ULTRASONIC METER CONDITION BASED MONITORING – A FULLY AUTOMATED SOLUTION

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1. INTRODUCTION

The customer requires a fiscal meter that measures with highest reliability within the required accuracy limits throughout the life time. Whenever this requirement isn't fulfilled due to changed process/flow conditions or changes to the meter, the user needs to be warned in real-time. To ensure such warning, the diagnosis parameters implemented into modern ultrasonic flow meter can be useful. Since the introduction of the global diagnosis concept major improvements in diagnosing a USM have been achieved. This requires a thorough understanding of the meter's operation and also understanding what normal, and non-normal responses of all diagnostic parameters are in order to insure proper operation. The automated diagnostics will monitor, and alarm, on all important parameters such as Profile Factor, Symmetry, SNR, Turbulence, etc. These warnings are today an important factor for driving the condition based maintenance of the installation. Additionally, it is very important to have a long-term history of these diagnostics in order to properly determine if a meter is still operating accurately.

Beside this features inherent to every ultrasonic flow meter with a multiple number of paths additional concepts to compare measurements directly exist. Two main concepts can be realised - permanent serial metering with two independent fiscal meters or with a combination of a fiscal and a check meter, introduced by TransCanada Pipeline (TCPL) several years ago. This concept involves using a single path USM downstream of the fiscal multipath meter. Papers have shown that single path USM meters are significantly affected by abnormal measurement conditions such as flow conditioner blockage, pipeline contamination from oil and mill scale, and any other change in operation that impacts accuracy. Since the single path meter has significantly more sensitivity, comparing the uncorrected readings of both meters provides a simple solution for determining if the fiscal meter is still operating accurately. If both are in agreement, then measurement must be OK. Should the two meters deviate, then more than likely there is some condition which might impact the accuracy of the fiscal meter. This paper will discuss the results and benefits in terms of reliability and economic impact of the TCPL-method installed in various field applications. Data will be presented on dirty vs. clean meters to show that the single path meter shifts significantly in a dirty environment while the 4-path custody meter is relatively insensitive to this.

2. AUTOMATED METER DIAGNOSTICS

A fully automated USM requires having all aspects of the meter's diagnostics monitored on a real-time basis within the meter. Traditionally users have collected periodic files and performed manual analysis of these to determine if the meter is operating correctly. That is no longer needed with today's technology.

All USMs have a variety of diagnostics to help the user determine if the meter is operating correctly. The basics for a typical chordal meter include the following:

- Gain for each transducer
- Performance (percent accepted signals by path)
- Signal to Noise Ratio (SNR)
- SOS for each path
- Velocity profile (path ratios or velocities)

Today these 5 are enhanced by additional diagnostics for the user to better understand if the meter is operating correctly. These include the following:

- Profile Factor
- Symmetry
- Turbulence

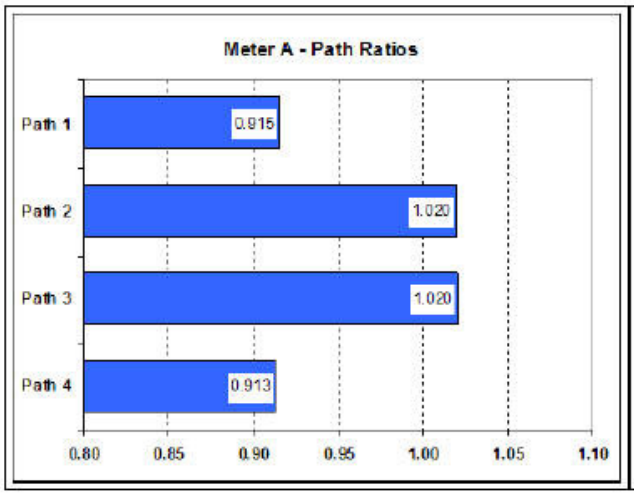
Profile factor and Symmetry are methods of analyzing the velocity profile (or path ratios). They are values which reflect the shape and amount of distortion in the basic velocity profile. They have been used for years to help understand the velocity profile which is often considered by many to be the most difficult diagnostic to understand [Ref 2 & 12]. These two are defined as follows:

- Profile Factor = (Path 2 + Path 3) / (Path 1 + Path 4)
- Symmetry = (Path 1 + Path 2) / (Path 3 + Path 4)

Many consider a meter's velocity profile the most difficult to understand because it can vary due to installation and type of upstream piping components, and to some degree, flow rate. Generally speaking these two diagnostics (Profile Factor and Symmetry) are very stable above a velocity of approximately 2-3 m/s.

However, this is only true if the piping design incorporates a flow conditioner. Without a flow conditioner, the velocity profile will have a wide range of both Profile Factor and Symmetry, and thus very difficult, if not impractical, to monitor and alarm on these value.

Figure 1 is an example of a profile with a flow conditioner (CPA type plate) and thus has an idea profile. It was collected at the calibration facility and had a flow conditioner upstream (at 10D) along with perhaps 50D of straight piping. Figure 2 shows a velocity profile of the same meter without a flow conditioner when it is subjected to piping that had 3 elbows and a tee upstream.



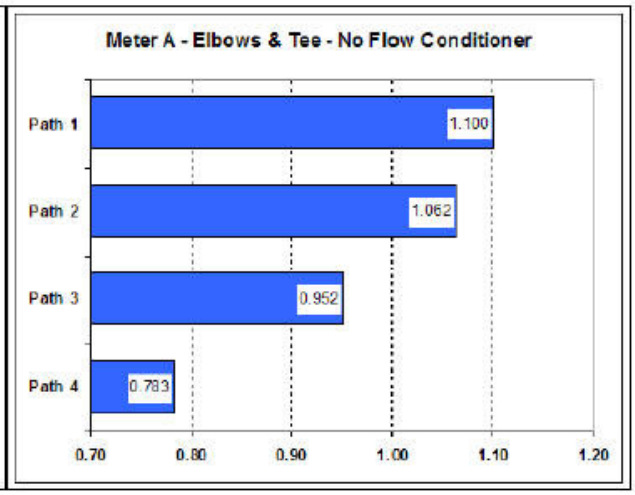


Figure 1: Path Ratios with CPA Conditioner Figure 2: Path Ratios w/o CPA Conditioner

Clearly the profile in Figure 2 is significantly distorted. This amount of profile change will impact the accuracy of the meter. The intent of velocity profile analysis is to identify if there are any changes from the baseline. If Figure 1 were the baseline profile in the field, and a future inspection revealed Figure 2, then obviously there is something wrong internally and would warrant inspection.

Turbulence is a third advanced diagnostic, and is a measure of flow stability, or variability, of each path's velocity reading. It is presented in percentage by path. Values are computed from the variability of all of the transit-time readings (per path) and updated once per second. More information is available from previously published papers [Ref 2, 11 & 12].

Typically a chordal meter will have a turbulence value of 2-3% for Paths 2 & 3, and 3-4% for Paths 1 & 4. The Turbulence values are higher for the outer paths (Paths 1 & 4) as they are located closer to the pipe wall and thus there is some influence due to the surface of the piping. Even more advanced diagnostics are provided by some meters and include the following:

- High meter velocity (exceeding programmed limit)
- Power supply voltage too low (below a programmed value)
- Logbook(s) warning when full of un-acknowledged entries

These previously identified advanced diagnostics, and more, can now be fully automated in the meter by having site-specific programmed values for each diagnostic parameter. There are many benefits to having these programmed in the meter rather than in the User's software or in a flow computer. Knowing within minutes that a problem may exist significantly reduces measurement uncertainty. Some of the many benefits include:

- The meter monitors all parameters/diagnostics on a real-time basis. When a diagnostic is approaching a limit, the meter then presents an alarm that can be remotely monitored.
- If diagnostic limits established in meter's software (User interface), the only time the user will know there is a problem is when they are connected to the meter. As a result, the meter can operate for weeks with a problem before a technician might identify it.
- Each location, and meter size, will have different limits due to the station design, meter size, pressure, flow rates, etc. By having these programmed in the meter, they can be tailored to the site-specific conditions and thus present an alarm more quickly and accurately.

- One additional benefit of having the meter do this, rather than the flow computer or RTU, is that no additional programming is required. Simply monitor a digital output (DO) and the RTU can then report if there is a problem with a diagnostic. This saves the user time and money and makes implementing this feature very easy.

To proof the feasibility of the concept to practical installations a special test was performed at CEESI facilities.

All testing was performed with a significant length of straight piping upstream of the metering package. This upstream length of straight pipe would present a very symmetrical and non-swirling profile to the CPA 50E flow conditioner.

Figure 3 shows the 12 inch meter installed at the CEESI facility for the testing.

Figure 3: 12-inch 4+1 CBM Meter CEESI

A CPA was installed 10D upstream for baseline testing. After the baseline testing was complete the 12-inch CPA was partially covered with duct tape (40% blockage). Figure 4 shows the 40% blocked flow conditioner prior to testing.

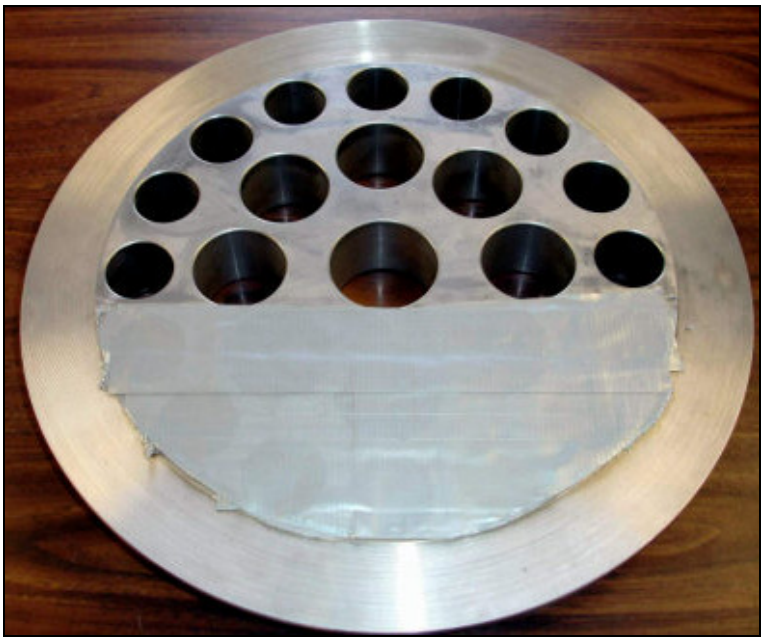


Figure 4: 12-inch CPA with 40% Blockage

Duct tape was used to block the holes as this provides a repeatable method of testing and can withstand the pressures created by the flow rates used.

The example shows the velocity profile changed from symmetrical to somewhat distorted towards the bottom of the meter (compare Figure 5 to Figure 6).

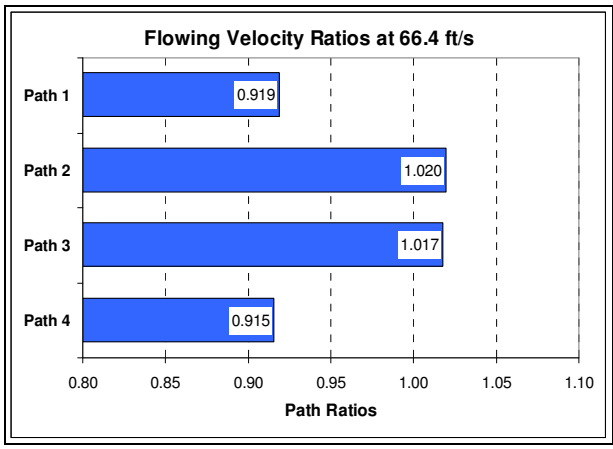


Figure 5: Path Ratios without Blocked CPA

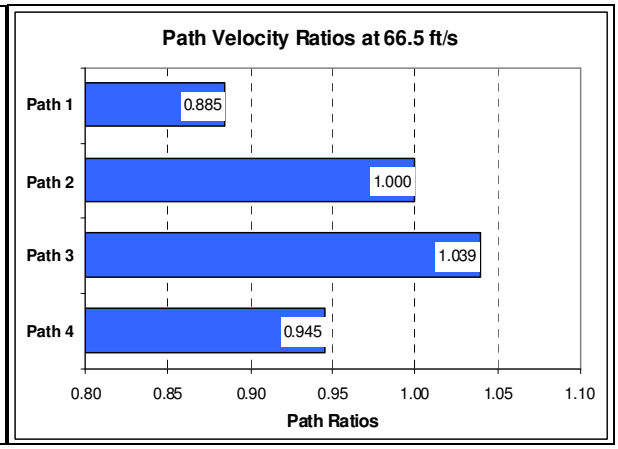


Figure 6: Path Ratios 40% Blocked CPA

Figure 5 shows the velocity profile in normal conditions with no blockage. The Profile Factor was 1.111 which is normal for this meter design, and the Symmetry was 1.004, or within 0.4% of a perfectly symmetrical profile. Meter data was collected at three velocities of approximately 7, 14, and 21 m/s. The data here is from the 21 m/s (64 fps) flow rate, but all three velocities essentially looked the same.

Figure 6 shows the distortion that occurred as a result of the blockage. The Profile Factor changed to 1.114, or only about 0.4% shift. This amount of change is relatively small compared to the baseline Profile Factor of 1.111, and if the technician were only monitoring Profile Factor, they would assume everything is OK. However, it is apparent these two graphs do not look the same.

This is the reason it is very important to also monitor the second diagnostic called Symmetry. For the 40% blocked condition the Symmetry is 0.950. This represents about a 5.5% shift in the velocity profile towards the bottom of the meter (high velocity average). This magnitude of change is very obvious and easily identified. By monitoring within the meter on a real-time basis, it can be reported to the RTU or flow computer within minutes as an abnormal profile.

One can argue that 40% blockage is very significant and not likely to occur often. Let's look at the profile with only one hole blocked. Figure 7 is a picture of the CPA prior to the testing.

Figure 7: 12-inch CPA with 1 Hole Blocked

The single blocked hole was located on the bottom of the meter. This location was chosen as the most likely place for such a blockage to occur. Figure 7 shows the profile with the one hole blocked at the bottom.

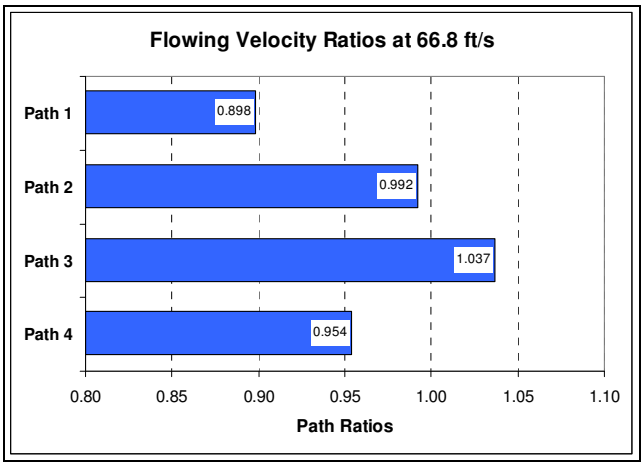


Figure 8: Path Ratios with One CPA Hole Blocked

Figure 8 shows a similar distortion as with 40% blockage. For this condition the Profile Factor was 1.096 and the Symmetry was 0.949. In this case the Profile Factor changed about 1.5% and the Symmetry almost 6%. Thus it is fairly easy to see that these two profiles (blocked vs. not blocked) create a flow profile (Path Ratios) that can be seen visually, and thus can be alarmed on via the meter's firmware.

A typical alarm limit on Profile and Symmetry, based upon these test conditions, and other testing, would suggest something between 3% and 5% tolerance for both the Profile Factor and Symmetry values. Thus, when this meter was installed in the field, it would have a baseline factor of perhaps 1.11 for Profile Factor, and 1.005 for Symmetry, and the Warning alarm limits

would be established at 5% for both. Thus if either the Profile Factor or Symmetry values were outside of the 5% limit, the meter would then report a Warning alarm.

Another very valuable tool for analyzing flow conditioner blockage is monitoring Turbulence. In the case of the baseline condition, the Turbulence values are typically around 2-3% for the middle paths (Paths 2 & 3) and 3-4% for the outer paths (Paths 1 & 4). These numbers are based upon many tests in the calibration lab and results from field installations.

Figure 9 shows the baseline results at 20 m/s with no CPA flow conditioner blockage, and Figure 10 with 40% blockage of the flow conditioner.

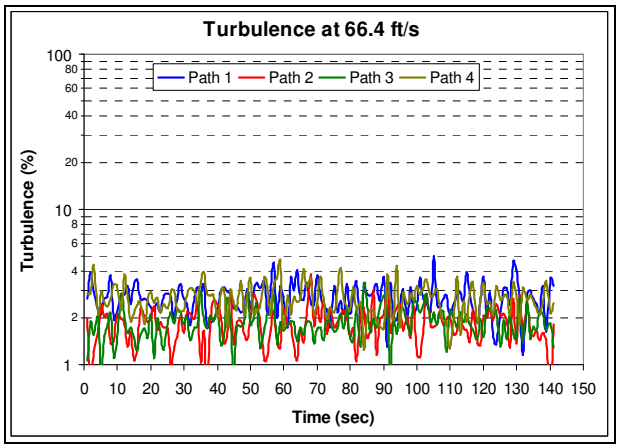


Figure 9: Turbulence without Blocked CPA

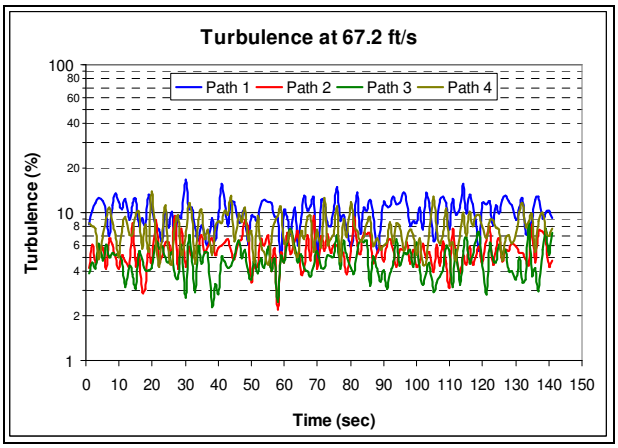


Figure 10: Turbulence 40% Blocked CPA

Figure 9 shows turbulence values that average around 2.8% for the outer paths and around 1.9% for the inner paths. Figure 10 has average values in the range of 7-10% for the outer paths and 5-6% for the inner paths. Clearly there is a significant difference in the baseline (Figure 9) and the blocked condition (Figure 10). Besides blockage, Turbulence can also identify a cyclic flow control valve or significant pulsation. In these cases Turbulence values can exceed 50% depending on the frequency and amplitude of the pulsation or flow control valve cyclic operation.

Based upon testing in the lab and field results, a setting of perhaps 5 or 6% for the field appears to be a viable limit for identifying problems. In the case of the single blocked flow condition, Figure 11 shows what the Turbulence would be under this condition.

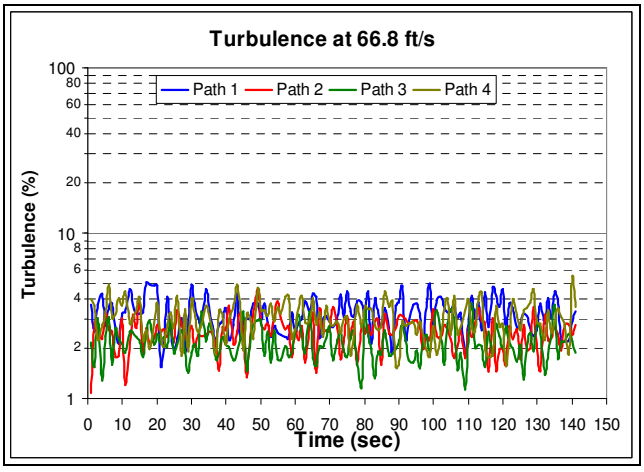


Figure 11: Turbulence with 1 Hole Blocked CPA

Figure 11 shows the Turbulence doesn't look much different than Figure 9. Analysis of the data shows the average for Paths 1 & 4 was about 3.1% and for Paths 2 & 3 the average was about 2.4%. In this example if the technicians were only looking at Turbulence as an indicator for blockage, it probably would have been over-looked since averages were not that significantly different. This example shows why it is important to monitor all aspects of the diagnostics.

When a technician connects to the meter using the factory software, it simply polls the meter for all the diagnostics and presents this in a graphical format. Each manufacturer has developed software in order to display the diagnostics for the user. In this case the software not only presents all the diagnostics, but also shows the alarm limits that have been established in the meter. Figure 12 shows a screen capture of a meter with all diagnostics within normal limits.

Figure 12: Diagnostics for a Meter with No Problems

Figure 12 shows all the diagnostics the user needs to monitor. The Velocity Profile is the graph that starts at the top left, and from there the graphs, from left to right on the top row, include SOS difference by path (in percentage), Performance by path (in percentage), AGC (Gains in dB) by transducer, and on the second row of graphs there is SNR (in dB), Turbulence (in percentage) and a Profile Indication Graph (more on that later).

The red dotted lines indicate the alarm limits that are programmed in the meter. Once any diagnostic exceeds (or in the case of Performance and SNR go below) the programmed limit, the individual graph turns yellow and the meter then reports via Modbus, and a digital output (DO), that a Warning alarm is activated.

Figure 13 shows an example of a condition where there may be contamination of the Path 4 transducer pair.

Figure 13: Possible Blockage or Contamination in Front of Path 4

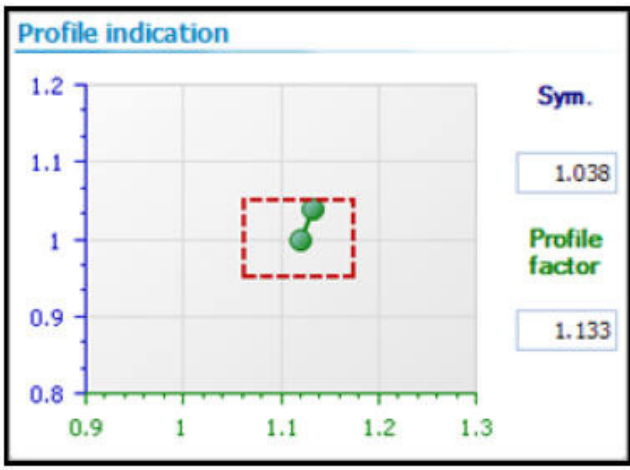
Figure 13 shows the SOS for Path 4 is exceeding the red line (Warning alarm limit), and also the AGC gains for Path 4 transducers are above the Warning alarm limit (Chart shows warnings in yellow). In this condition the meter is now reporting a problem, and when the technician connects to the meter, it is very apparent there is a problem. For this example there may only be a slight impact on accuracy, but if left un-attended it might mean that Path 4 could eventually fail.

Figure 14 shows a different condition which may be caused by a blocked flow conditioner.

Figure 14: Possible Blocked Flow Conditioner

In Figure 14 Turbulence in the graph is above the alarm point and it is reported as a yellow bar for Path 4. This graph was developed with the help of a demo model and thus only one path (Path 4) is reporting high turbulence due to the blockage being very close to the meter. In the real world more than one path would probably be reporting an alarm (many bar graphs would be yellow). The velocity profile is also distorted as can be seen in the Profile Indication.

Understanding the Path Ratios has perhaps been the most difficult diagnostic to understand. Previously in this paper two advanced diagnostics were explained. One is Profile Factor and the second is Symmetry. These two methods of analyzing the Path Ratios greatly simplify understanding if the meter's profile is normal. In the example of Figure 14 we can see the line in the Profile Indication is yellow. The following two graphs show a larger version of a normal Profile Factor and Symmetry (Figure 15), and an abnormal Profile Factor and Symmetry in Figure 16 when there is blockage in front of the flow conditioner.



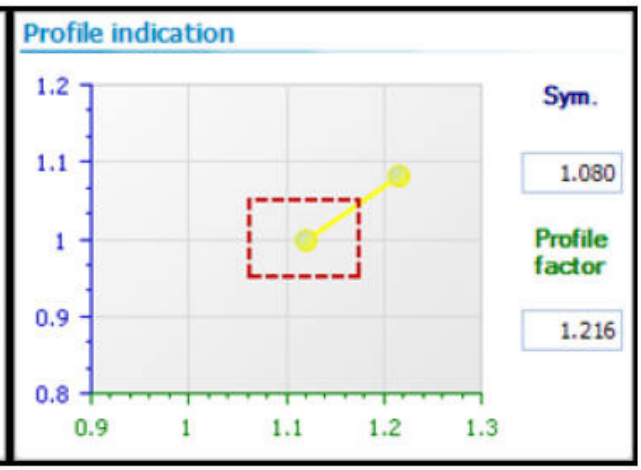


Figure 15: Normal Profile – No Warning Figure 16: Profile Distorted – Warning Reported

For each meter installed in the field the Profile Factor and associated Warning alarm limits can be programmed for the site-specific conditions. For the example in Figure 15 the normal Profile factor is 1.11 as shown on the X axis, and 1.00 for Symmetry on the Y axis. This is represented by the dot in the middle of the red box. This dot stays in this location to indicate what the normal values are. The size of the box is also programmed in the meter, and in this case a 5% tolerance (plus and minus for both Profile Factor and Symmetry) from the baseline has been determined as the limits. Thus the size of the box is ±5% from the baseline values.

The dot at the end of the line (towards the top of the red box in Figure 16) represents the current average for the Profile Factor and Symmetry. The current value of Profile Factor is 1.133 and the Symmetry is 1.038 as shown in the dialog boxes to the right of the graph. The dot is near the red box but inside of it so the meter is not reporting any Warning alarms.

In Figure 16 the dot at the end of the line is outside of the box. This causes the line to turn yellow and indicates a Warning alarm, and thus is reported via Modbus and the DO. In this example the Profile Factor is 1.216 or about 10% from normal, and the Symmetry is 1.08 or about 8% from normal. The velocity profile is perhaps the most important, and most difficult, diagnostic to understand. This combined graphical representation of Profile Factor and Symmetry (Profile Indication) greatly simplifies understanding the velocity profile and makes it very easy to identify if the meter is operating within normal limits or not.

3. DIAGNOSIS ON READINGS OF TWO DIFFERENT METERS CBM 2PLEX 4+1 DESIGN

The first part of the CBM 2Plex 4+1 meter design is a conventional fiscal 4-path chordal ultrasonic meter. The meter incorporates an additional, independent single-path meter and associated electronics incorporated into the same body. The purpose of the additional path is for continuous comparison of volumes to the fiscal 4-path meter's measurement results.

The transducers for the independent single path are located in such a fashion as to traverse the meter in the center of the meter body. The transducers for the fiscal 4-path meter are located in the traditional Westinghouse configuration. The reason for locating the single-path in the middle (center vertically) is to put it in the most profile-sensitive measurement position of the meter. This will result in a difference in volumes between the single path and the fiscal 4-path when the velocity profile changes. That is, the single-path meter, with the sensors located in the center of the flowing gas, is more sensitive to flow disturbances than the 4-path meter design.

These disturbances (velocity profile changes) can be caused by several external factors including partially blocked flow conditioners and pipeline contamination. All of these will cause a change in the velocity profile seen at the meter. This concept works because changes in profiles significantly impact the reading by the centrally located single path while having very little affect on the 4-path meter. Figure 17 is an artist drawing of this design. Figure 18 shows an 8-inch 4+1 meter with plastic covers over the transducer mounting area.

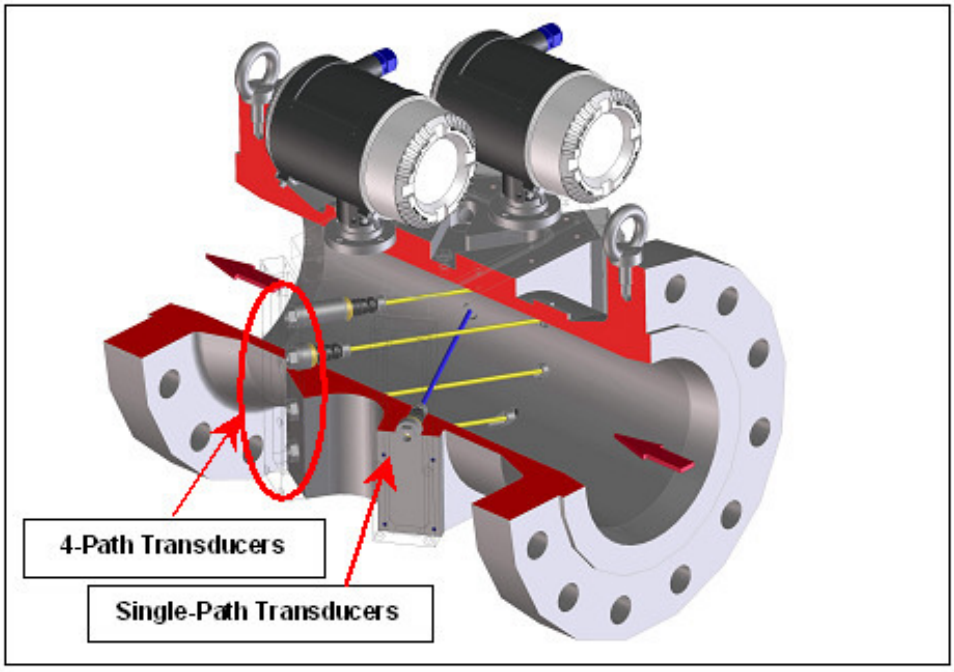


Figure 17: CBM 2Plex 4+1 Meter Design

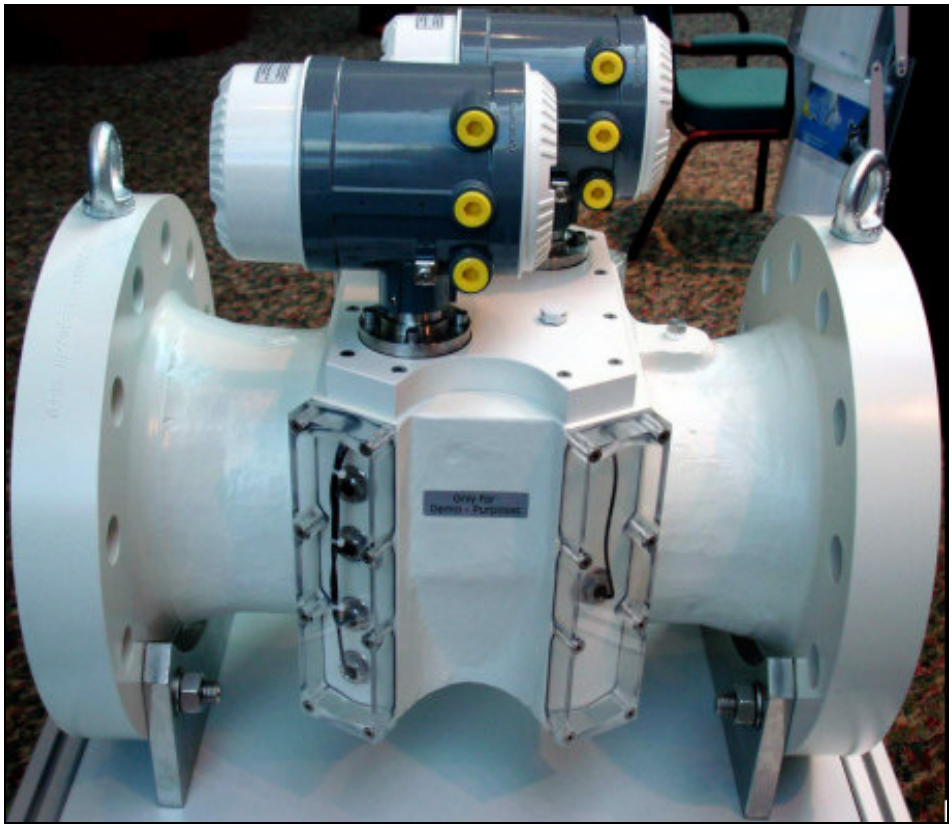


Figure 18: 8-inch CBM 2Plex 4+1-Path Meter

Note that the plastic is simply for a better view and certainly would not be used in the field. The single-path transducers on the right of the meter are located in the center of the meter (vertical axis) and do not bounce off of the meter body (direct path configuration). Figure 1 shows this direct path uses the traditional angle of 60 degrees. Thus the overall path length of this single-path pair of transducers is only slightly longer than the longest paths (paths 2 and 3) in a 4-path meter.

Two independent Signal Processing Units (SPUs) are used, one for the 4-path configuration, and one for the single-path configuration. Both electronics energize their transducers independently of each other. There is also no communication between the electronics, and no interaction between the sound pulses from one "meter" to the other.

The comparison of the output of both meters is not on a real-time basis, but rather performed once per day, or even once per hour. That is, the uncorrected accumulated volume in the 4 path meter is compared to the single path meter at the daily (or hourly) level. Daily checks help eliminate the minor differences that can occur on a real-time basis between the two meters due to their different velocity sampling techniques. This also permits using a tighter tolerance and increases the reliability of the comparison.

During operation, conditions can change in the piping system that can impact the accuracy of the meter, even when using a flow conditioner. These changes include blockage of the flow conditioner with a foreign object, contamination over time from oil and mill scale, unexpected or unanticipated pulsation of gas, and potential changes within the 4-path meter electronics and transducers. By incorporating a second independent electronics with an independent path, this design essentially provides a real-time flow check against the 4-path meter. But why use a single path design to check the 4-path meter instead of another 4-path design checking the fiscal 4-path meter?

During the past several years data has shown that single path meters, with the transducers located to send sound pulses through the middle of the meter body, are more sensitive to profile changes. In a paper published in 1998 by Terry Grimley [Ref 3], installation effects were measured on two multi-path meters, and on two single-path meters. A variety of installation effects were tested including two elbows in and out of plane upstream of the four meters. The multipath meters performed relatively well with errors attributed to the installation effects on the order of 0.5% or less. In the same piping configuration the single path meters had errors that were on the order of 2-5%. Clearly the multipath meters could deal with the asymmetrical and swirling profiles far better than the single-path meters.

Profile changes also occur when contamination develops on the inside of the piping and meter. As the buildup occurs, the wall friction increases causing the velocity profile in the center of the meter to be higher relative to the area along the pipe wall. A paper published at the North Sea Flow Measurement Workshop (NSFMW) in 2005 [Ref 1] discusses how the profile changed over time due to internal pipeline contamination. This paper shows examples of the meter's response when blockage occurs upstream at the flow conditioner. The velocity profile differences between the 4 path meter and the independent single path meter resulted in significantly different measurements between the two designs.

Placing the single-path pair of sensors in the center of the meter body was done intentionally as this is the most sensitive location for flow measurement. That is the center-line path will shift far more than if located at any other position within the meter. This makes it an excellent check against the 4-path which experiences much less shift when the profile changes.

Through the use of meter diagnostics, and the associated manufacturer's software, many of the above problems can be identified. The problem with the conventional method of identifying potential measurement errors is that most users only check the meter's diagnostics on a monthly basis, and sometimes less often that that. When a problem occurs, it may be weeks before it is identified, and thus the impact on billing can be substantial.

By using the CBM 2Plex 4+1 method of comparing the output of a single-path meter to that of the fiscal 4-path chordal meter, the performance of the two meters is validated every day. This means if a problem occurs, a potential measurement error can be identified by the system within one day. Once a problem has been identified, technicians can be dispatched to investigate or the meter can be monitored more closely for further action. In today's environment where the price of gas is ever increasing, errors in transportation, buying and selling of natural gas can lead to more significant financial risk than ever before. Knowing a meter has a potential problem within a day (or hours) will help reduce unaccounted for gas (UAF).

4. PROVING THE CONCEPT

Does this technique really work when both meters are incorporated into one meter body? To answer this question, testing was conducted at the CEESI Iowa high flow calibration facility in Garner, Iowa. For this test a 12-inch 4+1 meter was installed with a CPA 50E flow conditioner upstream. This type of flow conditioner has been used in many USM applications around the world.

One of the issues with using a flow conditioner is that debris can collect in front of the flow conditioner. When this occurs there can be an affect on the USM accuracy. The effect has been documented in several presentations [Ref 1, 5 & 6] and is demonstrated in the first part of this paper.

To quantify the benefits of this design, testing with several blockage scenarios was conducted. Not only were the 40% blockage, but additional testing was done only 1 hole blocked. Three velocities were used for all of these tests. These were approximately 7 m/s, 14 m/s and 21 m/s.

Figure 19 shows the results of the 4-path meter after baseline calibration (piecewise linearization) and subsequent results with 40% blockage of the flow conditioner.

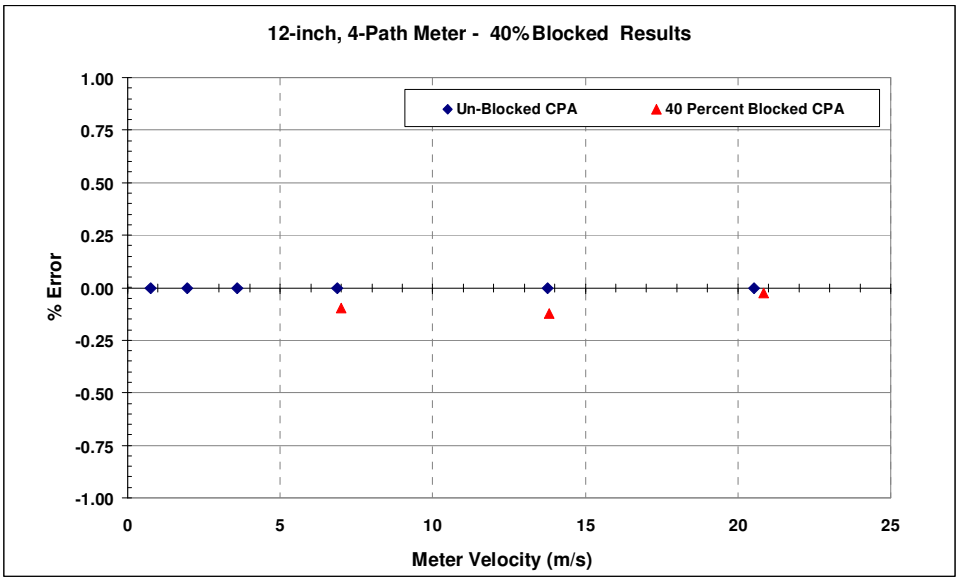


Figure 19: 12-inch, 4-Path Meter Results with 40% Blockage

Figure 19 shows that the 12-inch, 4-path meter shifted on the order of -0.15%, or less, for all three velocities tested. Figure 20 shows the results of the single-path during this same time.

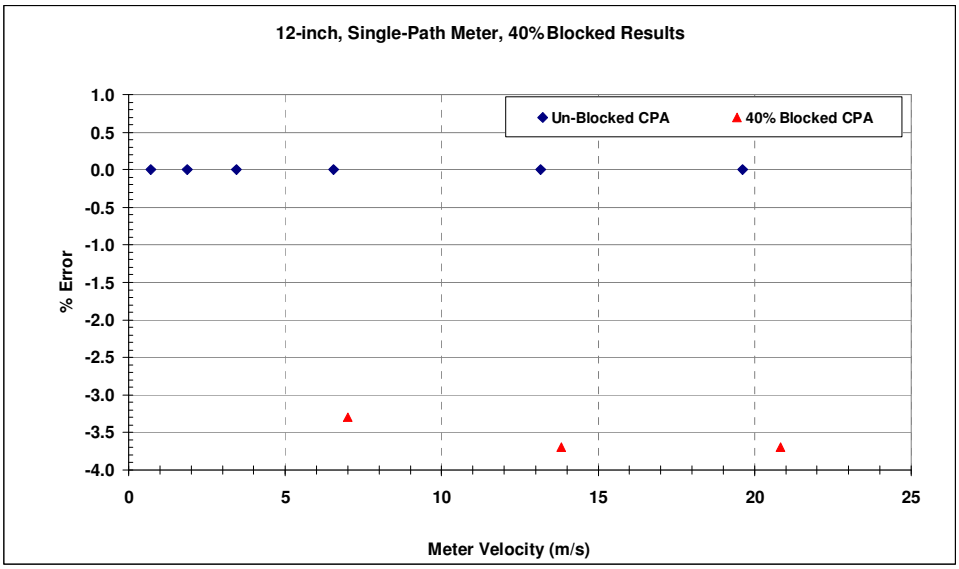


Figure 20: 12-inch, single-Path Meter Results with 40% Blockage

The accuracy impact on the single-path meter is on the order of -3.5%. Thus for the same blockage upstream of the 12-inch meter, the single-path meter shifted more than 20 times as much as the 4-path meter.

The next step was to test the meter with only one blocked hole. Figure 21 shows the results of the 12-inch, 4-path meter with this blockage and Figure 22 shows the results of the 12-inch, single-path meter.

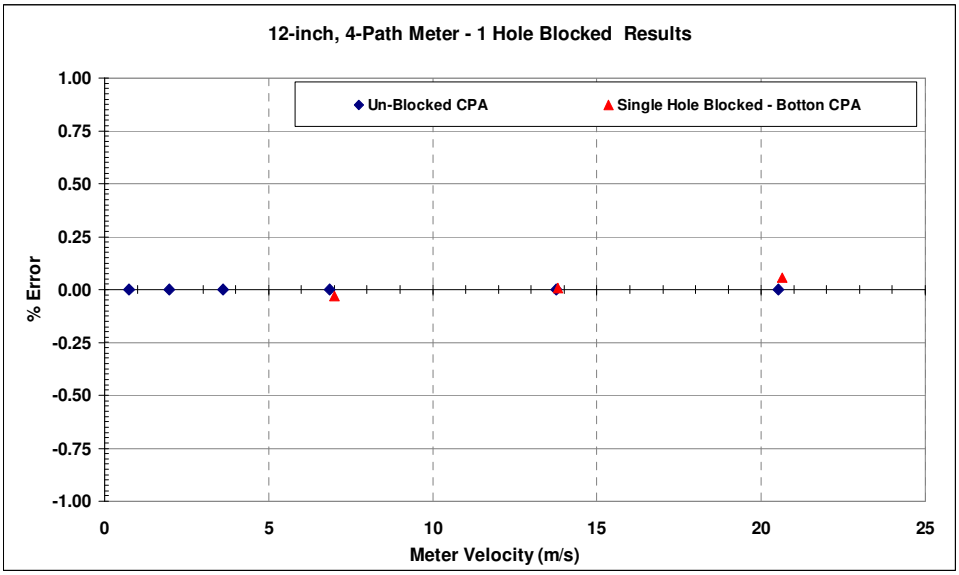


Figure 21: 12-inch, 4-Path Meter Results with 1 Hole Blocked

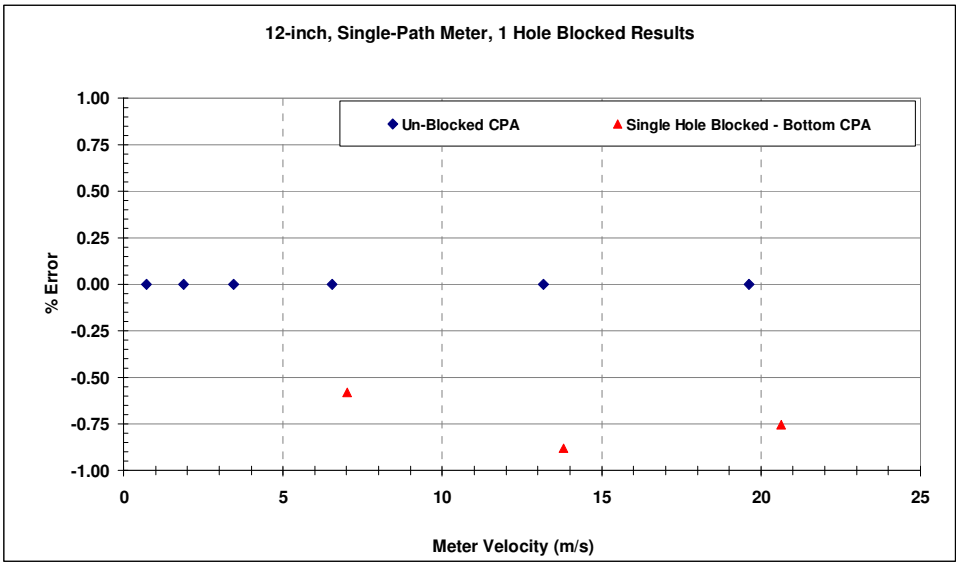


Figure 22: 12-inch, Single-Path Meter Results with 1 Hole Blocked

Figure 21 shows there is no impact on the 4-path meter's accuracy, while the single-path meter, shown in Figure 22, shifted between -0.6% and -0.85%. Thus, even with one hole blocked, the single-path meter shift was very significant, and thus the difference between the 4-path and single-path could be easily identified.

Pipeline contamination, especially over time, is a more challenging problem for the technician. Many pipelines have some minor amount of oil and mill scale that is being transported down the pipeline. Although this contamination is generally small, it can accumulate over time and have a significant impact on a meter's accuracy.

Several papers have been published over the past 10 years [Ref 4, 7, 8, 9 & 10] which discuss the impact on the meter's accuracy. Some meter designs tend to register fast when contamination coats the meter piping and meter body, while others tend to register slower. The challenge for all users of USMs is to identify this contamination and then to decide when it is time to clean the meter run.

The question is: "Can the 4+1 CBM meter design identify contamination in the piping?". To answer this question an existing 4-path meter was borrowed from an installation. This particular meter is an inter-company operational meter, in a bi-directional application installed in the late 1990's and uses a 19-tube bundle flow conditioner. During the several years of service it had been cleaned numerous times due to contamination.

For this test the entire meter run (including all piping and flow conditioner) was removed, and sent to the CEESI Garner calibration facility. As the installed meter was not a 4+1 CBM design, only the piping was used for this testing to see if the contamination could be identified by the CBM meter.

Unfortunately the meter run had been cleaned recently and the upstream piping was not as dirty as was expected. Figure 23 shows the "as-found" condition of the piping between the flow conditioner (19-tube bundle) and the meter.

Figure 23: 12-inch Dirty Piping

As Figure 23 shows, there was not a lot of contamination remaining due to the recent cleaning of the meter piping.

Today most designers do not use this type of flow conditioner but instead select a perforated plate like the CPA 50E. The customer chose to re-install the meter after testing and replace the 19-tube bundle with the CPA unit. For this reason all testing was conducted with a CPA flow conditioner. To simulate what the flow conditioner may have looked like it had been subjected to normal pipeline contamination, "texture" paint was applied to the CPA flow conditioner. Figure 24 shows the flow conditioner just prior to being installed for the testing.

Figure 24: 12-inch CPA with "Texture Paint"

Although this coating might not represent the identical contamination to the piping, it was felt at the time that some type of contamination was needed to at least simulate surface buildup. Because it was previously decided to re-install the 4+1 CBM meter, after all testing was completed, for some long-term testing and wanted the CPA to be used during this time. In order to save some calibration time, rather than conduct testing with the 19-tube bundle, it was decided to contaminate the CPA for the "as found" dirty testing.

Figure 25 shows the results for the 4-path meter both dirty and clean.

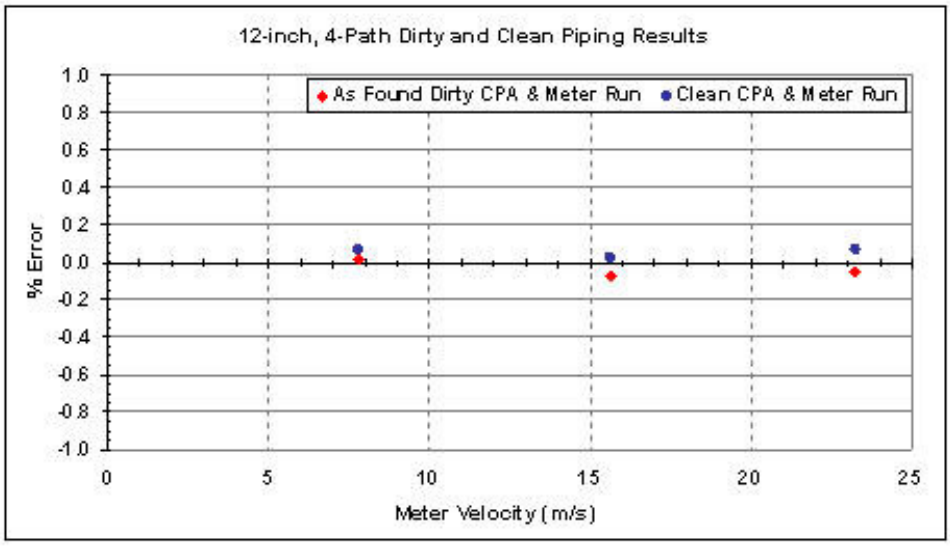


Figure 25: 12-inch, 4-path As-Found Dirty and As-Found Clean

The results of the 4-path meter as-found baseline are shown with the blue dots after the piping was cleaned (meter was brand new and thus clean). The red dots represent the as-found results with the upstream piping and CPA dirty. The table in Figure 26 shows the difference between the two at each flow velocity in m/s.

Velocity	% Diff.
23.3	-0.12
15.7	-0.10
7.8	-0.05

Figure 26: 4-path Dirty vs. Clean Differences

Figure 26 shows the meter registered slightly slower with the upstream piping being dirty compared to the clean piping. This is the expected results since a previous paper [Ref 4 & 7] had demonstrated that the upstream piping tends to cause the chordal meter to register slightly slower when dirty.

Figure 27 shows the results for the single-path during the same conditions.

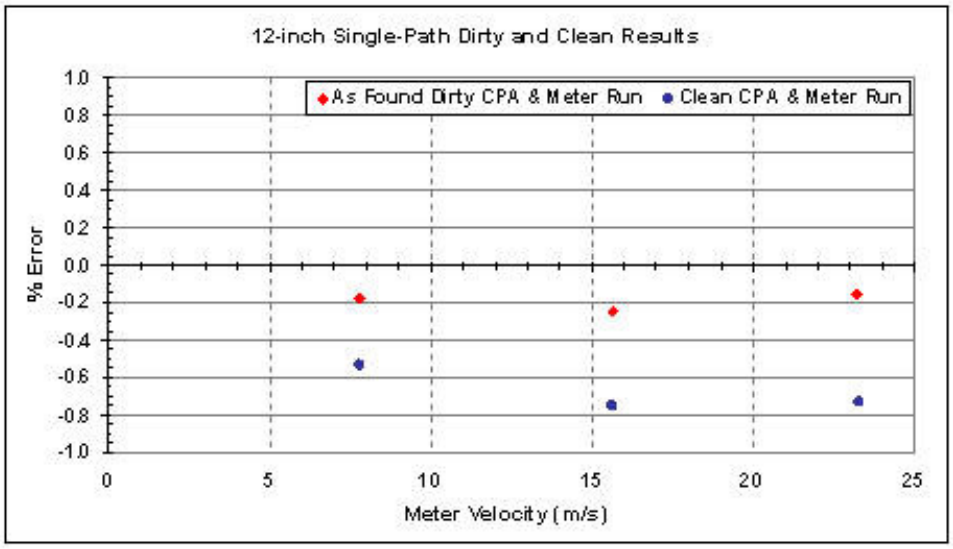


Figure 27: 12-inch, 4-path As-Found Dirty and As-Found Clean

In Figure 27 the single path meter registered faster (red dots) when the upstream piping was dirty compared to the clean upstream piping as shown with the blue dots. This difference is summarized in Figure 28.

Velocity	% Diff.
23.3	0.57
15.7	0.50
7.8	0.35

Figure 28: Single-path Dirty vs. Clean Differences

As this table shows the single path meter registered faster when dirty and is just the opposite of what the 4-path meter showed. Although this isn't as thorough of a test as a uniformly dirty meter, it does show that the single-path meter behaves differently than the 4-path meter. With very little contamination on the upstream pipe wall, the change in the single path meter's response was easily seen.

5. IMPLEMENTING THIS DESIGN

As discussed earlier in this paper, both electronics operate independently. The output of each meter needs only to be brought into the same flow computer and volumes stored for both as would normally be done for two separate meters. To take advantage of this feature, the hourly uncorrected volumes would then be compared and an acceptable tolerance would be determined based upon some history established during commissioning. The tolerance may vary somewhat from site to site, and will depend slightly upon the upstream piping conditions and the symmetry of the profile downstream of the flow conditioner. However, the typical agreement that has been seen from some field data is on the order of ±0.5%.

The comparison test probably should not be conducted when meter velocities are below perhaps 3 m/s as the profile effects can become more significant. For this reason the flow computer should accumulate separate totals for comparison testing since the effective cutoff for the comparison would be perhaps 3 m/s. Thus it may not be practical to use the absolute uncorrected volumes through each meter if the flow rate is frequently below this velocity.

For most installations meter velocities are usually always above 3 m/s. This is common in mainline stations where there is always flow. For these cases a direct comparison of hourly (or daily) uncorrected volumes would suffice. Many users already have this capability built into their flow computers. They do comparisons of "run ratios" in order to spot potential problems. For these users they simply have to connect the meter to the flow computer, set the comparison ratio to a value, and start monitoring for the alarm. Thus full advantage of this meter design can be incorporated immediately without special flow computer programming.

Figure 29 is an example of a 2Plex 4+1 meter in a bi-directional application that has been compared at the daily level for more than 19 months.

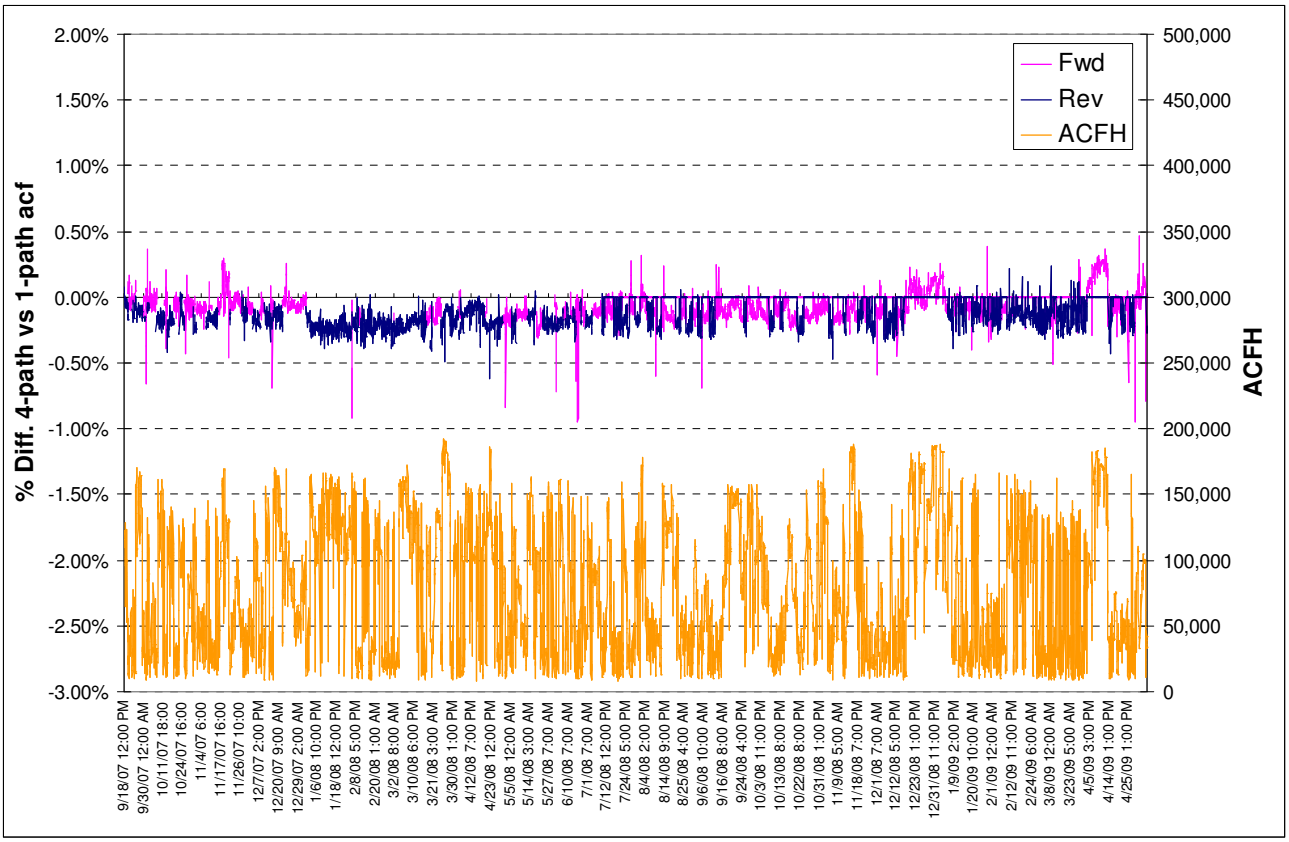


Figure 29: 4-Path vs. 1-Path Daily Comparison for 19 Months of Hourly Flow Rates

This graph shows the comparison of the percent difference in dark blue for the forward direction, and magenta in the reverse with the scale on the left axis. The average flow rate is in orange and the scale is on the right. This graph is of hourly flow comparisons graphed over 19 months time.

For the most part, all hourly comparisons are all within 0.25%. On a few occasions the difference exceeds ±0.5%. This is when the flow rate is low and perhaps during this time some minor contamination occurs. When the flow rate increases, the difference goes back to the normal (which is approximately -0.15%). This may indicate some clearing out of minor contamination since the meter difference generally goes positive which is expected if the piping becomes dirty.

Many users today know they have contamination in their metering systems. They periodically clean the meter in order to minimize the uncertainty effect due to contamination. If the amount of difference between the 4-path meter and the single-path meter can be used to determine the cleaning interval, these users will then benefit from extended inspection intervals and thus save significant O&M expenses.

6. CONCLUSIONS

Today the cost of energy is higher than it was several years ago, and it is not likely this trend will reverse itself. By implementing ultrasonic metering technology many users have been able to improve their measurement and reduce their un-accounted for (UAF) gas during the past several years. One task always remains for the technician and that is to insure the meter is operating correctly and accurately. This applies to all measurement technologies, not just USMs. The significant benefit of the USM is the ability to provide diagnostic information for the user to help determine the meter's "health."

Today technicians have software to help understand the operation of their USM. Since each manufacturer of USMs uses a different velocity integration technique (different path configurations), it is often difficult for the technician to fully understand whether his USM is operating correctly or not. Additionally, since most only inspect the meter's operation once per month, problems can occur and go undetected for many days or weeks. This can significantly increase measurement uncertainty during this time.

The CBM 2Plex 4+1 meter design relies on basically two principles. First, the fiscal meter is chosen to be the least sensitive to any flow profile changes that may occur in normal operation. And second, the "check" meter design is chosen to be one that is the most sensitive to any flow profile changes. Ideally any affect from a profile change would not only have a significantly different impact on accuracy for each path layout, but the affect would be in opposite directions, making the difference much easier to detect.

The benefit of the CBM 2Plex 4+1 meter design is that the flow computer is used to check the health of the fiscal 4-path chordal meter by simply comparing it to the single-path meter. If the velocity profile remains relatively constant, both meters will agree. Should some process condition upset the normal profile, the single-path meter will respond significantly different than the 4-path. These upsets can include the following:

- Blockage in front of the flow conditioner
- Contamination due to oil and mill scale buildup over time
- Pulsation in the pipeline due to compressors (sampling rate for the single-path is much faster than the 4-path and thus less sensitive to pulsation)
- Potential problems with the fiscal meter including transducers and electronics problems
- Full redundancy should there be a failure of the electronics.

When a meter is equipped with automated meter diagnostics, as described in Section 2, it expands the monitoring of the fiscal meter's health to an even higher level. The 2Plex 4+1 design only validates that the velocity profile hasn't changed. By monitoring all of the remaining diagnostics on a real-time basis, the meter's health can be validated on a real-time basis. This is important should a diagnostic value such as gain for a pair of transducers, or low SNR from a control valve, approach a value that may cause a path to fail.

By monitoring all aspects of the meter's diagnostics, both with the 2Plex redundant design, and with continuous checking of all other diagnostics (for both the 4-path and 1-path meter), the user can have a much higher degree of confidence that the measurement is accurate.

Today the cost of accuracy has never been more important. Virtually all applications today require the measurement accuracy be maintained at the highest possible level. The CBM 2Plex 4+1 meter design, combined with automated real-time internal monitoring of all diagnostic values, provides a complete "health check" on the custody transfer meter (4-path). This can significantly reduce both operation and maintenance (O&M), and measurement uncertainty, and thus reduces the cost of doing business.

7. REFERENCES

1. John Lansing, *How Today's USM Diagnostics Solve Metering Problems*, North Sea Flow Measurement Conference, October 2005, Tonsberg, Norway
2. Klaus Zanker, *Diagnostic Ability of the Daniel Four-Path Ultrasonic Flow Meter*, Southeast Asia Flow Measurement Workshop, 2003, Kuala Lumpur, Malaysia
3. T. A. Grimley, *The Influence of Velocity Profile on ultrasonic Flow Meter Performance*, AGA Operations Conference, May 1998, Seattle, Washington, USA
4. John Lansing, *Dirty vs. Clean Ultrasonic Flow Meter Performance*, North Sea Flow Measurement Conference, October 2004, St. Andrews, Scotland
5. Larry Garner & Joel Clancy, *Ultrasonic Meter Performance – Flow Calibration Results – CEESI Iowa – Inspection Tees vs. Elbows*, CEESI Ultrasonic Conference, June 2004, Estes Park, Colorado, USA
6. John Lansing, *Features and Benefits of the SICK Maihak USM*, CEESI Ultrasonic Conference, June 2006, Estes Park, Colorado, USA
7. John Lansing, *Dirty, vs. Clean Ultrasonic Gas Flow Meter Performance*, AGA Operations Conference, May 2002, Chicago, Illinois, USA
8. L. Coughlan, A. Jamieson, R.A. Colley & J. Trail, *Operational Experience of Multipath Ultrasonic Meters in Fiscal Service*, North Sea Flow Measurement Conference, October 1998, St. Andrews, Scotland
9. John Stuart, Rick Wilsack, *Re-Calibration of a 3-Year Old, Dirty,* Ultrasonic Meter, AGA Operations Conference, April 2001, Dallas, Texas, USA
10. James N. Witte, *Ultrasonic Gas Meters from Flow Lab to Field: A Case Study*, AGA Operations Conference, May 2002, Chicago, Illinois, USA
11. John Lansing, *Operation and Maintenance Considerations for Ultrasonic Meters*, Appalachian Gas Measurement Short Course, August 2008, Coraopolis, Pennsylvania, USA
12. John Lansing, *Advanced Ultrasonic Meter Diagnostics*, Western Gas Measurement Short Course, May 2007, Seattle, Washington, USA