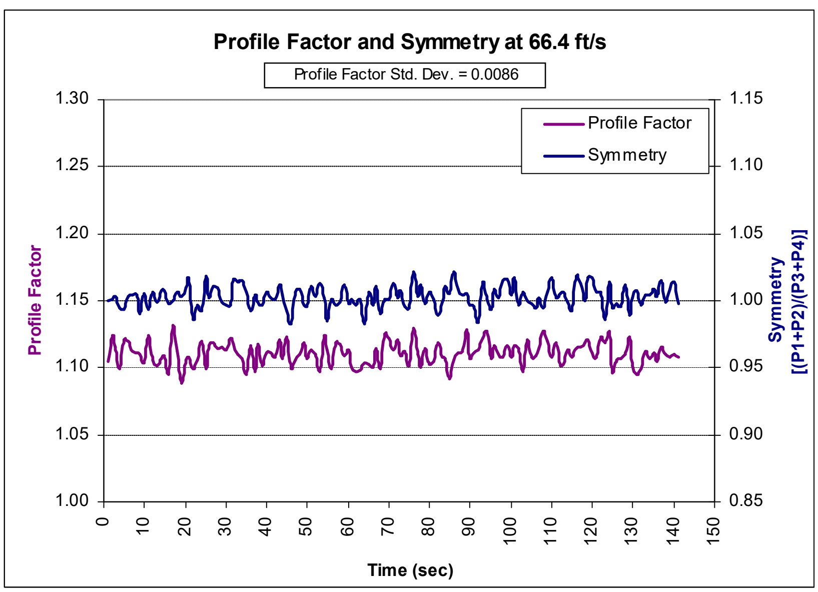


Figure 7 – Profile Factor and Symmetry at 66.4 fps

From Figure 7 the average Profile Factor is 1.111 and the average Symmetry is 1.003. These are just about the ideal values for both. Figure 8 shows the Profile Factor and Symmetry graph with 40% blockage.

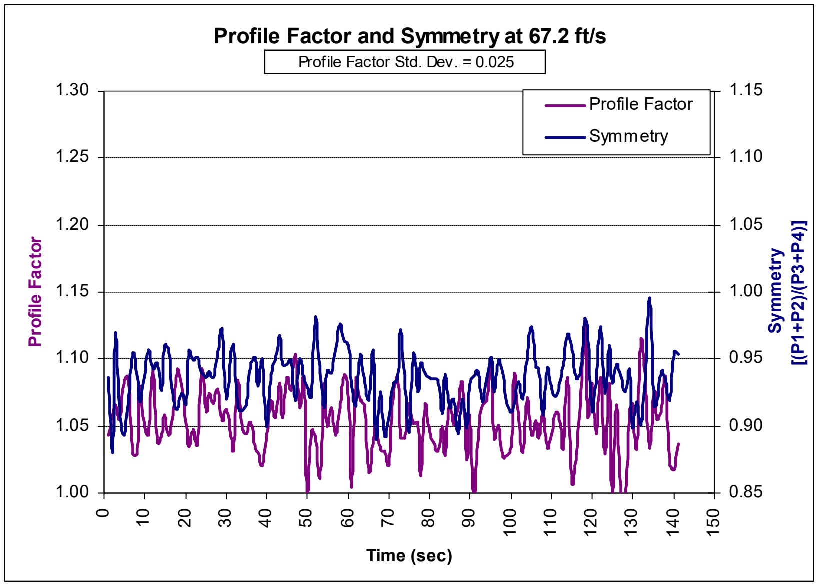


Figure 8 – Profile Factor and Symmetry at 67.2 fps – 40% Blocked Flow Conditioner

Figure 8 shows the results of the Profile Factor and Symmetry with 40% blockage of the flow conditioner. The average of the Profile Factor is 1.053 and the Symmetry is 0.936. This is about a -6% change in Profile Factor and about a -7% change in Symmetry. Both would be considered significant and should be treated as a cause for investigation.

After installation in the field a meter typically will generate a Profile Factor that is repeatable to ±0.02 (or about 2%). 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 9 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 9 – Blocked CPA Results

As can be seen the meter was affected by an average of about -0.08% for all flow rates. In this case the meter slightly under-registered with this distorted profile. A more advanced diagnostic feature will be discussed later that indicates the meter has blockage, but for now one can see the Profile Factor and Symmetry both have indicated a significant change.

In the past many have believed that looking at the Profile Factor alone would be a good indication if any contamination or flow conditioner blockage existed. This may not always be true. Figure 10 shows a picture of a flow conditioner with 3 holes blocked at the bottom.

Figure 10 – 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 11 shows a graph of the Path Ratios during this test with the 3 blocked holes located at the bottom of the meter piping.

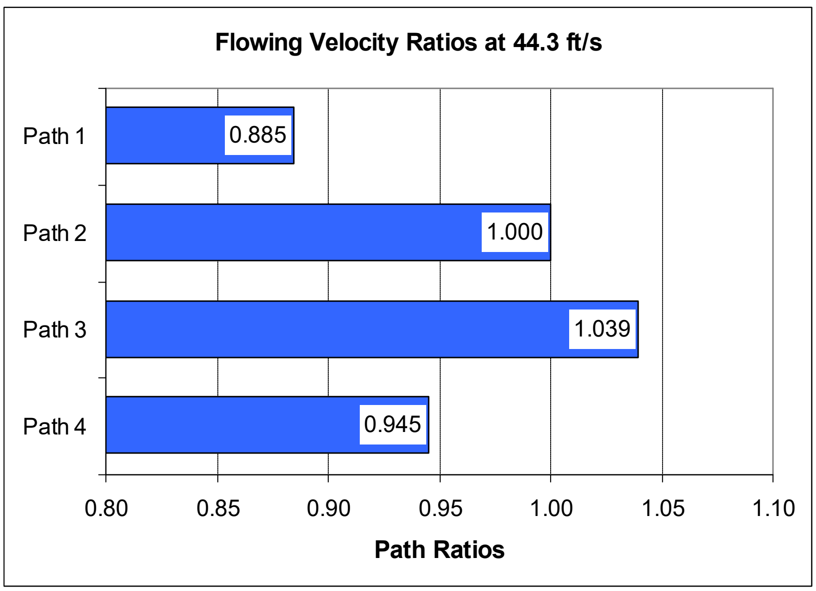


Figure 11 – Path Ratios with 3 Holes Blocked - Bottom

Comparing Figure 11 with Figure 4 (the normal Path Ratio profile) it is obvious that the two graphs of path ratios do not look the same. However, when computing the Profile Factor, the average value for Figure 31 is 1.114 (1.11 is the ideal factor). This is almost the perfect number for this meter.

Upon further investigation Figure 12 shows that the Symmetry has changed significantly.

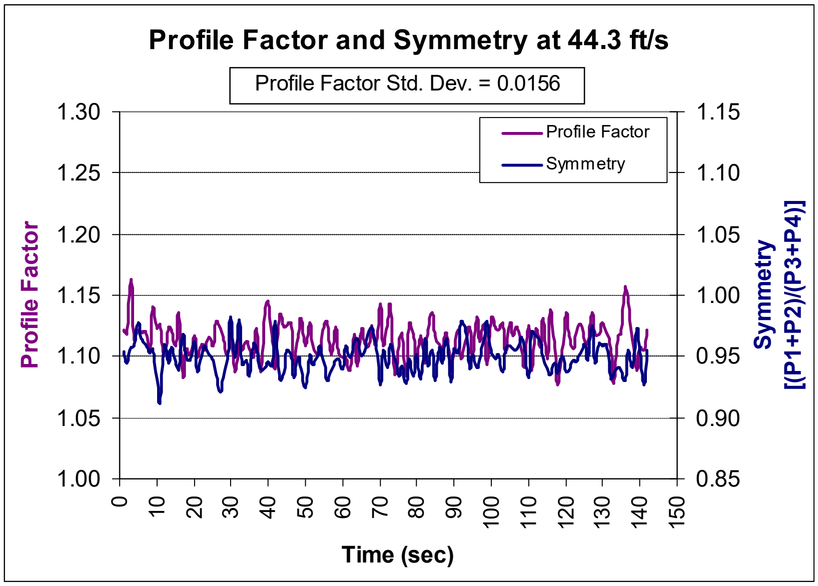


Figure 12 – Profile Factor and Symmetry – 3 Holes Blocked (at Bottom of Pipe)

In Figure 12 the average for the Profile Factor is 1.114, and is almost normal, but that the Symmetry value average is about 0.95, or approximately a -5% shift from normal (1.00 being normal). Thus, it is possible for the Profile Factor to be normal even though the velocity profile in the meter is not. **This is the reason a combination of Profile Factor and Symmetry are both require to fully analyze the velocity profile entering the meter.**

Figure 13 shows what the affect on the meter's accuracy when this blockage was located at the bottom, and rotated 90 degrees so the blockage affected paths 2 & 3 more significantly (than when it was at the bottom of the pipe.

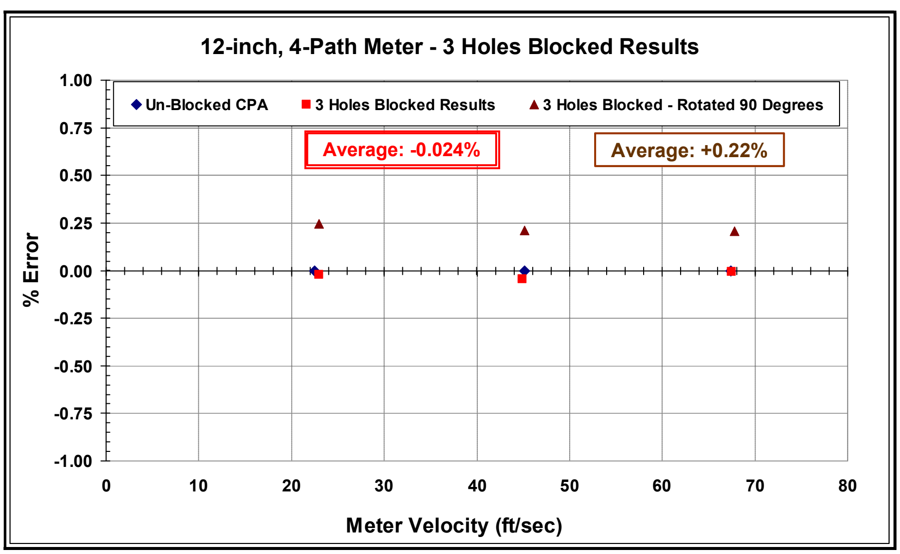


Figure 13 – As-Found Results – 3-Holes Blocked – CPA Rotated 90°

When the blockage was at the bottom of the meter run, there was very little impact on accuracy (on average -0.024%). When the blockage was rotated 90 degrees to the side, the meter responded with a shift of about +0.22%. All other blockage tests to date had shown the meter responded with a negative shift in error, but for the first time the meter now measured fast with this blockage.

The question might be asked as to why this has occurred? Let's look at the velocity profile when this blockage occurred on the side of the flow conditioner.

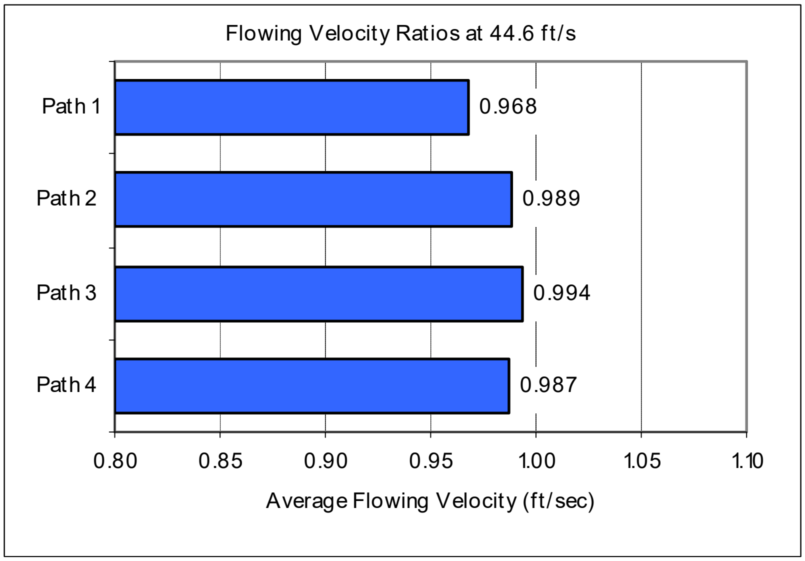


Figure 14 – Path Ratios with 3 Holes Blocked – CPA Rotated 90°

Figure 14 shows that the velocity profile is much flatter than normal. That is the center two paths (paths 2 & 3) are reading much less than normal and are almost the same as the outer paths (2 & 3). This makes sense since the blockage was in direct line with the middle two paths when it was rotated 90 degrees vs. blocking primarily the bottom path when at the bottom.

When analyzing the Profile Factor and Symmetry a rather interesting result is apparent. Figure 15 shows a graph of the Profile Factor and Symmetry for the 3-hole blockage on the side.

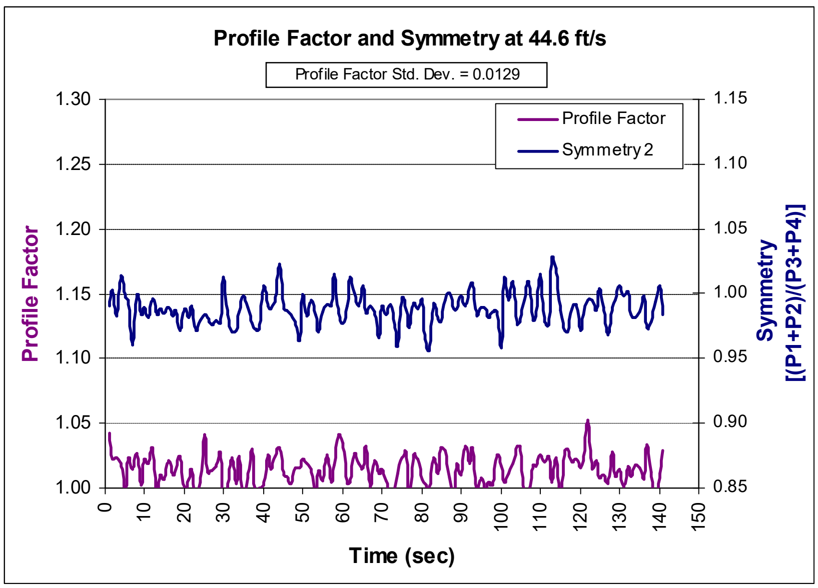


Figure 15 – Profile Factor and Symmetry – 3-Holes Blocked – CPA Rotated 90°

Figure 15 shows that the average Symmetry is almost normal (0.985, or about 1.5% change from ideal), but the average Profile Factor is 1.011, or about a 10% change. If only Symmetry alone was monitored, a shift of 1.5% would not be considered significant. Thus, a problem might be over-looked.

This is why both the Profile Factor and Symmetry need to be computed, and monitored, to state the meter's profile is the same and hasn't changed. If both are the same, then there is no combination of velocity profile ratios that can produce a distorted profile and still provide the same average values of 1.11 for Profile Factor and 1.00 for Symmetry.

Sometimes when reviewing path ratios as shown by the USM software, it is difficult to see if everything is normal. By reviewing a Maintenance Report, where the average value is generally presented, it is easier to see. Figures like 6, 11 and 14 show the path ratios that are typical of today's USM software. When significant changes occur, it is easy to see. However, what is needed is a simpler way to present this. The following graph is from a manufacturer's USM software, and it shows all the typical diagnostics that are available to the technician.

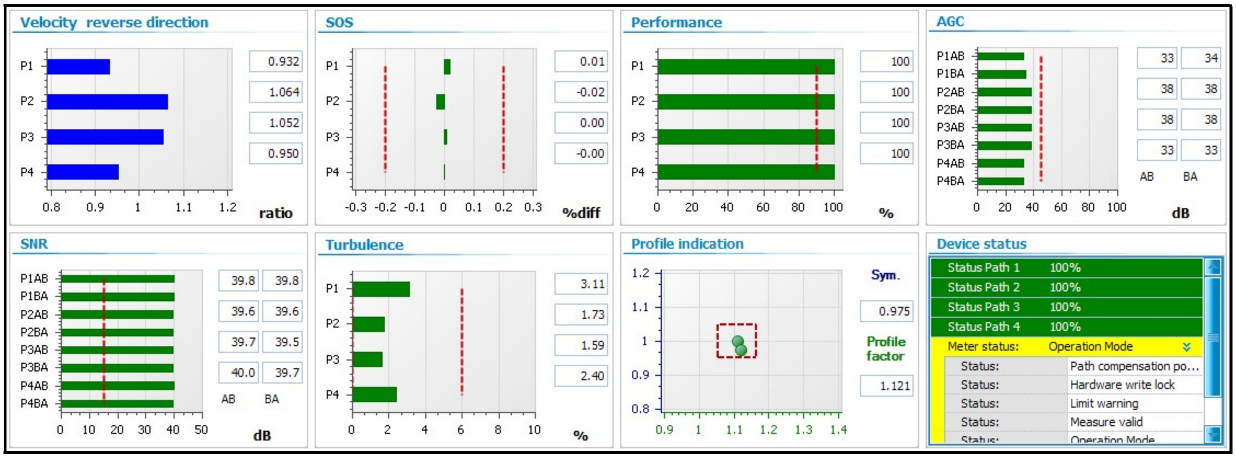


Figure 16 – Summary of All Diagnostics – Normal Velocity Profile

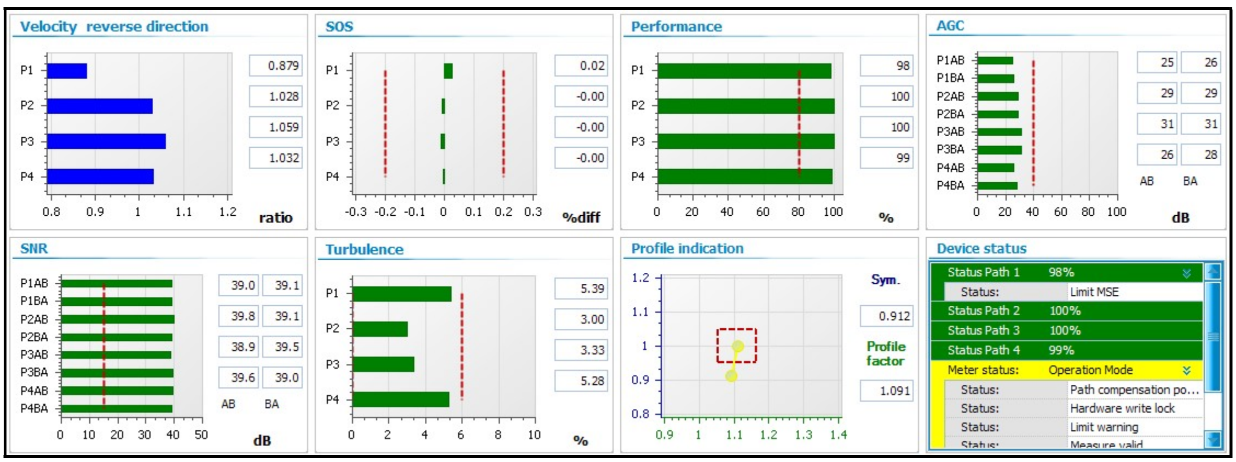
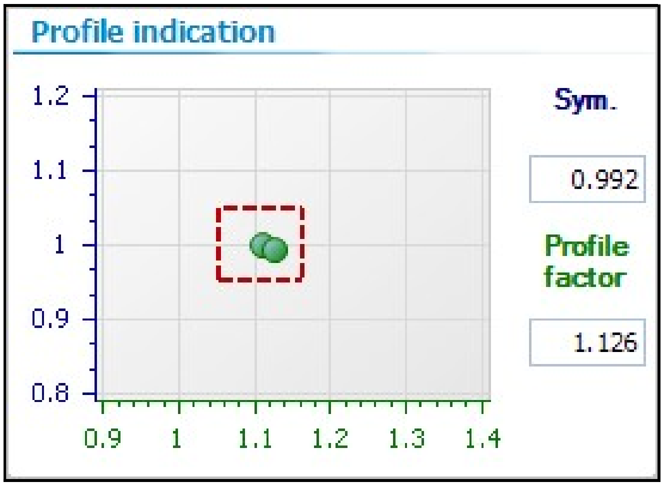


Figure 17 – Summary of All Diagnostics – Abnormal Velocity Profile

In Figure 16 we see a very symmetrical velocity profile (upper left corner). In Figure 17 we see a distorted velocity profile. The Profile Factor and Symmetry are shown in the graph called Profile Indication. It is the 3rd graph from the left on the second row. In Figure 16 we can see there are two dots inside the red box and in Figure 17 we see that one of the dots is outside the red box and the line is yellow. This is telling us the Symmetry is outside of normal tolerances.

The Profile Indication box is really a summary of both the Profile Factor and Symmetry. The dot in the middle of the box is established when commissioning the meter and is the average value when first started up. The second dot is the current, or live, value of the Profile Factor value (represented by the X axis) and the Symmetry value (represented by the Y axis). When either of these values causes a change of more than 5% (an adjustable value but just a baseline for this example), then the line turns yellow indicating there is a significant change. Figure 18 shows a close-up of a normal value, and Figure 19 shows a problem.



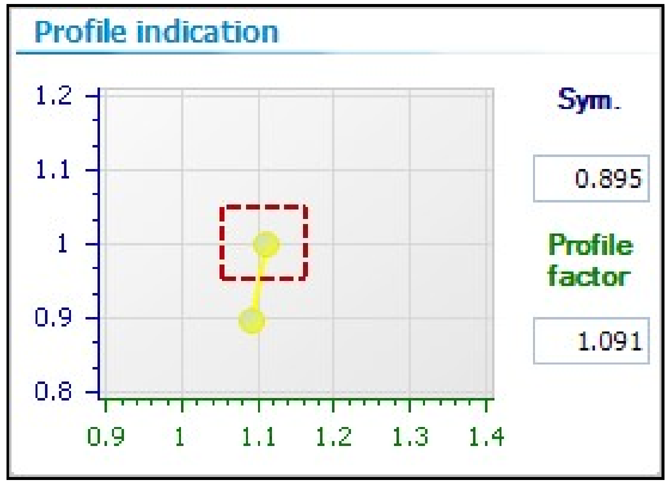


Figure 18 – Normal Profile Factor and Symmetry Figure 19 – Abnormal Profile Factor and Symmetry

Figure 18 shows a dot just to the right of the centered one (which is configured in the meter) and it represents the current reading of both Profile Factor and Symmetry. These values are show to the right of the graph.

When a problem occurs that causes a shift in either Profile Factor or Symmetry, by more than the programmed limit in the meter (shown here as 5%), then the dot will move outside of the box and turns yellow. Such is the case for Figure 19 where we see the Symmetry is 0.895, or more than 10% from normal (1.00 being normal). Thus, the technician can very easily see there is a problem with the profile.

Turbulence

During the past several years many USM manufacturers have implemented an additional diagnostic feature. This feature, called "Turbulence," is discussed in a previous paper [Ref 5]. Essentially Turbulence is a measure of the variability of each path's velocity reading during the time the meter was sampling and is updated for each calculation cycle. This gives the technician an idea of the steadiness of the flow on each path as seen by the meter.

Typically, the level of turbulence on Westinghouse and British Gas designs show paths 1 and 4 to have around 3-4% turbulence, and paths 2 and 3 around 2-3%. This is based upon the history of many meters. The outer paths 1 and 4, being closer to the pipe wall, exhibit higher turbulence under normal conditions because they are more affected by the surface friction of the upstream piping.

In some older meters, turbulence can be computed from the maintenance log file. 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.

Using Turbulence has helped solve many metering problems. Distorted velocity profiles often cause concern about metering accuracy. If the velocity profile, as shown in Figure 4, now appears like that in Figure 6, 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 20 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. The average for these is 2.44% and this is considered normal.

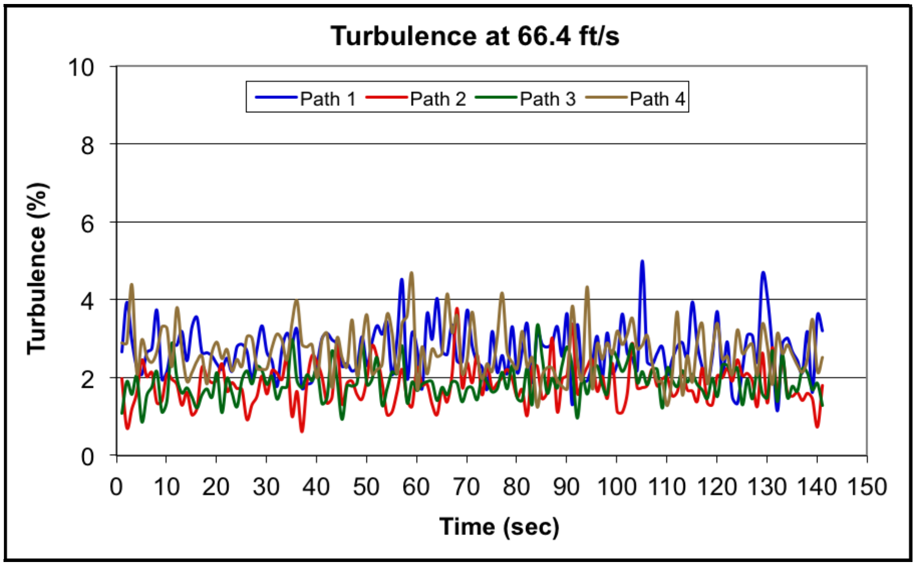


Figure 20 – Normal 12-inch Meter Turbulence

Figure 21 show the Turbulence with a 40% blocked flow conditioner as shown in Figure 5.

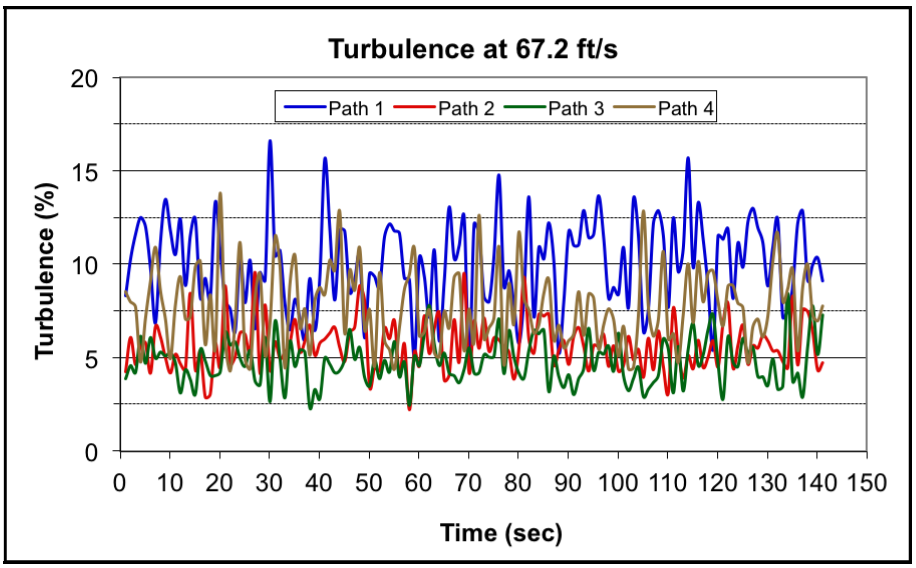


Figure 21 – High 12-inch Meter Turbulence

It is clear the turbulence in Figure 21 is about 3 times higher, or an average of 7.03%. Certainly, the velocity profiles for this meter, shown in Figures 4 and 6, also 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, or piece of carpet, and have a relatively symmetrical profile. In this situation the turbulence would be very high, indicating there is a problem with blockage. This has been observed in the field, and without Turbulence, it may have gone un-detected.

The following figure shows another example of a distorted velocity profile. This is a 12-inch meter graph taken at the time of a monthly inspection.

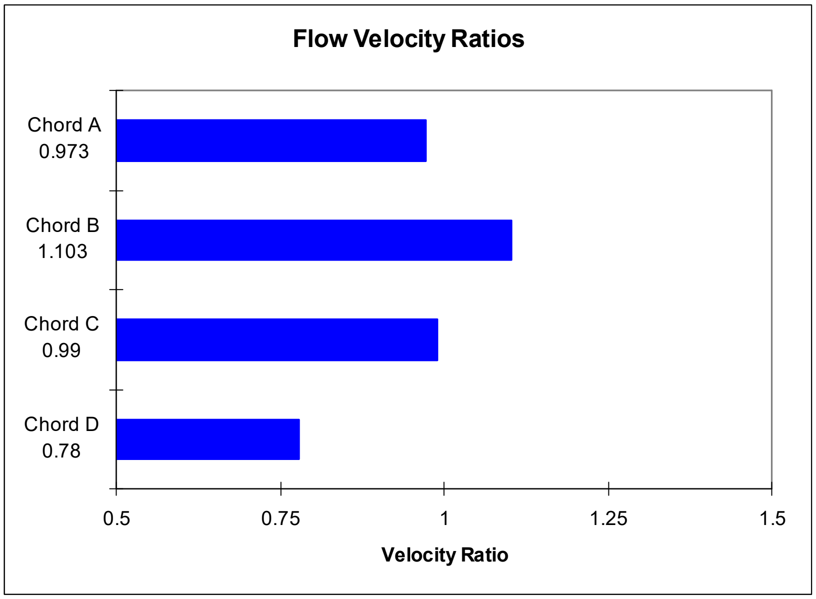


Figure 22 – 12-inch Meter with Distorted Profile

The graph shows a low velocity at the bottom of the meter. This is most likely caused by contamination in front of the flow conditioner. To validate this assumption, Turbulence should also be high. The following graph shows the turbulence for this meter.

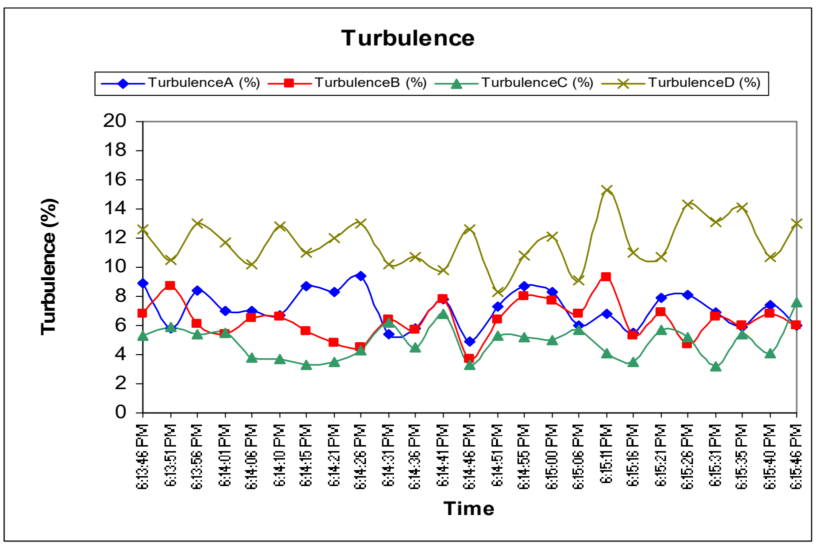


Figure 23 – 12-inch Meter with High Turbulence

Figure 23 shows all the turbulence values are significantly above the normal values that are 3-4%. Since all Turbulences are high, there must be something blocking the flow conditioner. Figure 24 shows the results from the manufacturer's software with the profile analysis. Show is the Profile Factor, Symmetry and Crossflow results.

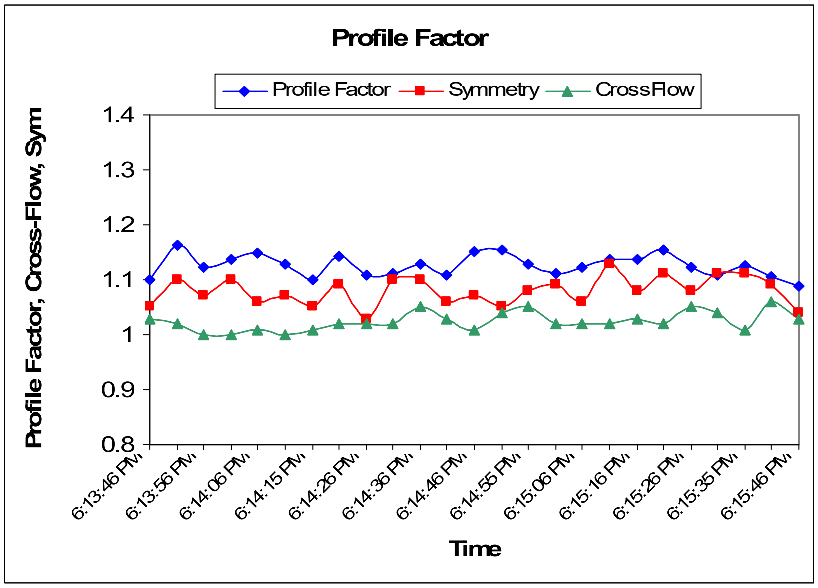


Figure 24 – 12-inch Meter Profile Factor, Symmetry and Crossflow Example

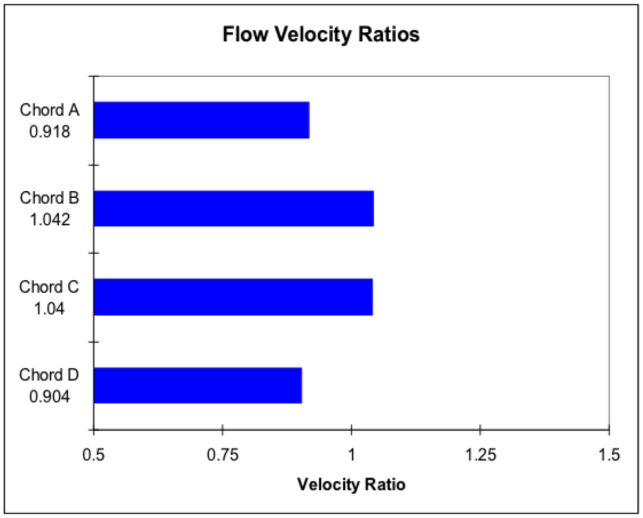
This graph shows the Profile Factor to be approximately 1.194, the Symmetry to be 1.098 and the Crossflow to be about 1.051. Normal values for Symmetry and Crossflow are 1.000 and the Profile factor should be about 1.15 for this meter.

The following pictures show the cause for the distorted flow and high Turbulence.

Figure 25 – 12-inch Flow Conditioner Blockage

Figure 26 – 12-inch Flow Conditioner Blockage

Figures 25 and 26 show the debris that was in front of the flow conditioner. These two items caused the distorted profile and high turbulence. Figure 27 shows the Path Ratios after the debris is removed, and Figure 28 shows the Turbulence values that have now returned to normal.



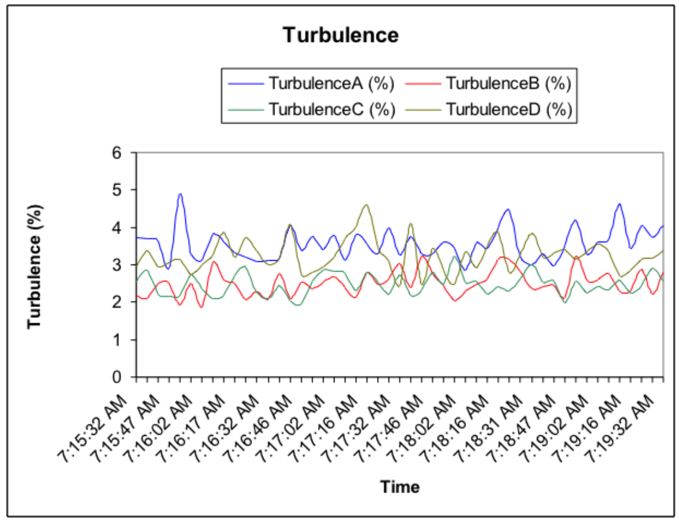


Figure 27 – 12-inch Meter With Normal Profile

Figure 28 – 12-inch Meter With Normal Turbulence

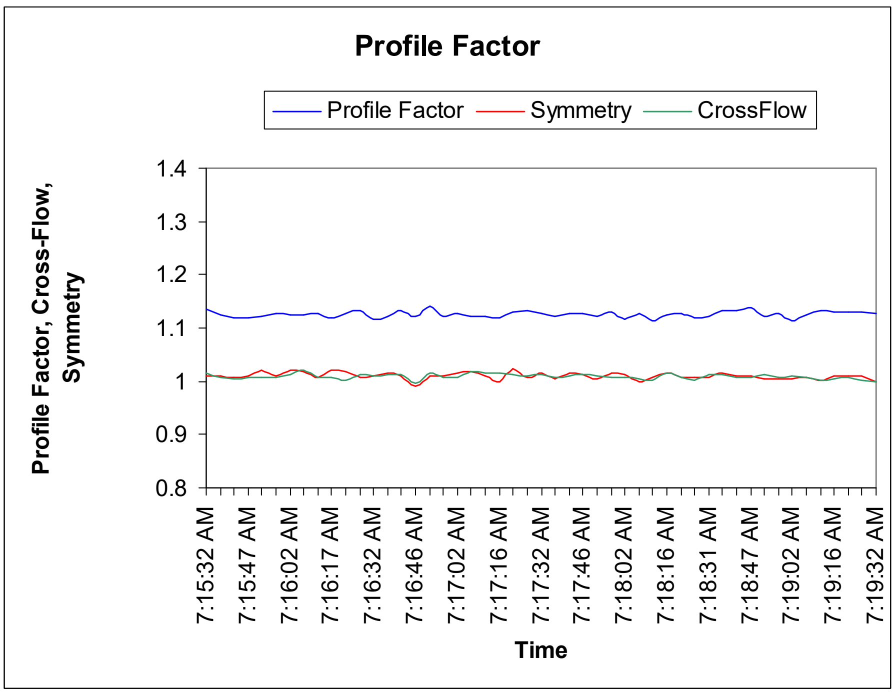


Figure 29 – 12-inch Meter Profile Factor, Symmetry and Crossflow Example

Once the debris has been removed, all the meter's diagnostics have returned to normal. All Chord Ratios in Figure 27 have returned to normal, the Turbulence values in Figure 28 are typical, and the Profile Factor, Symmetry and Crossflow values in Figure 29 are all normal.

These two examples demonstrate the power of diagnostics. If this blockage were in front of an orifice meter, it would have gone undetected until the site was visually inspected. The USM diagnostics quickly and easily identified the problem. **Turbulence, in conjunction with Path Ratios, is generally the best combination of diagnostics to help identify flow conditioner blockage.**

Liquid Detection

This section will show examples of what the diagnostics report when liquid is present. As shown in previous sections, changing conditions in the pipeline can be seen with a deviation in one or more of the meter's diagnostics. Liquid detection is a bit more unique in that there are several key indicators that all assist in determining liquid is present, and that the profile change is not due to contamination or flow conditioner blockage.

There are 4 basic diagnostic parameters that can be used to identify when liquids are present. They are Performance, Path Ratios, path SOS and Turbulence values. These are addressed in more detail in a previously published paper [Ref 6]. The following four graphs represent data from a 4-inch, 4-path Westinghouse design meter when it is subjected to increasing amounts of liquid. The baseline is 100% Gas Volume Fraction (GVF), and then liquid is systematically increased at the lab under controlled conditions until the GVF is 95% (5% Liquid Volume Fraction).

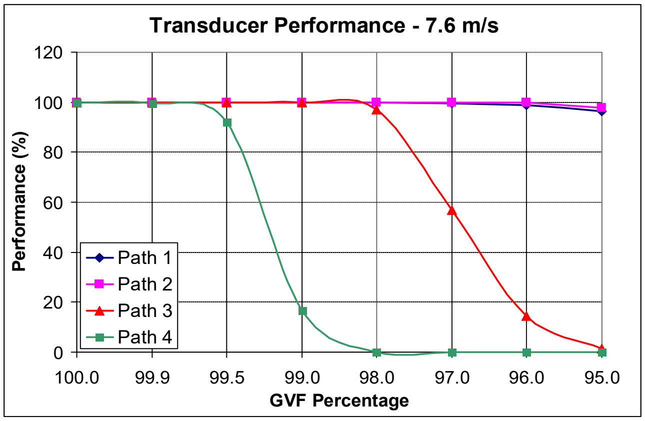


Figure 30 – 4-inch Transducer Performance

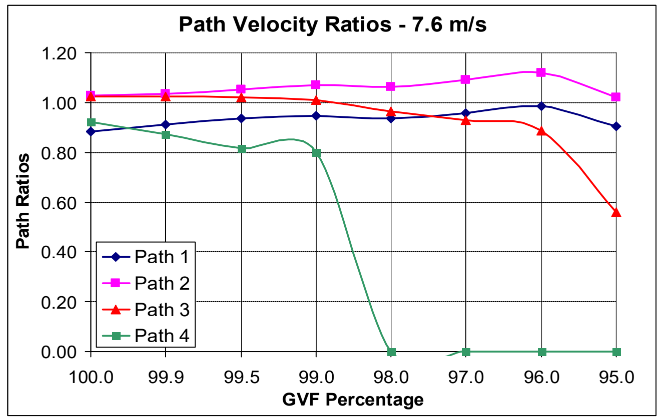


Figure 31 – 4-inch Path Velocity Ratios

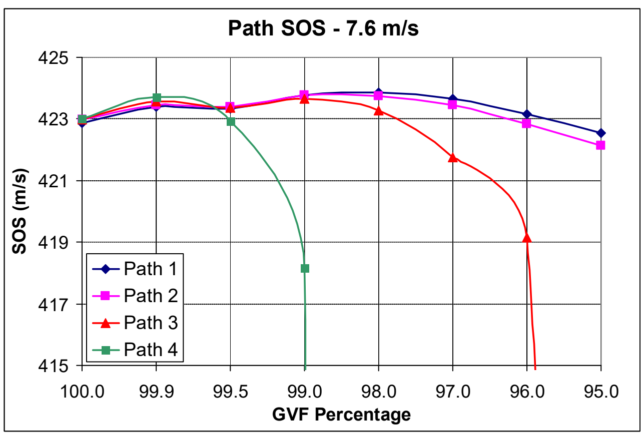


Figure 32 – 4-inch SOS Readings

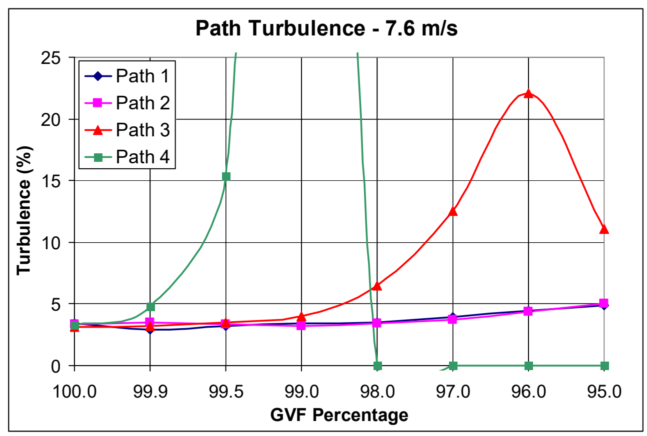


Figure 33 – 4-inch Turbulence

Figure 30 shows Path 4 performance begins to decrease when the GVF is around 99.5%, and as the liquid is increased, eventually it fails around 98%. Path 3 begins being affected at 98% and at the highest tested liquid loading of 95% GVF, it also fails. Just looking at this one diagnostic doesn't clearly show what the problem is since this could be the result of contamination or other affects. By looking at Figure 31 it is apparent the Path Ratios are changing at the same time. Path 4 begins going slower when compared to Path 1, and the same is true for Path 3 compared to Path 2.

Figure 32 shows something different is happening with per-path SOS. The SOS on Path 4 is now going slower relative to the other three paths. This might be the reverse of "common wisdom" since the SOS in liquid is higher than gas, and at this point probably mostly at the bottom of the meter. Now there are three distinctly different looking graphs of diagnostics telling us there is a problem. When these are combined with the final diagnostic, Turbulence, it is clear liquids are present. Figure 33 shows the sensitivity of Path 4 Turbulence for even the slightest amount of liquids. The important part of the Turbulence graph is that only Path 4 turbulence has increased significantly compared to all the others (which remain relatively normal until very high levels of liquid are present). This is further confirmation that liquids are present.

Let's look at what happens to the Path Ratios for the various liquid loading conditions (GVF percentages).

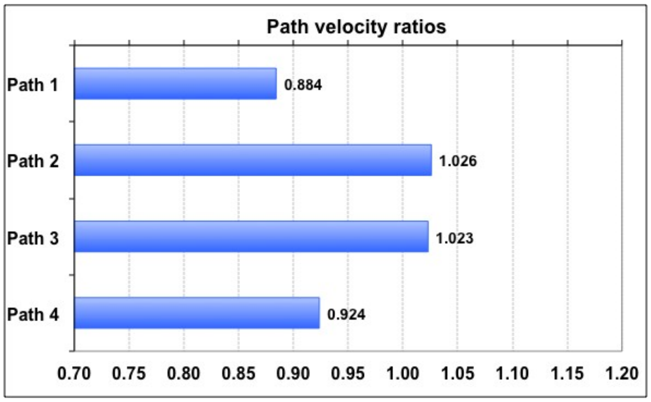


Figure 34 – 4-inch Path Ratios – 100%GVF

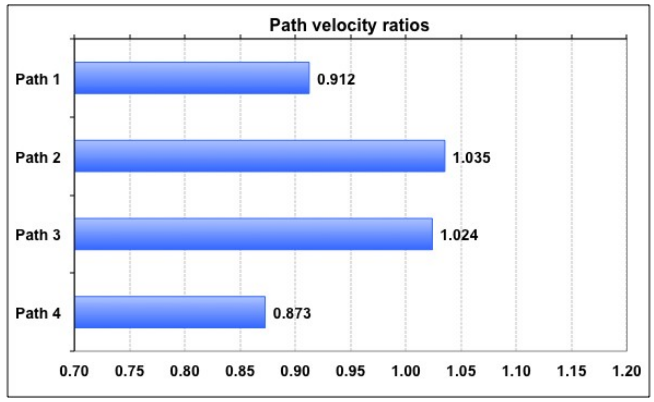


Figure 35 – 4-inch Path Ratios – 99.9%GVF

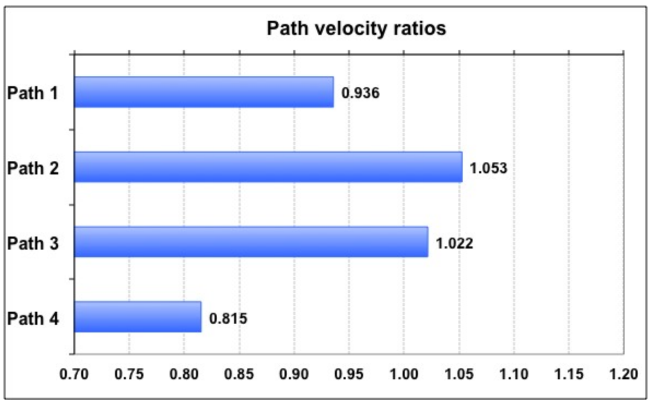


Figure 36 – 4-inch Path Ratios – 99.5%GVF

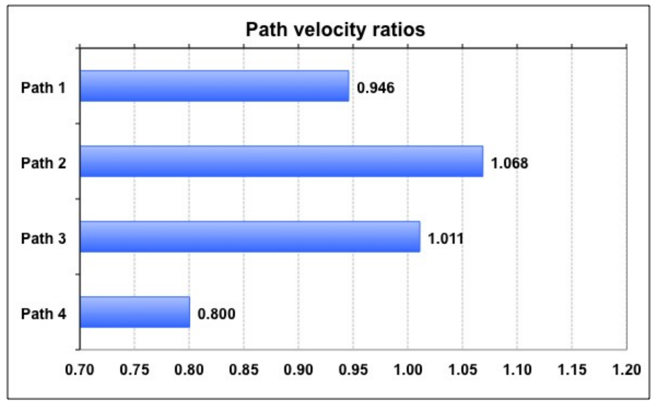


Figure 37 – 4-inch Path Ratios – 99.0%GVF

As the amount of liquid is increased, Path 4 continues to register slower relative to Path 1. As the liquid gets to a GVF of 99.5%, even Path 3 begins to read slower relative to Path 2. This is due to the liquids having to be pushed along by the gas thus causing the gas velocity for the lower paths to be lower than the upper ones. The liquids are not traveling at the same velocity as the gas. The drag caused by the liquid density being much higher results in the path reading lower gas velocities when compared to other paths of the same location from the centerline. These diagnostics clearly show the only cause for these changes can be liquids.

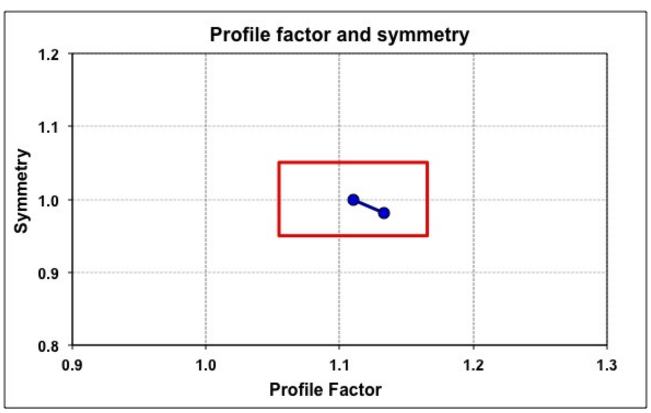


Figure 38 – 4-inch Path Ratios – 100%GVF

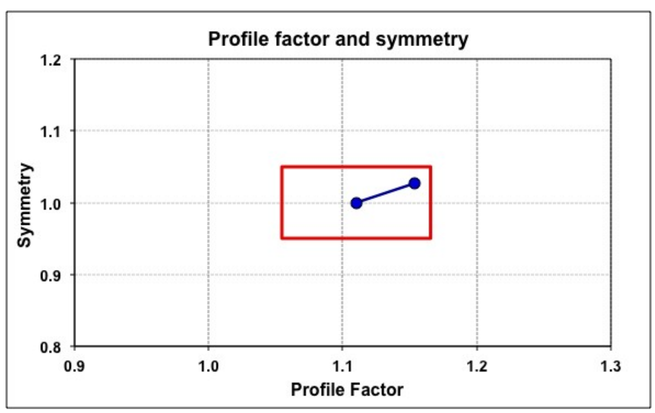


Figure 39 – 4-inch Path Ratios – 99.9%GVF

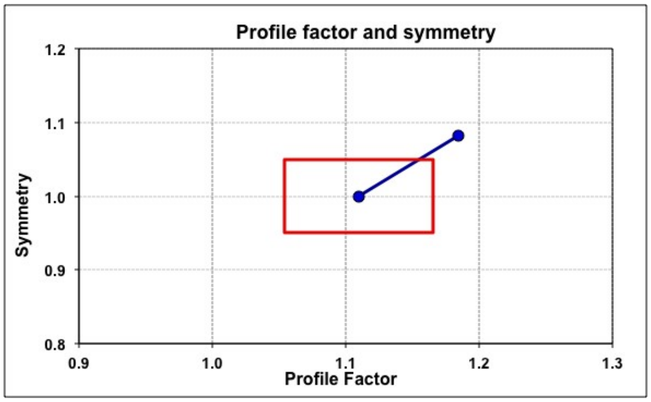


Figure 40 – 4-inch Path Ratios – 99.5%GVF

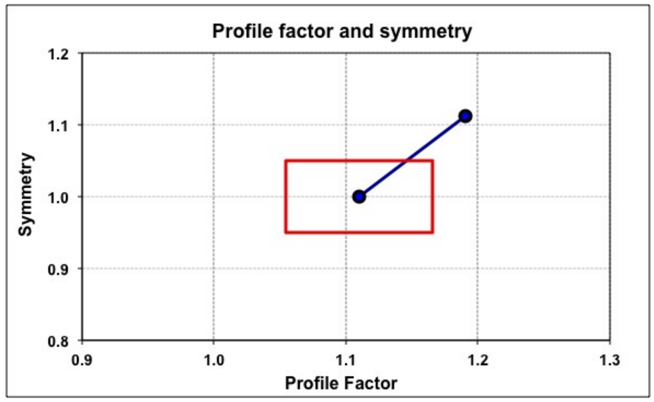


Figure 41 – 4-inch Path Ratios – 99.0%GVF

Figures 38-41 show what happens to the Profile Factor and Symmetry when liquids are present. Figure 38 is 100% natural gas and Figures 39-41 show how the profile changes as the liquids are increased. These graphs represent the analysis of the Path Ratios as shown in Figures 34-37. The dot that represents the current Profile Factor and Symmetry goes "Northeast" as more liquids are present. Combining the profile information along with Turbulence makes identifying liquids very easy.

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 wealth 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, Profile Factory, Symmetry and Crossflow 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 and immediately send this through the client's data acquisition system.

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 gas ultrasonic metering technology.

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