

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

Initially GUSMs had basic or functional diagnostics that indicated that the meter and all of its components were operating correctly per manufacturers requirements. These included:

- Per Path performance
- Individual path velocities
- Individual path speed of sound
- Gains for each transducer
- Signal-to-noise (SNR) for each transducer

These Diagnostic values will not be expanded on in this paper as they are analyzed and displayed differently by each meter manufacturer, however it is important to note that any use of Advanced diagnostics is basically useless if the basic diagnostic used to validate the meter performance fail.

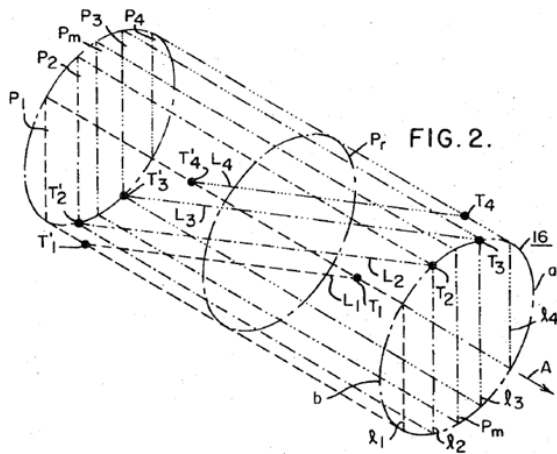
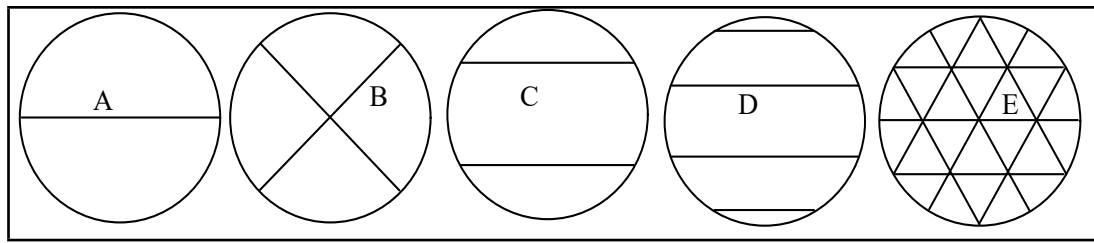
Some manufacturers provide additional diagnostic features such as swirl angle, Turbulence, AGA 8 Part 2 and/or AGA 10 SOS vs. the meter's reported SOS, and many others.

Initially data that was collected was automatically converted in Excel format and graphed to help end user easily view and interpret that data without the need to try and use the raw data. Improvements were made to further enhance the graphs by adding sanity bands which made it easier to see if the graphed values were within range. This has been further enhanced by adding internal algorithms that are designed to help further analyze the data and provide simple green, yellow and red indications. These values become even more valuable when baseline values for the metering assembly are established during the calibration and startup of the units.

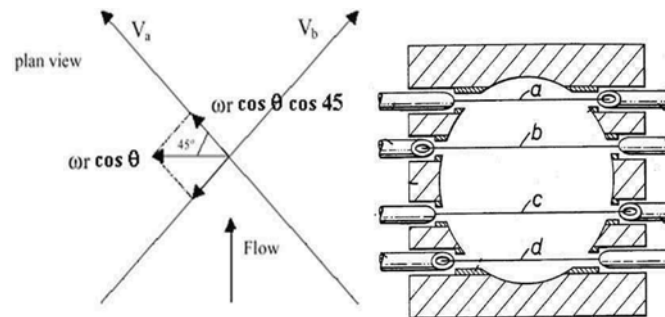
It is vital for users to collect periodic maintenance log files, however some manufactures have implemented archiving capabilities that allow for less frequent data collection and show the meter performance over extended periods of time. This data is available either through direct connection to the meters either locally or by remote connections and the enhanced meter analysis can also be collected on a regular basis.

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 3], 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. Looking at differences in SOS between the various paths may require somewhat different analysis. Most analysis in this paper will be applicable to design D in Figure 1. An offshoot of the Westinghouse design which is D in Figure 1 is the British Gas design which uses alternating cross paths to give a 3D view of the flowing gas.



Westinghouse Design



British Gas design

Figure 1 – USM Path layouts and Four Path Chordal USM 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 meters, 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 at.

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 conditions. Flow conditioners significantly reduce gas profiles distortions arriving at the meter, but in extreme cases may not 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.

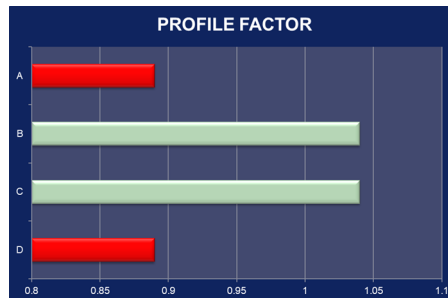
To understand if the velocity profile has changed over time, enhanced methods of diagnosing the USM have been developed. Since the velocity profile is the most difficult, due to the wide range of possible scenarios, a simpler method of summarizing these profiles would be beneficial.

Velocity Diagnostics

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. Below are a list of velocity diagnostics

$$\text{Profile Factor} = (Bvel + Cvel)/(Avel + Dvel)$$

This is a ratio of the meter's four chordal velocities, the calculated value is independent of velocity remaining constant throughout the full velocity range of the meter. When the velocity Profile Factor (PF) goes out of the specified range it is an indication that the meter or the installation is changing. Long term shifts in Profile Factor are usually due to build up in the meter tube piping and on the flow conditioner, a sudden shift in this value indicate an upstream blockage. A generic value for PF is around 1.17 however this will be different depending on meter size and upstream piping components.



$$\text{Symmetry} = (Avel + Bvel)/(Cvel + Dvel)$$

Asymmetry compares the upper and lower portions of the pipe, this will indicate if there is a distorted flow profile that may not appear as a Profile Factor error. This can be caused by horizontal disturbances in the piping such as blocked flow conditioners or debris lodged in the line. Under normal conditions these values should be around 1.00, subtle changes over time can indicate internal build up while sudden changes normally indicate a block upstream.



$$\text{Cross Flow} = (Avel + Cvel)/(Bvel + Dvel)$$

Cross flow is a comparison of the velocities of paths in the same vertical angular plane. The paths of the meter alternately cross, therefore A and C are in the same vertical plane as are B and D. A result that is not close to 1.00 indicates that there could be a vertical disturbance, this could be caused by a partially closed valve or a blocked flow conditioner.

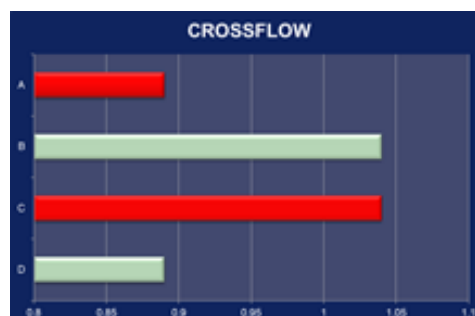


Figure 2, shows all of the velocity diagnostics values discussed above. There are some slight changes in the values throughout the velocity range of the meter

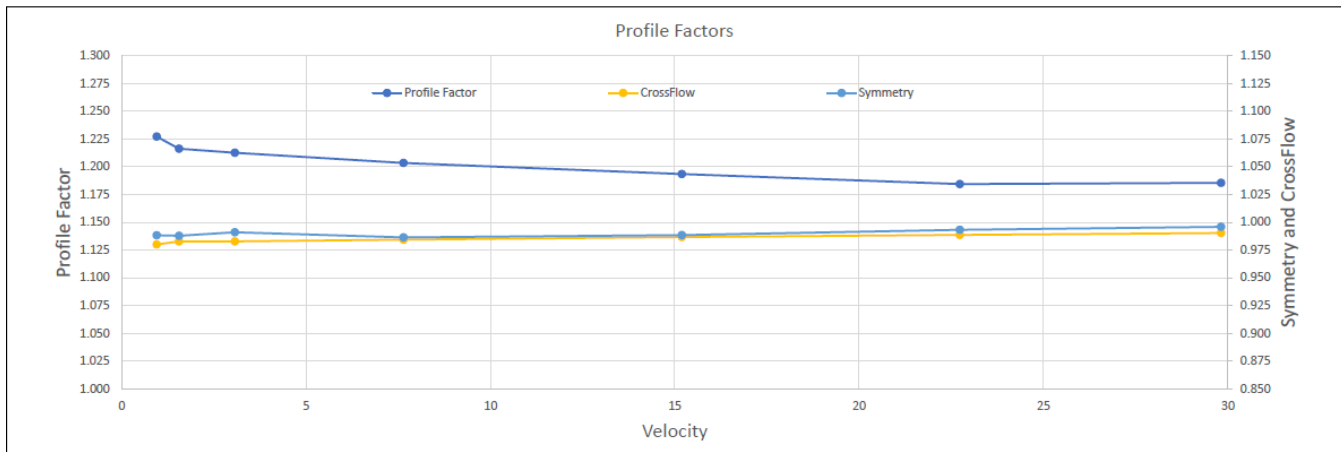


Figure 2 – Profile Factor, Symmetry and Crossflow

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 3 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.

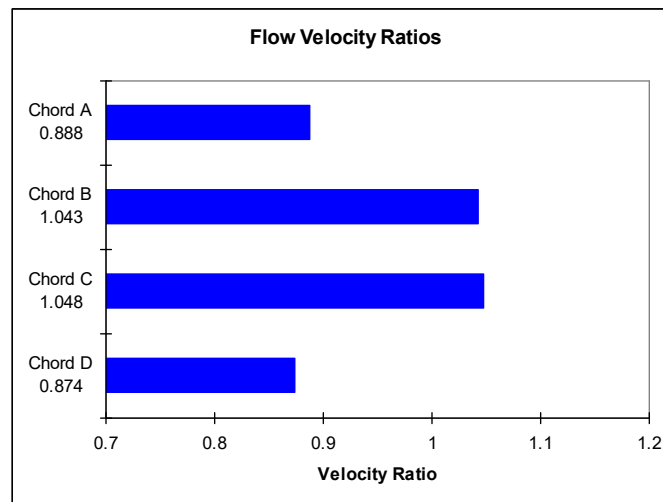


Figure 3 –12-Inch Meter Profile – Normal

To test the effects of blockages the flow conditioner was modified to have about 40% of the holes blocked with duct tape to simulate a glove which was found in front of a meter in service. Duct tape was used to ensure repeatability. Figure 4 shows the flow conditioner just before it was installed in the pipeline.



Figure 4 – 40% Blocked Flow Conditioner

Figure 5 shows the velocity ratios during the time the flow conditioner was blocked. This was taken at a velocity of 18 mps (59 fps). The profile at two other velocities, 6 mps (19.68 fps) and 12 mps (39.37 fps), looked the similar.

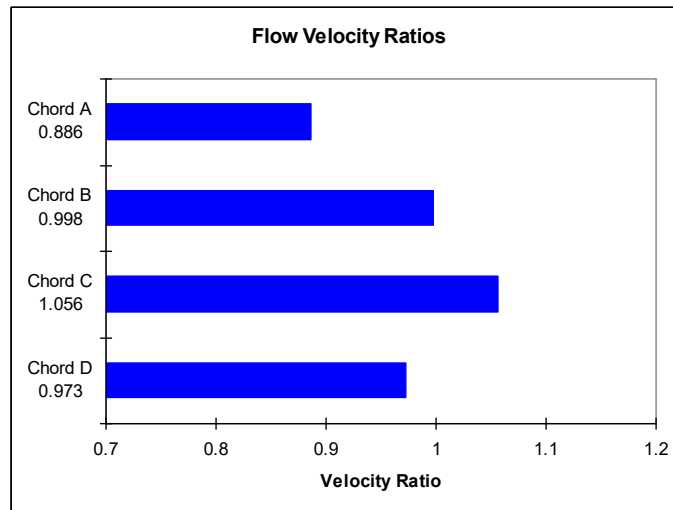


Figure 5 – 12-inch Meter Profile – 40% Blocked

The Profile is obviously distorted with higher-than-normal readings on paths C and D, and lower than normal on paths A and B. The flow conditioner was installed with the blockage at the bottom of the pipe. As the gas flowed through the open holes the velocity increased and Bernoulli's effect caused, lower pressure to be created just downstream of the blockage causing the gas to then accelerate downward, thus causing the higher velocity at the bottom of the meter than at the top.

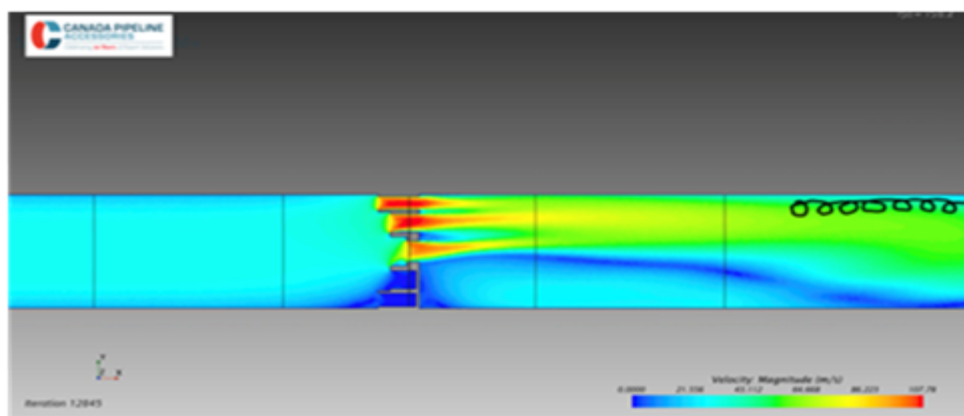


Figure 6 – CFD of Bernoulli's effect at the blockage

From Figure 6 you can see the gas accelerate over the blockage and then get pulled down on the back side of the Flow Conditioner due to the pressure reduction. Bernoulli's equation states that as velocity increases pressure decreases, this causes the flow to also become unstable on the opposite side of the blockage. The squiggly black lines on the upper right of figure 6 attempts to show where the instability would occur. This instability introduces another diagnostic called turbulence. Turbulence values are somewhat misleading as all fluid flow has Turbulence, however this diagnostic is basically the standard deviations of the per path velocities between consecutive measurements. Figure 7 shows the turbulence values for the blockage tests discussed above, the green band shows where we would normally expect turbulence to be, paths A and D around 4-5% and B and C around 2-3%.

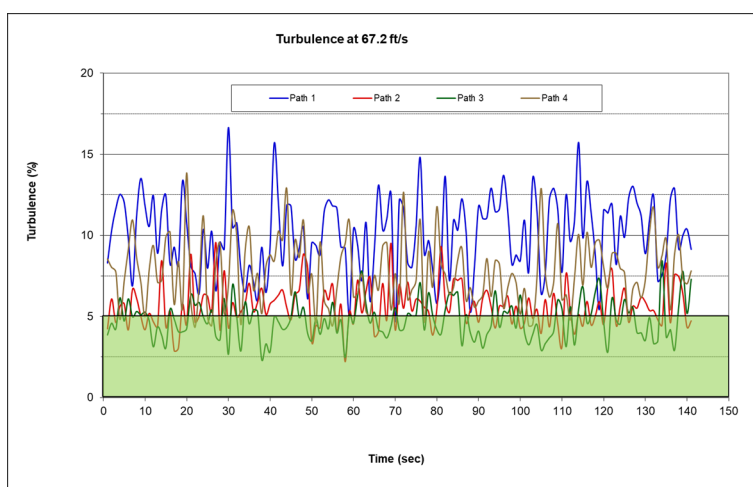


Figure 7 – Turbulence – 40% Blocked Flow Conditioner

After installation in the field a meter typically will generate a Profile Factor that is repeatable to ± 0.05 (or about 5%). 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 8 shows the result of the three test velocities and the impact on metering accuracy.

Velocity (ms ⁻¹)	% Diff
18	0.22
12	0.19
6	0.17

Figure 8 – Blocked Flow Conditioner Results

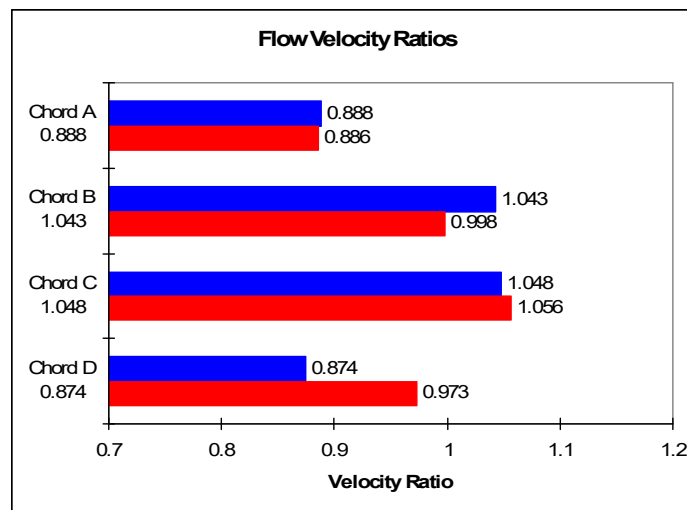


Figure 9 – Blocked Flow Conditioner Profile Factors

As can be seen in Figure 8 the meter was affected by an average of about .2% for all flow rates. In this case the meter slightly over-registered with this distorted profile. Figure 9 show that profiles for the meter with no blockage in blue and with the blockage in red.

The assumption may be made that if you monitor Profile factor alone that it will indicate whether a meter is operating correctly, nothing could be further from the truth. There are a suite of diagnostics that need to be monitored to ensure that the measurement uncertainty is at its lowest. Figure 10 shows a graph of a Profile Factor with a mean value of 1.1510 which is right in the expected range.

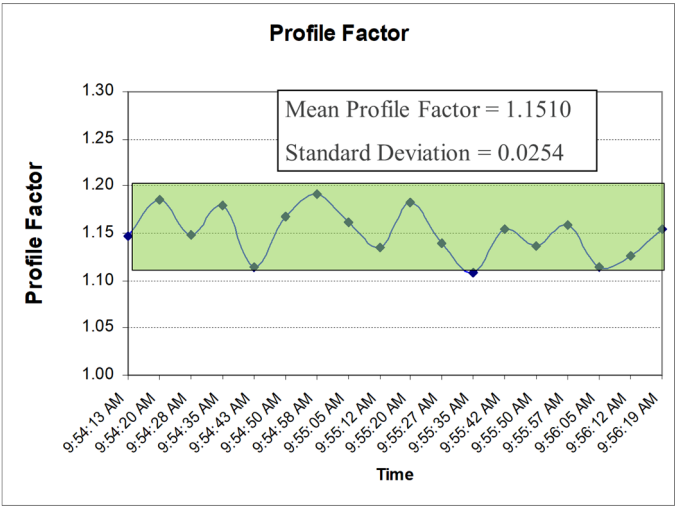


Figure 10 – Profile Factor

If only the Profile Factor were observed the meter would be assumed to be operating correctly, Figure 11 shows the Turbulence values which are outside the expected range

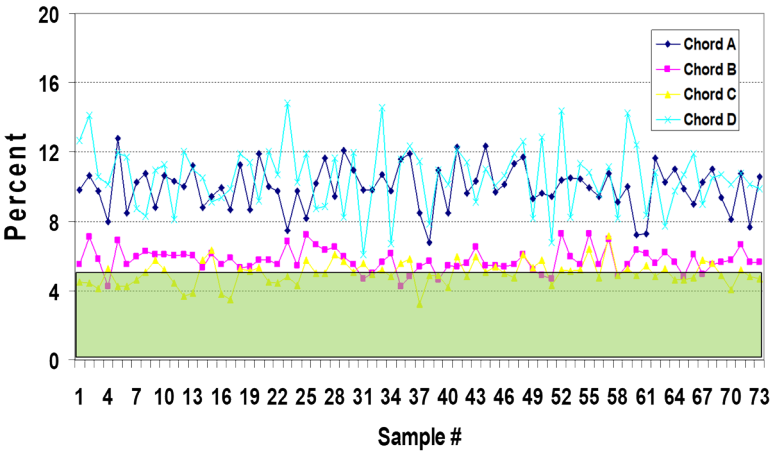


Figure 11 – Turbulence

Looking at Figure 11 it clearly shows that there is some sort of problem, Figure 12 shows what was causing the high Turbulence values while the Profile Factor stayed in the expected range.

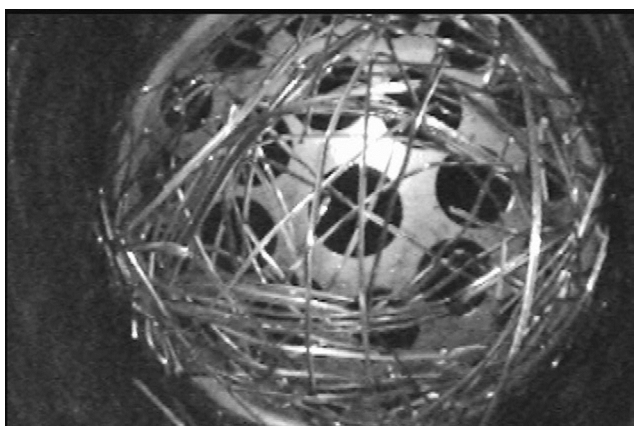


Figure 12 – Unwound spiral gasket against the Flow Conditioner

Turbulence

This was briefly discussed previously but requires some further discussion. 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. The term Turbulence is somewhat confusing as all flow is turbulent. 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 shows paths A and D to have around 3-5% turbulence, and paths B and C around 2-3%. This is based upon the history of many meters. The outer paths A and D, 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, and is graphed out automatically for quick review.

Using Turbulence has helped solve many metering problems as shown in Figures 10 and 11. Distorted velocity profiles often cause concern about metering accuracy. If the Profile Factor shown in Figure 10 were used as a stand-alone diagnostic a series issue would have been overlooked.

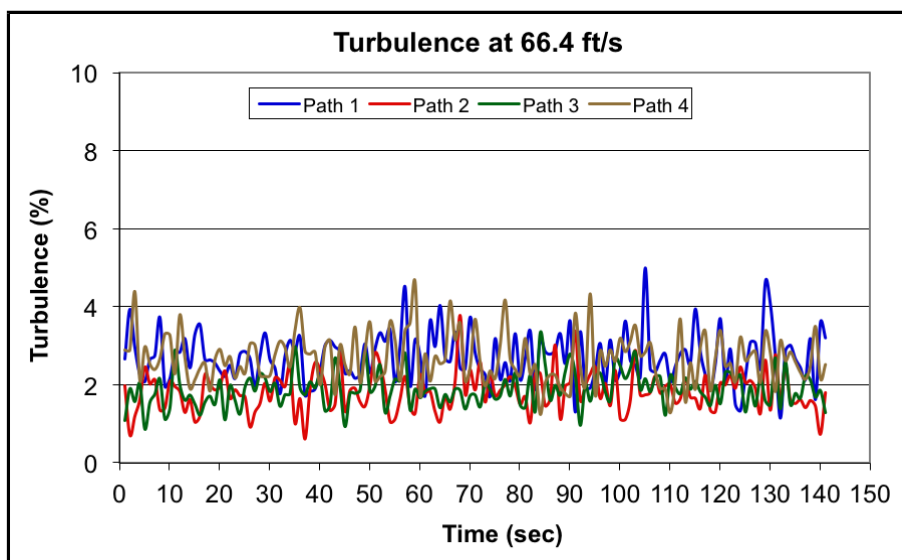


Figure 12 – Normal 12-inch Meter Turbulence

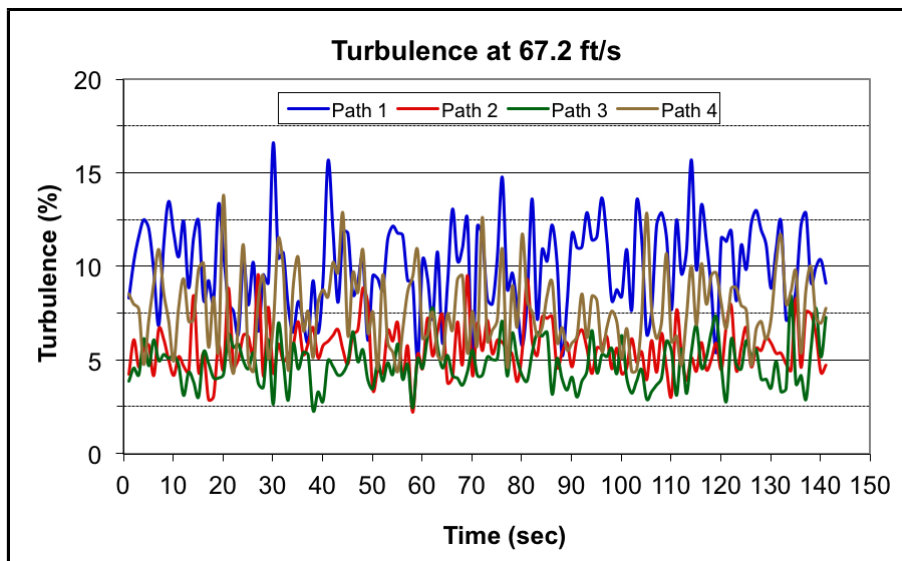


Figure 13 – High 12-inch Meter Turbulence

It is clear the turbulence in Figure 13 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 during a monthly inspection.

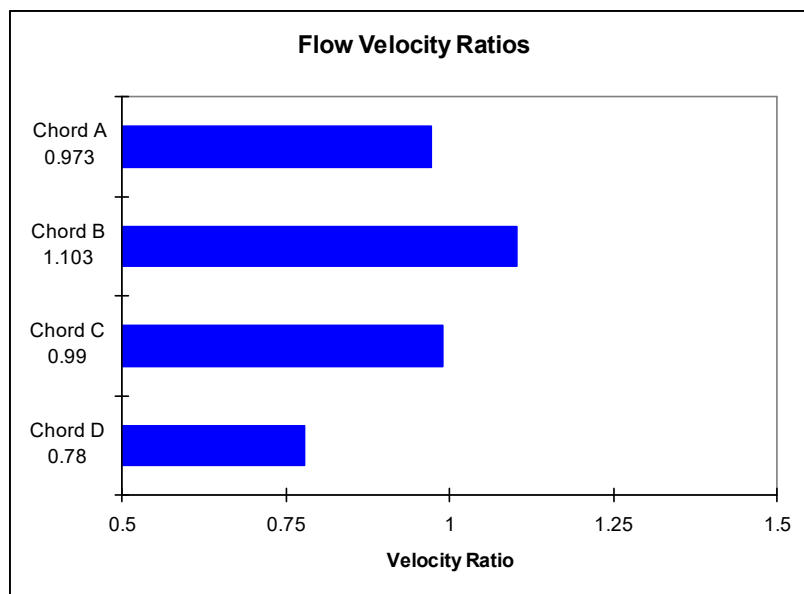


Figure 14 – 12-inch Meter with Distorted Profile

The graph shows a low velocity at the bottom of the meter. This is most likely caused by a blockage in front and on the top of the flow conditioner. To validate this assumption, Turbulence should also be high on path D as previously discussed. The following graph shows the turbulence for this meter.

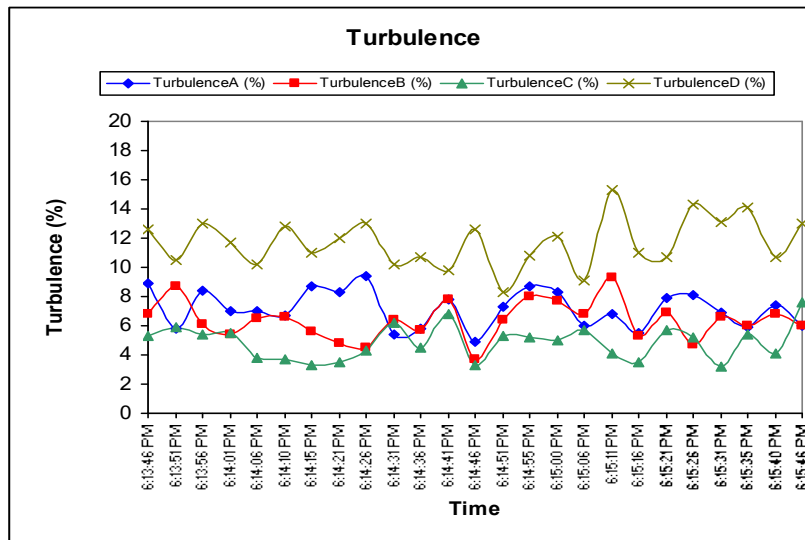


Figure 15 – 12-inch Meter with High Turbulence

Figure 15 shows all the turbulence values are significantly above the normal values that are 3-5%. Since all Turbulences are high, there must be something blocking the flow conditioner. Figure 16 shows Profile Factor, Symmetry and Crossflow results.

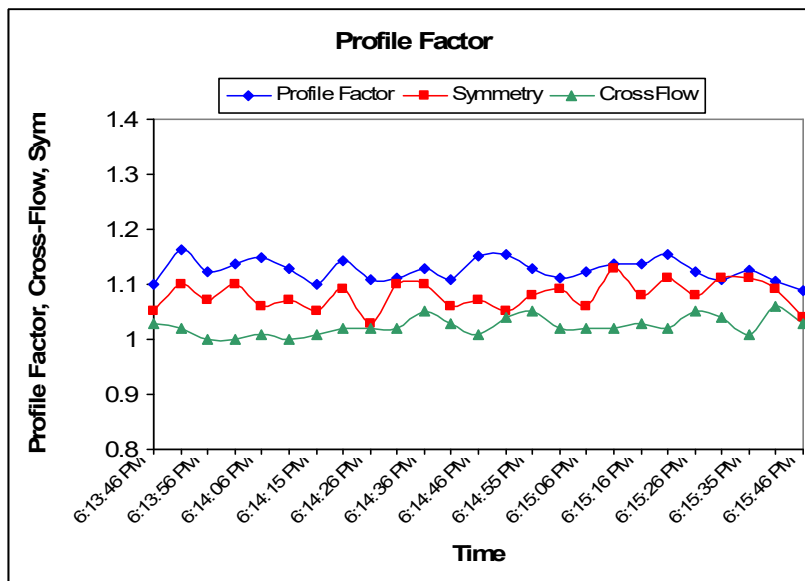


Figure 16 – 12-inch Meter Profile Factor, Symmetry and Crossflow Example

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 17 – 12-inch Flow Conditioner Blockage



Figure 18 – 12-inch Flow Conditioner Blockage

Figures 17 and 18 show the debris that was in front of the flow conditioner. These two items a 2 x 6 and a piece of foam caused the distorted profile and high turbulence. Figure 19 shows the Path Ratios after the debris is removed, and Figure 20 shows the Turbulence values that have now returned to normal.

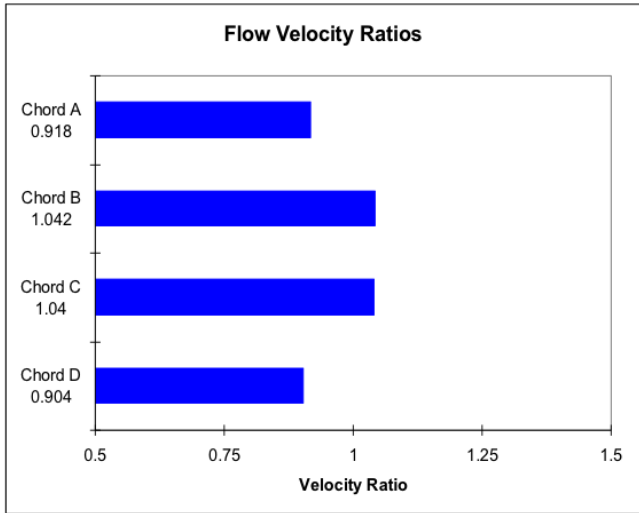


Figure 19 – 12-inch Meter With Normal Profile

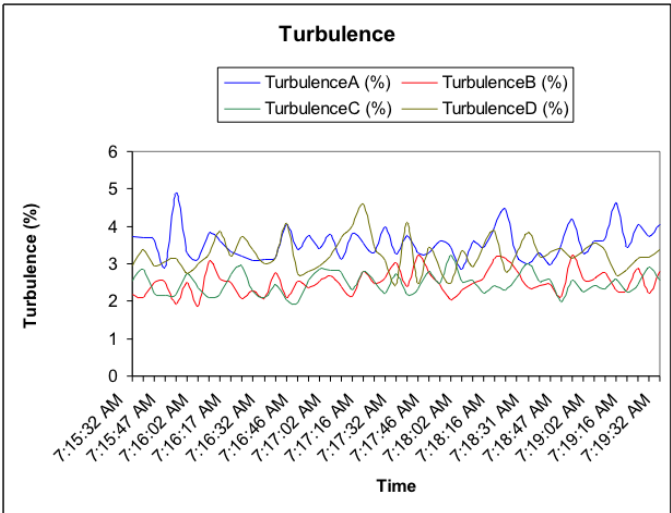


Figure 20 – 12-inch Meter With Normal Turbulence

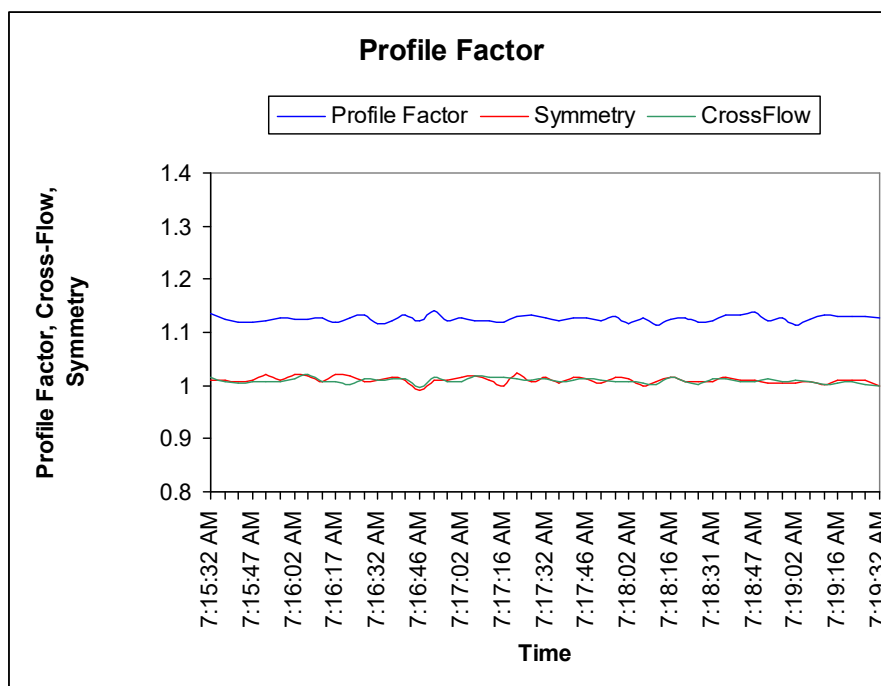


Figure 21 – 12-inch Meter Profile Factor, Symmetry and Crossflow Example

Once the debris was removed, all the meter's diagnostics have returned to normal. All Chord Ratios in Figure 19 are within sanity limits, the Turbulence values in Figure 20 are typical, and the Profile Factor, Symmetry and Crossflow values in Figure 21 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 if 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. 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).

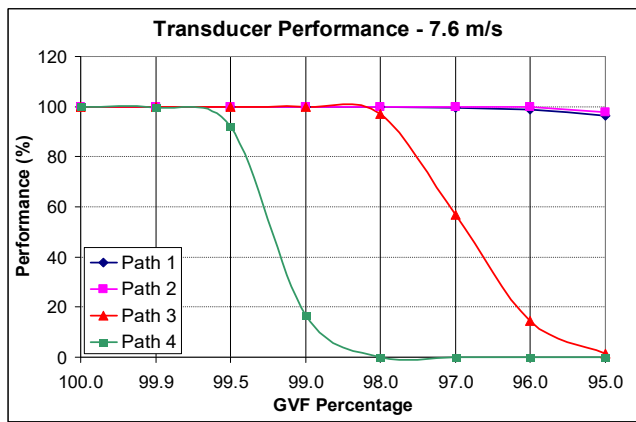


Figure 22 – 4-inch Transducer Performance

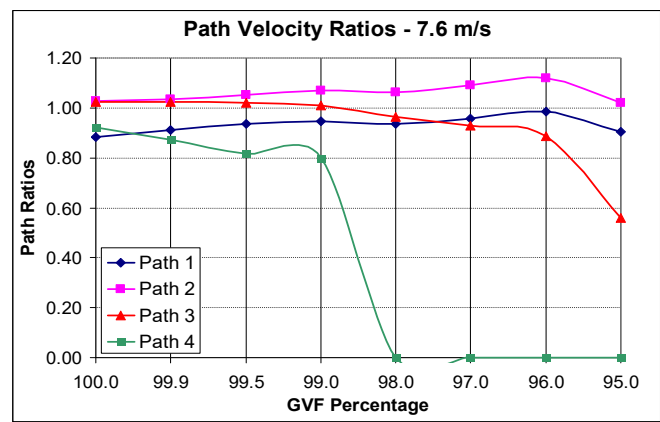


Figure 23 – 4-inch Path Velocity Ratios

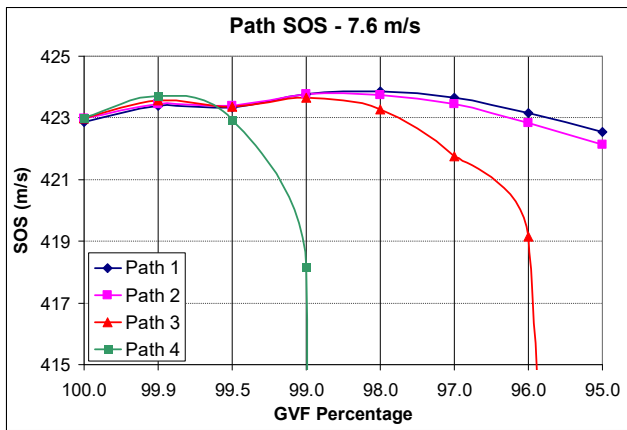


Figure 24 – 4-inch SOS Readings

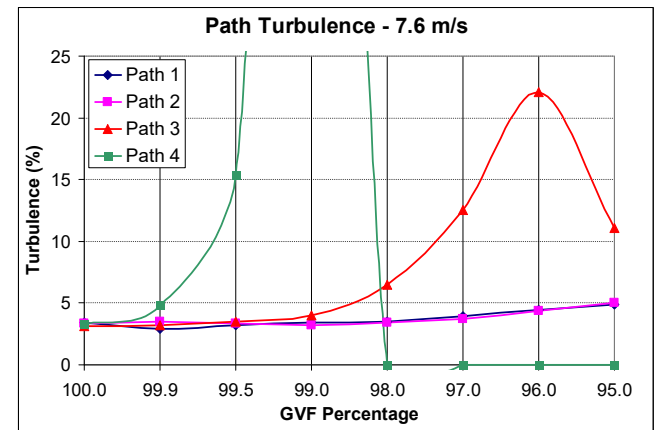


Figure 25 – 4-inch Turbulence

Figure 22 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 23 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 24 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 25 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).

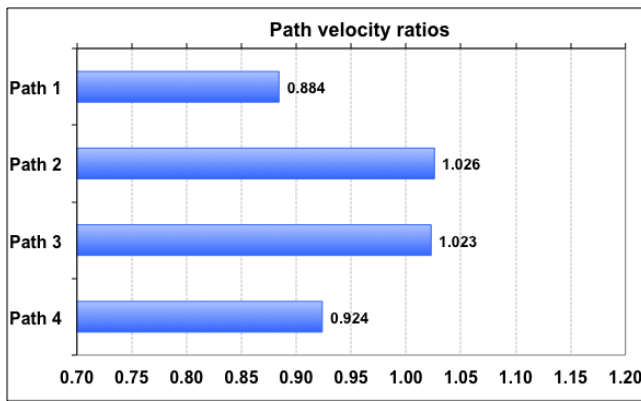


Figure 26 – 4-inch Path Ratios – 100%GVF

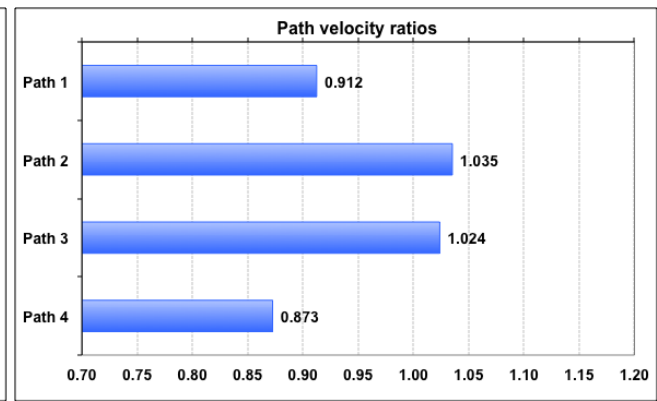


Figure 27 – 4-inch Path Ratios – 99.9%GVF

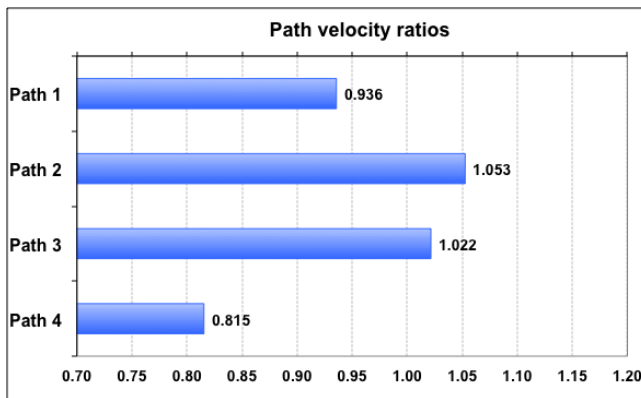


Figure 28 – 4-inch Path Ratios – 99.5%GVF

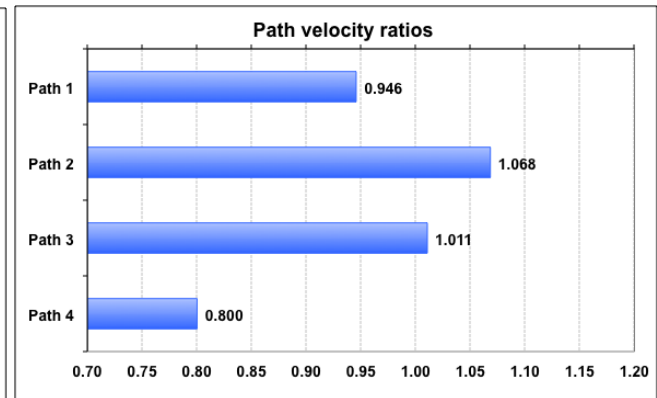


Figure 29 – 4-inch Path Ratios – 99.0%GVF

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 whose density is 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.

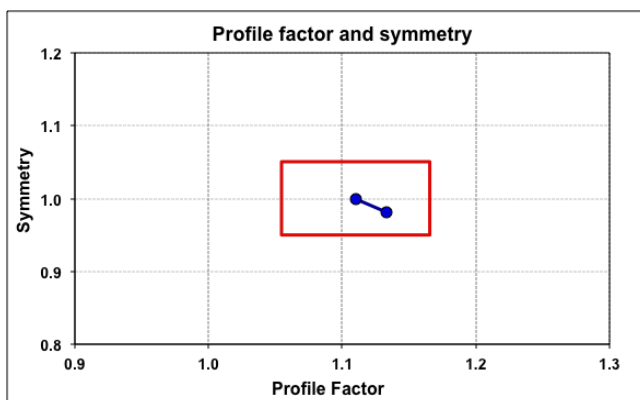


Figure 30 – 4-inch Path Ratios – 100%GVF

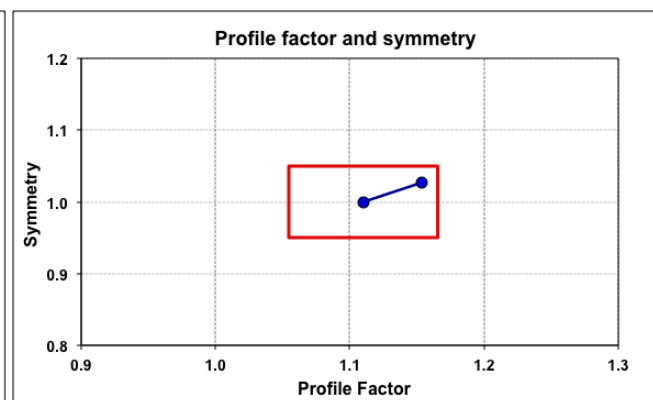


Figure 31 – 4-inch Path Ratios – 99.9%GVF

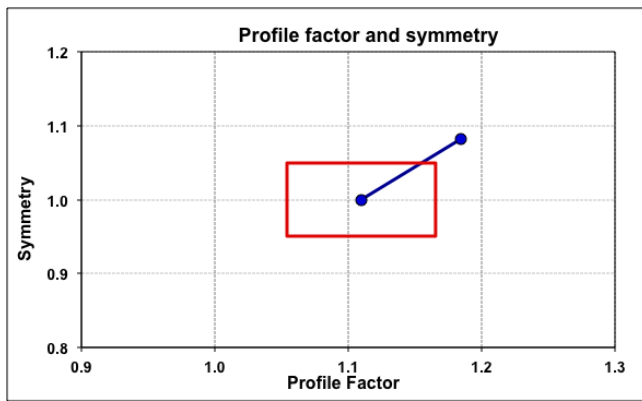


Figure 32 – 4-inch Path Ratios – 99.5%GVF

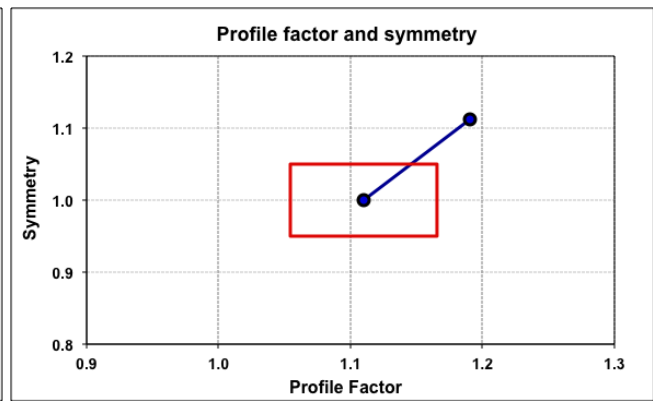


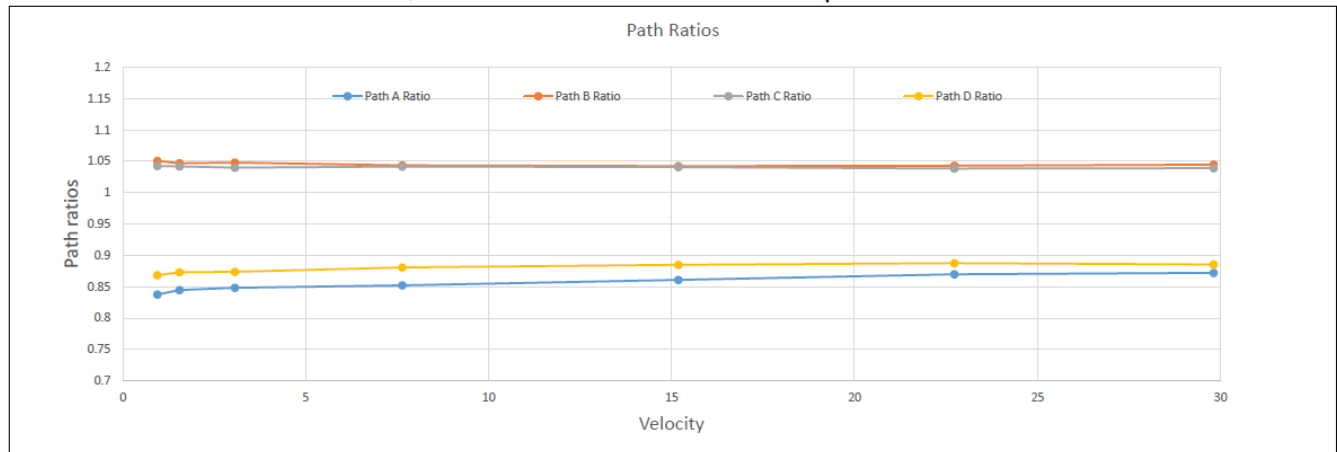
Figure 33 – 4-inch Path Ratios – 99.0%GVF

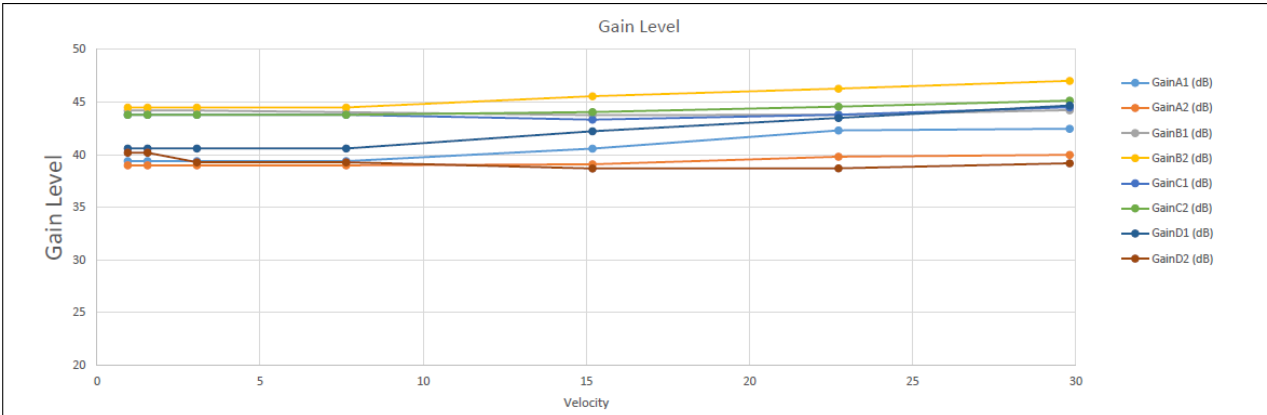
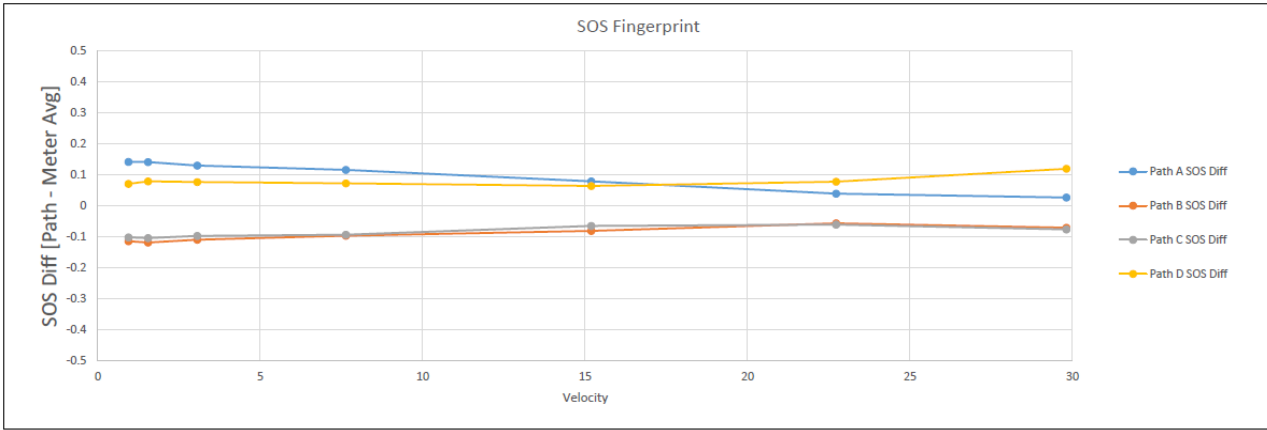
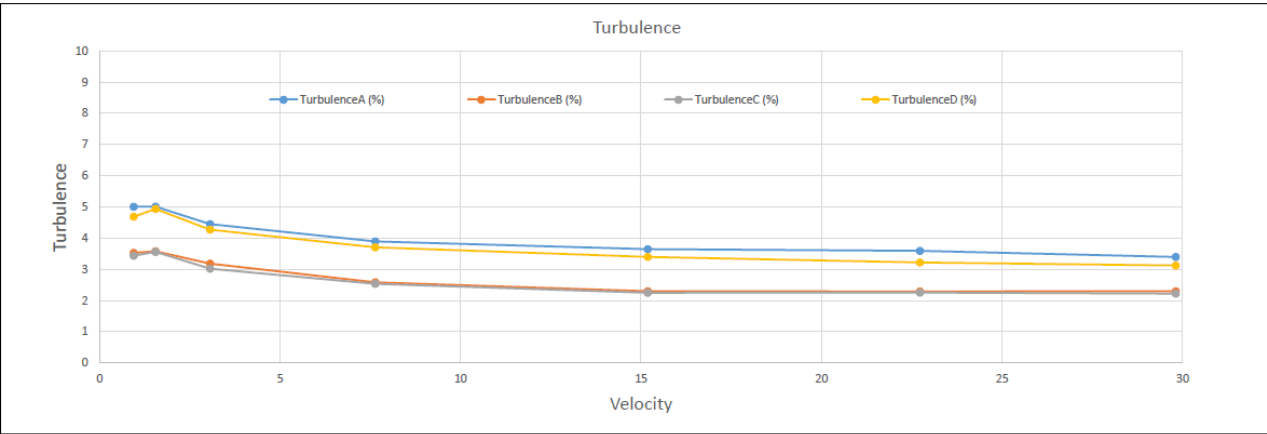
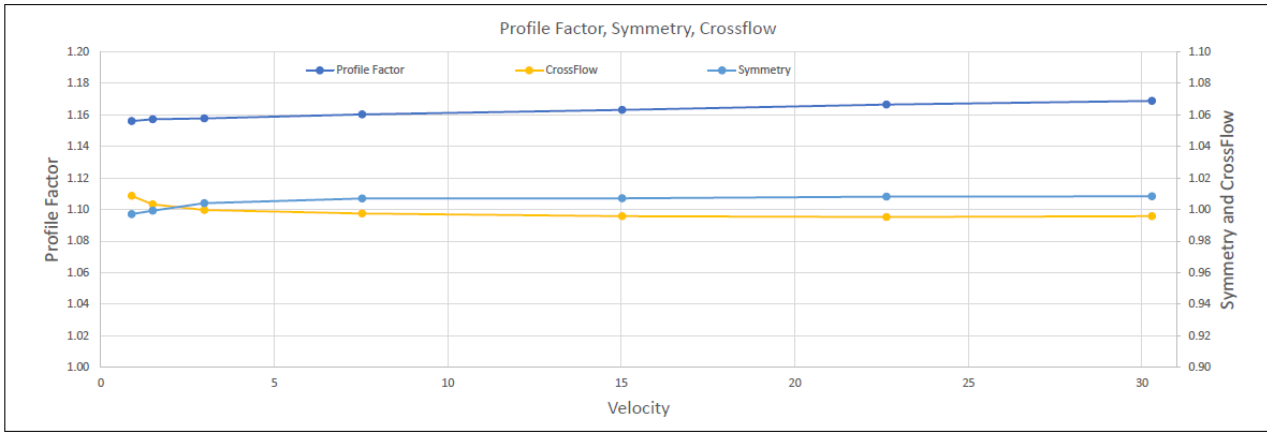
Figures 30-33 show what happens to the Profile Factor and Symmetry when liquids are present. Figure 30 is 100% natural gas and Figures 30-33 show how the profile changes as the liquids are increased. These graphs represent the analysis of the Path Ratios as shown in Figures 26-29. The dots that represents 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.

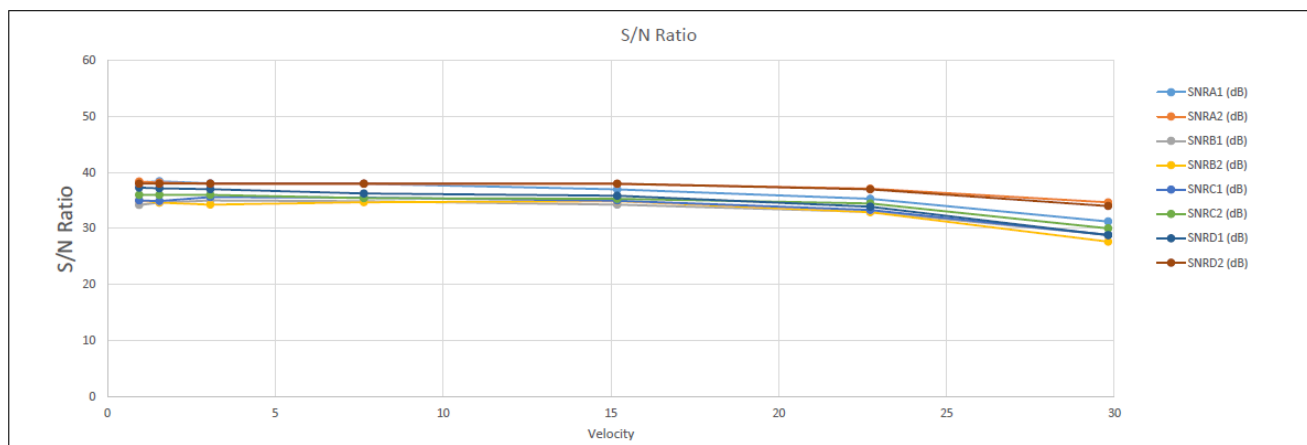
BASELINE AND FINGER PRINTING

During all these discussions we have looked at changes in the meter’s diagnostics, most manufacturers have added the ability to baseline meters when they are started up, these values give a starting point that can be used as a reference to ensure that there have been no significant changes in the meter’s operation. As well calibration facilities are providing detailed summaries of the diagnostic data throughout the entire calibration giving a baseline reference for all of the velocities that the meter may see. Below is an example of diagnostic analysis, the graphs show all of the basic and advanced diagnostics. The last image shows one of the detailed views that show a snapshot of the diagnostics at a certain velocity.

S/N 160048571 15-Apr-20 TCC







S/N 160048571 15-Apr-20

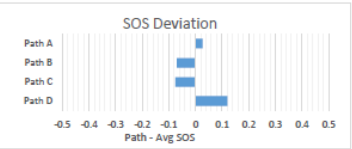
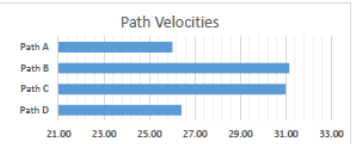
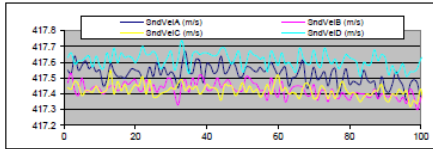
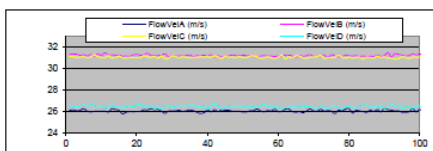


Profile Factor: 1.198 QFlow (m3/hr): 3164.23
 Symmetry: 0.9958 AvgFlow (m/s): 29.82
 CrossFlow: 0.9902 AvgSndVel (m/s): 417.50

	FlowVelA (m/s)	FlowVelB (m/s)	FlowVelC (m/s)	FlowVelD (m/s)
AVG	28.01	31.15	30.99	28.41
MAX	28.24	31.42	31.21	28.68
MIN	25.73	30.94	30.81	26.14
STDEV	0.11	0.09	0.08	0.11

	SndVelA (m/s)	SndVelB (m/s)	SndVelC (m/s)	SndVelD (m/s)
AVG	417.52	417.43	417.42	417.82
MAX	417.87	417.53	417.55	417.74
MIN	417.36	417.30	417.29	417.51
STDEV	0.06	0.05	0.04	0.05

	TurbulenceA (%)	TurbulenceB (%)	TurbulenceC (%)	TurbulenceD (%)
AVG	3.39	2.30	2.22	3.12
MAX	4.03	2.81	2.68	5.65
MIN	2.63	1.78	1.74	2.51
STDEV	0.32	0.22	0.19	0.35



	PerfAUp (%)	PerfADown (%)	PerfBUp (%)	PerfBDown (%)	PerfCUp (%)	PerfCDown (%)	PerfDUp (%)	PerfDDown (%)
AVG	100.00	100.00	100.00	99.98	99.98	100.00	99.82	99.63
MAX	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
MIN	100.00	100.00	100.00	99.00	99.00	100.00	98.00	97.00
STDEV	0.00	0.00	0.00	0.20	0.20	0.00	0.57	0.41

	GainA1 (dB)	GainA2 (dB)	GainB1 (dB)	GainB2 (dB)	GainC1 (dB)	GainC2 (dB)	GainD1 (dB)	GainD2 (dB)
AVG	42.48	40.00	44.24	47.03	44.52	45.15	44.68	39.28
MAX	43.90	40.90	45.20	48.10	45.90	46.20	46.40	40.30
MIN	41.00	38.80	42.80	45.80	43.30	44.10	42.70	35.90
STDEV	0.67	0.45	0.51	0.55	0.51	0.49	0.68	0.60

	SNRA1 (dB)	SNRA2 (dB)	SNRB1 (dB)	SNRB2 (dB)	SNRC1 (dB)	SNRC2 (dB)	SNRD1 (dB)	SNRD2 (dB)
AVG	31.24	34.66	28.86	27.65	28.85	30.02	28.80	34.00
MAX	32.00	35.00	30.00	28.00	30.00	31.00	30.00	35.00
MIN	31.00	34.00	28.00	26.00	28.00	29.00	28.00	33.00
STDEV	0.43	0.47	0.40	0.50	0.48	0.42	0.47	0.23

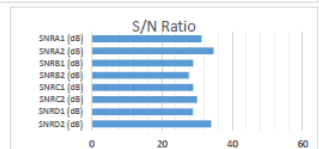
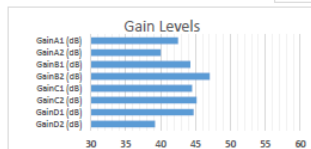
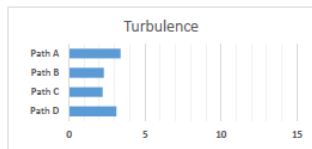
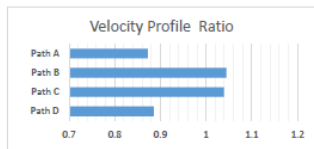
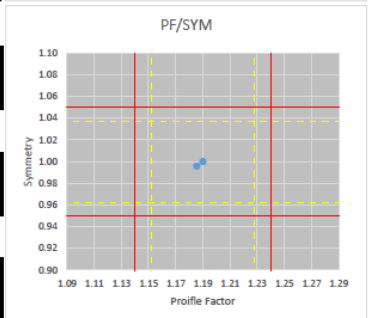


Figure 34 – Detailed Diagnostic View at 29.82 fps

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. Newer meters with enough computing 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.

REFERENCES

1. AGA Report No. 9, *Measurement of Gas by Multipath Ultrasonic Meters*, Fourth Edition, January 2022, American Gas Association, 1515 Wilson Boulevard, Arlington, VA 22209
2. AGA Report No 10, *Speed of Sound in Natural Gas and Other Related Hydrocarbon Gases*, July 2002, American Gas Association, 1515 Wilson Boulevard, Arlington, VA 22209
3. BSI 7965:2000, Guide to the Selection, Installation, Operation & Calibration of Transit Time Ultrasonic Flowmeters for Industrial Gas Applications