THE RELEVANCE OF TWO DIFFERENT PATH LAYOUTS FOR DIAGNOSTIC PURPOSES IN ONE ULTRASONIC METER

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ABSTRACT

During the past several years the use of ultrasonic meters (USMs) has gained world-wide acceptance for fiscal applications. The many benefits of USMs have been documented in several papers at virtually every major conference. As the cost of gas continues to increase, the importance of knowing that the ultrasonic meter is operating accurately has never been more important. The use of diagnostics to help identify metering issues has been discussed in several papers over the past few years [Ref 1 & 2].

The traditional method of verifying whether the USM is operating accurately essentially requires using the USMs' diagnostic information to help understand the meter's health. This has often been referred to as Conditioned Based Maintenance, or CBM for short. Different USM meter designs require different analysis techniques, especially for the velocity profile analysis. For the field technician, it is often difficult to understand all the diagnostic features of each USM meter design. Through the years software has been developed to help determine if the meter is operating correctly or not. However, it is still very difficult to clearly define limits on some of the diagnostic parameters that translate into a quantifiable metering error.

This paper will discuss a new CBM concept to assist in understanding if the fiscal 4-path USM meter is operating accurately. Rather than relying entirely on the understanding and interpretation of the meter's diagnostics, a meter designed with an additional built-in diagnostic path has been developed. In this paper the meter design will be referred to as the CBM 4+1 meter.

1. INTRODUCTION

The CBM 4+1 meter design is a conventional fiscal 4-path chordal (Westinghouse path layout) ultrasonic meter that incorporates an additional, independent single-path and associated electronics incorporated into the same meter body. The purpose of the additional path is to continuously check 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 common to many 4-path chordal meters. The reason for locating the single-path in the middle is to put it in the most sensitive position of the meter. This will result in a difference between this single path and the fiscal 4-path when the velocity profile changes. That is, the single-path meter, with the sensors located in the middle 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 1 is an artist drawing of this design.

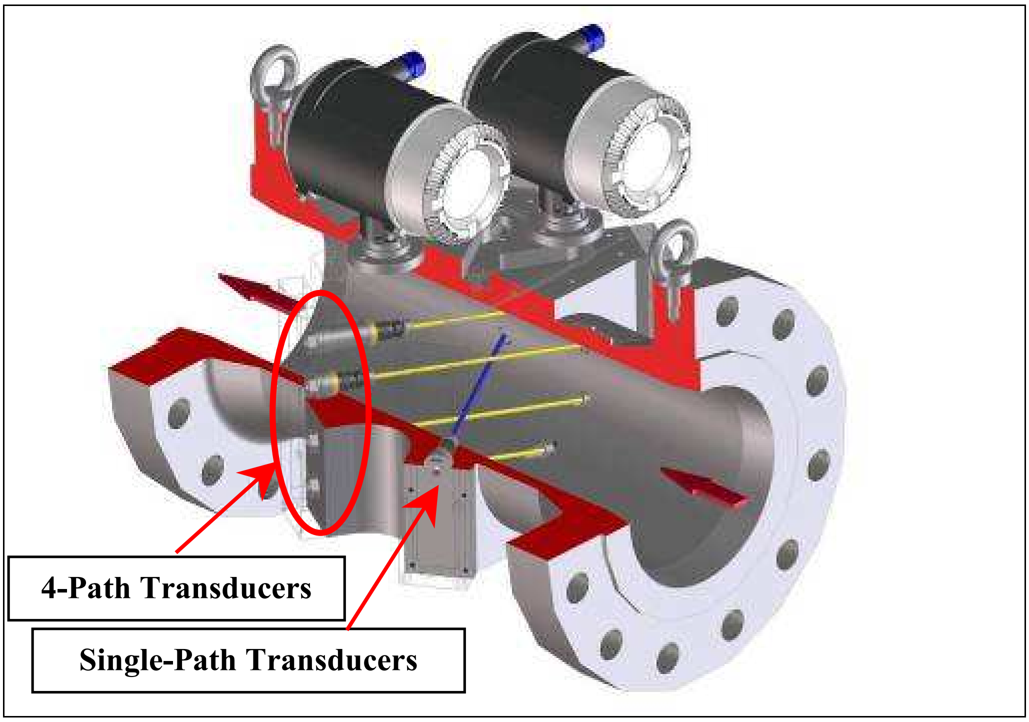

Figure 1: CBM 4+1 Meter Design

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

Figure 2 shows an 8-inch 4+1 meter with plastic covers over the transducer mounting area. The plastic is simply for a better view and certainly would not be used in the field. Figures 3 and 4 show the transducer locations as well as the installation of the two electronics.

Figure 3: CBM 4+1 Transducers

Figure 4: CBM 4+1 Dual Electronics

Figure 3 shows a close-up of the transducers in a demo model. The single-path transducers on the right of the meter are located in the center of the meter 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 (SPU) are used, one for the 4-path configuration, and one for the single-path configuration. Both electronics energize their transducers independently of the other. There is also no communication between the electronics, and no interaction between the sound pulses from one “meter” to the other. Figure 4 shows the dual electronics and the mounting on the top of the meter.

The concept of comparing the flow determined by the 4-path to that of the single-path is not new. This technique has been used by TransCanada Pipelines for many years. In their installation configuration they often utilize a single-path center-line bounce meter installed approximately 5 nominal diameters downstream of a 4 path chordal custody transfer meter. The single path meter would be adjusted to agree with the calibrated 4-path at the time of commissioning. In other words, the single path meter would not be flow calibrated at a laboratory, but rather “in situ” calibrated after installation in the field. This would be performed at the time of commissioning when the meter station piping was clean and there were no measurement problems.

The theory behind this technique is relatively simple. The purpose of using 4 paths to measure gas volumes in fiscal applications is to reduce measurement uncertainty due to changes in the profile that can occur over time. As the profile may change due to operating conditions, it is desired that the accuracy of the fiscal meter not be affected. The TransCanada Pipeline installations, as well as most other North American designs, utilize a perforated plate style of flow conditioner, known as the CPA 50E, to reduce the effects of upstream piping disturbances. The flow conditioner produces a relatively symmetrical, non-swirling and repeatable velocity profile throughout the operational velocity range of the meter.

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

Over time 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. These include asymmetry, swirl and other profile changes that occur due to contamination or anything that causes a different profile entering the meter.

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.

The benefit of the chordal design and understanding the velocity profile has been discussed in several published papers [Ref 1, 4, 5 & 7]. When the meter is installed with a flow conditioner, the technician can identify problems by looking at the velocity profile. Some problems develop over time, some occur very quickly as in the case of a foreign object lodging itself against the flow conditioner. Other blockage conditions can occur due to hydrate formation when the gas may be cold, or encounters significant pressure change. This hydrate condition has been known to completely block the transducer ports and thus render the meter inoperative.

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 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 hour. This means if a problem occurs, a potential measurement error can be identified by the system within one hour. 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 an hour will help reduce unaccounted for gas (UAF).

2. PROVING THE CONCEPT

Does this technique really work when it is contained within only 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].

To quantify the benefits of this design, testing with several blockage scenarios was conducted. Not only were the 40% blockage tests duplicated from previous tests [Ref 5 & 6], but additional testing was done with just 3 holes blocked on the CPA, and also with only 1 hole blocked. In order to identify whether location of the blockage was an influence, the 3 holes blockage test was performed with the blocked holes on the bottom, and then also with the blocked holes located 90 degrees from the bottom. Three velocities were used for all of these tests. These were approximately 7 m/s, 14 m/s and 21 m/s.

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

Figure 5: 12-inch 4+1 CBM Meter CEESI

A CPA was installed 10D upstream for baseline testing. After the baseline testing was complete, and the adjusted output for both the 4 path meter and the single path meter were verified, the 12-inch CPA was partially covered with duct tape (40% blockage). Figure 6 shows the flow conditioner prior to testing.

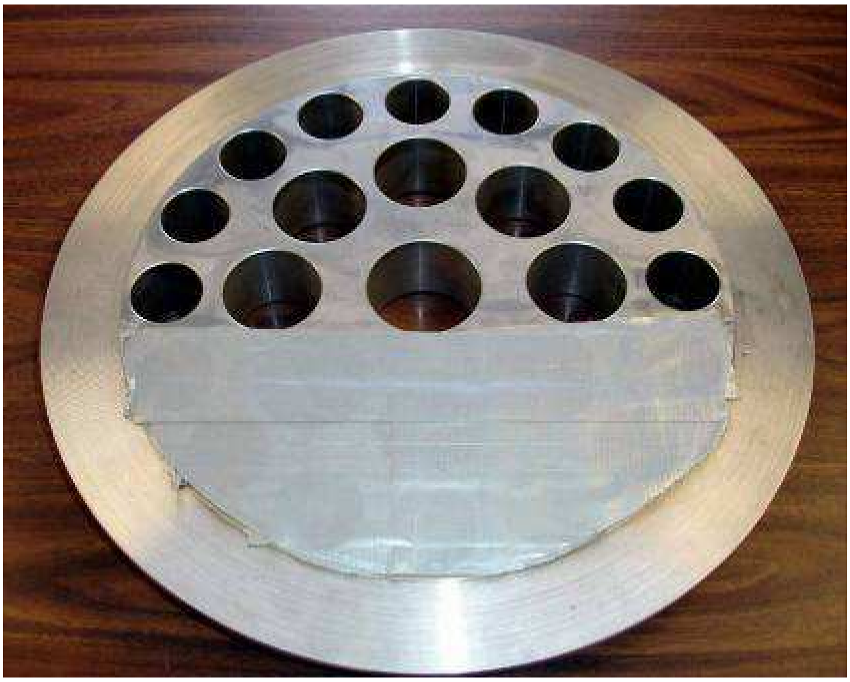

Figure 6: 12-inch CPA with 40% Blockage

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.

Figure 7 shows the results of the 4-path meter after baseline calibration (piecewise linearization) and subsequent results with 40% blockage of the flow conditioner.

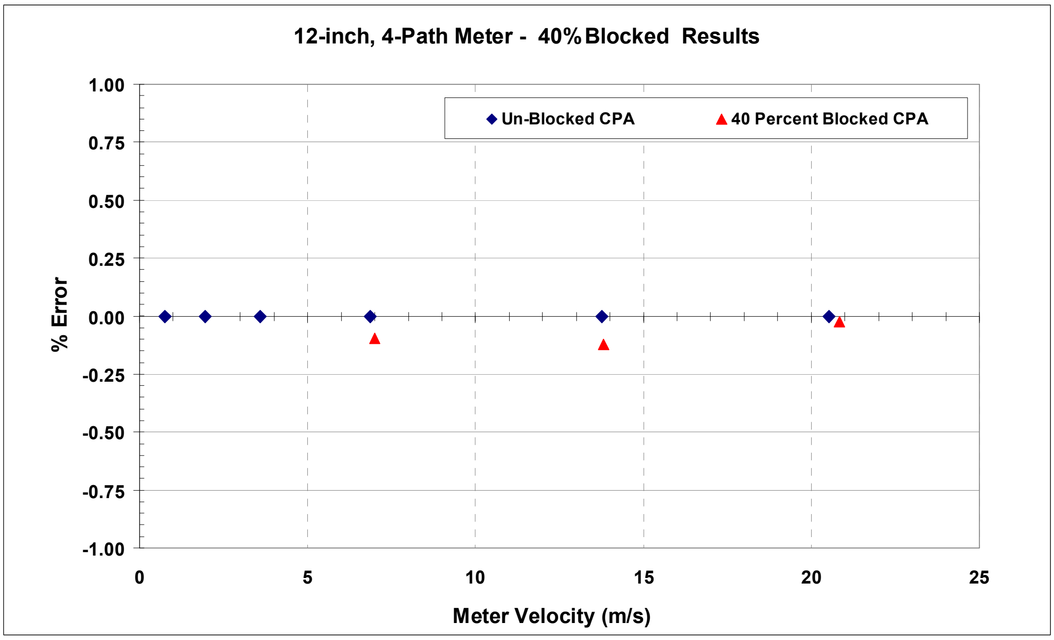

Figure 7: 12-inch, 4-Path Meter Results with 40% Blockage

Figure 7 shows that the 12-inch, 4-path meter shifted on the order of -0.15%, or less, for all three velocities tested. Figure 8 shows the results of the single-path during this same time.

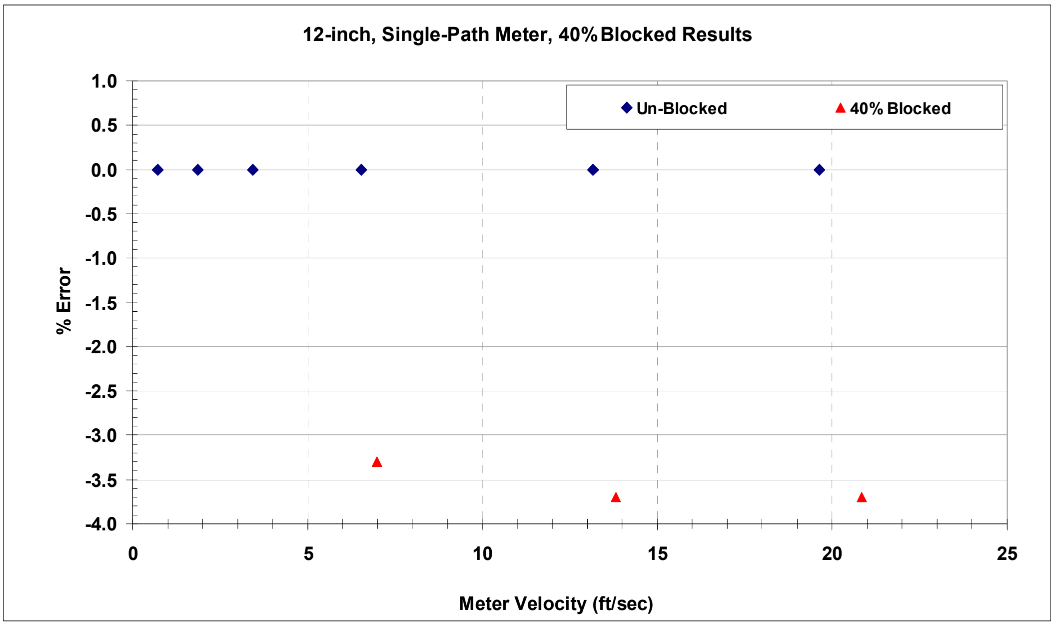

Figure 8: 12-inch, single-Path Meter Results with 40% Blockage

Figure 8 shows the impact on the single-path meter to be on the order of -3.5%. Thus for the same blockage the 12-inch meter, the single-path meter shifted more than 20 times as much as the 4-path meter.

The next test involved blocking only 3 holes at the bottom of the meter. Figure 9 shows the flow conditioner with these holes blocked.

Figure 9: 12-inch CPA with 3 Holes Blocked

The blockage of the three holes was developed by simply removing some of the duct tape that had been used to block 40% of the CPA. Thus there is some residual adhesive left on the face of the flow conditioner.

Figure 10 shows the results of the 4-path meter with blockage at the bottom, and then rotated to the side (90 degrees from the original location).

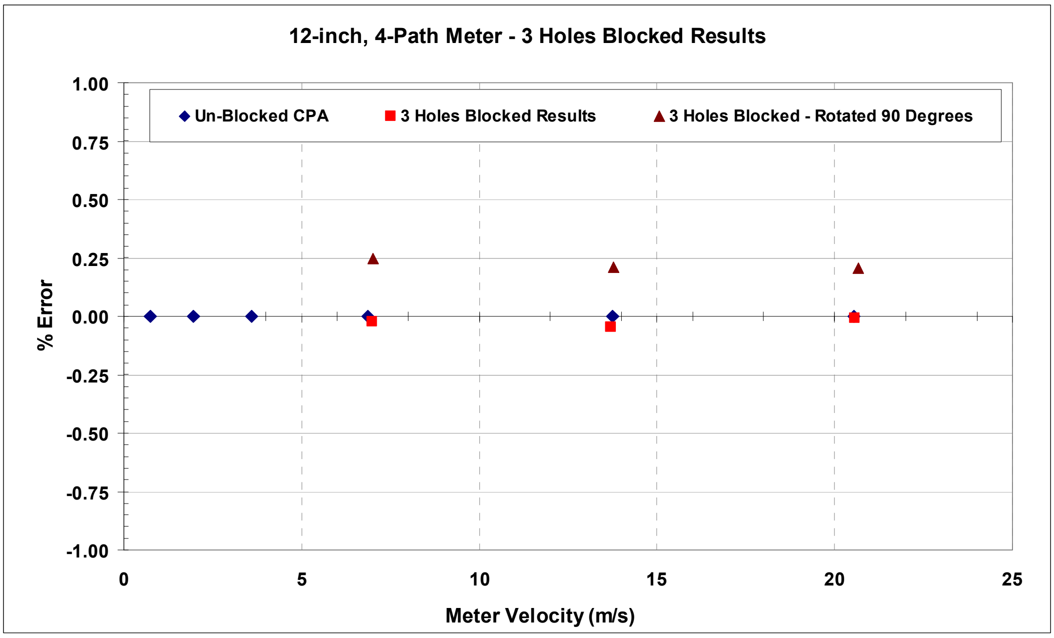

Figure 10: 12-inch, 4-Path Meter Results with 3 Holes Blocked

When the blockage was at the bottom of the meter run, there was very little impact on accuracy. When the blockage was rotated 90 degrees to the side, the meter responded with a shift of about +0.25%. 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.

Figure 11 shows the results of the single-path during these tests.

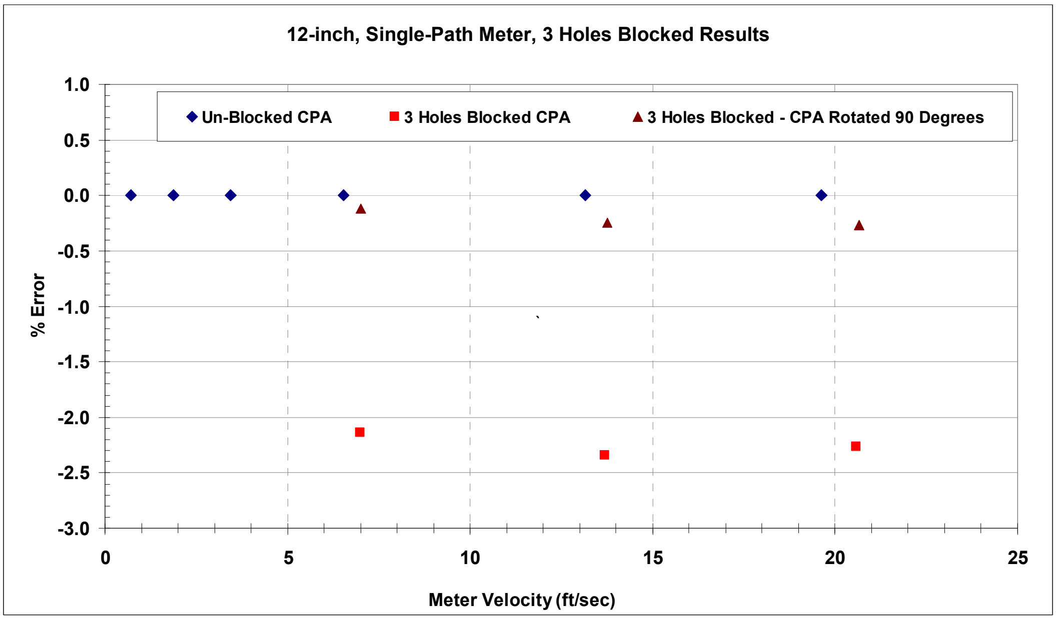

Figure 11: 12-inch, Single-Path Meter Results with 3 Holes Blocked

The single path meter shifted more than 2% slow when the blockage was at the bottom, and about 0.3% slow when the blockage was on the side. Even though the shift in the single-path meter was only 0.3% slow when the blockage was on the side, the difference between the 4-path and the single-path was still approximately 0.5%. The next step was to test the meter with only one blocked hole. Figure 12 is a picture of the CPA prior to the testing.

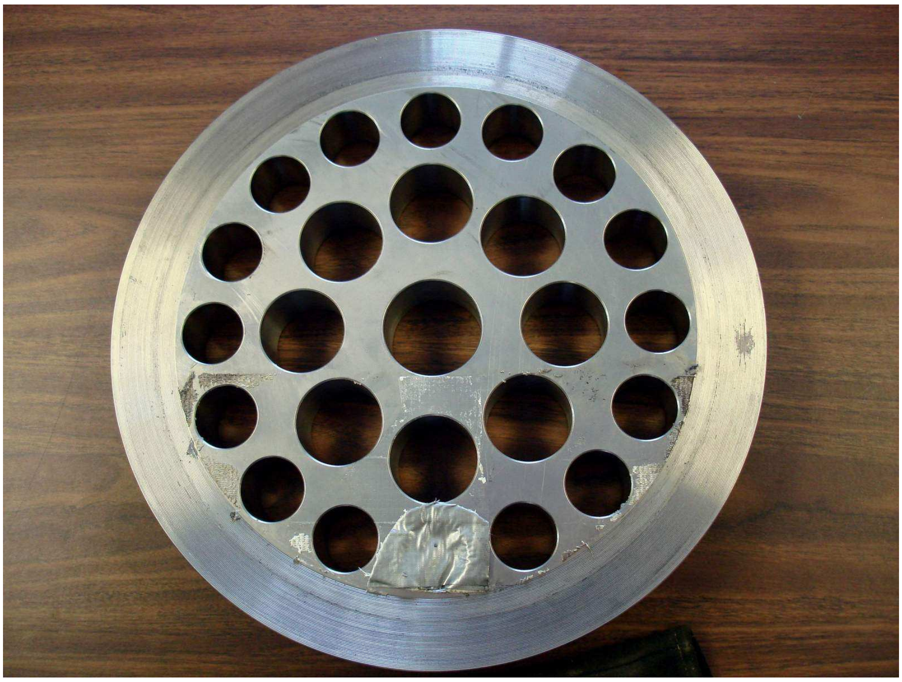

Figure 12: 12-inch CPA with 1 Hole Blocked

The single hole that was blocked was located on the bottom of the meter. This location was chosen as the most likely place for blockage to occur.

Figure 13 shows the results of the 12-inch, 4-path meter with this blockage and Figure 14 shows the results of the 12-inch, single-path meter.

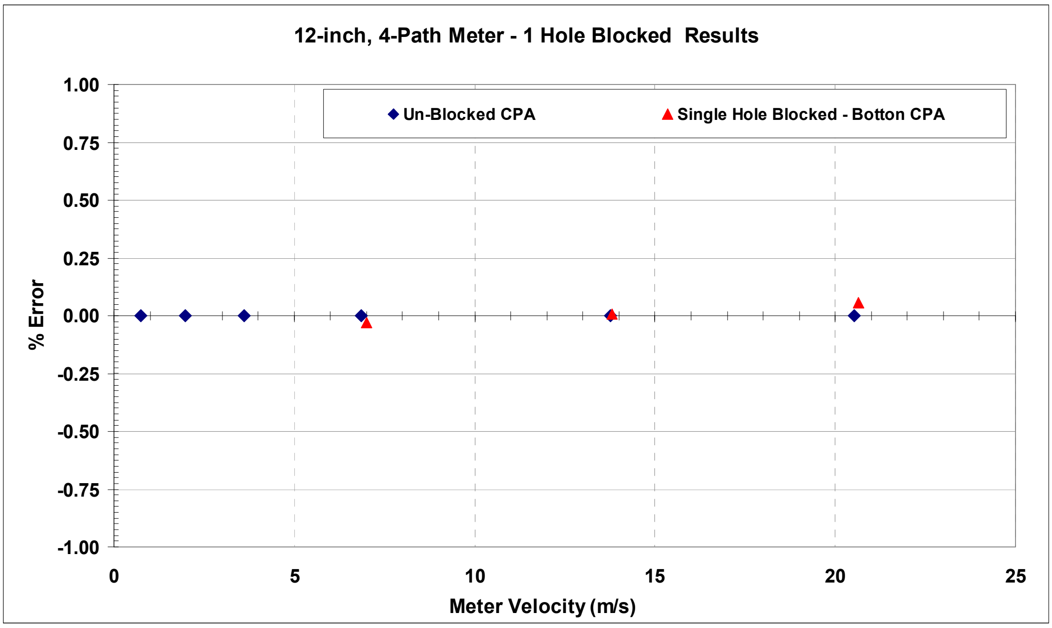

Figure 13: 12-inch, 4-Path Meter Results with 1 Hole Blocked

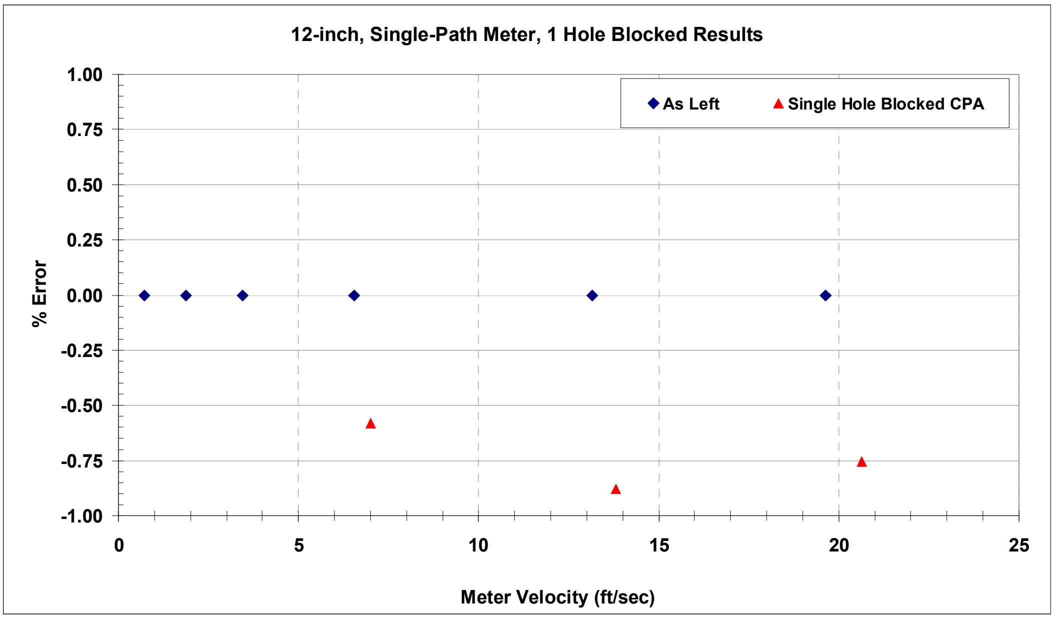

Figure 14: 12-inch, Single-Path Meter Results with 1 Hole Blocked

Figure 13 shows there is no impact on the 4-path meter's accuracy, while the single-path meter, shown in Figure 14, 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 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 a customer. This particular meter is an inter-company operational meter, in a bi-directional application. During the several years of service it has 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.

As this meter was installed in the late 1990's, it used a 19-tube bundle. Figures 15 and 16 show this flow conditioner during disassembly at the CEESI facility.

Figure 15: 19-Tube Bundle

Figure 16: Close-up of 19-Tube Bundle

Unfortunately the meter run had been cleaned recently and the upstream piping was not as dirty as was expected. Figure 17 shows the "as-found" condition of the piping between the flow conditioner (19-tube bundle) and the meter.

Figure 17: 12-inch Dirty Piping

As Figure 17 shows, there was not a lot of contamination remaining due to the recent cleaning of the meter piping. This was a bit of a disappointment for the customer as they expected the piping to be a bit dirtier.

Figure 18 is a close up of one of the meter pipes prior to any cleaning.

Figure 18: 12-inch Dirty Piping Close Up

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 look like had it been subjected to normal pipeline contamination, "texture" paint was applied to the CPA flow conditioner. Figure 19 shows the flow conditioner just prior to being installed for the testing.

Figure 19: 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. The 19-tube bundle could have been used for this testing. The customer had previously decided to re-install the 4+1 CBM meter, after all testing was complete, 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 20 shows the results for the 4-path meter both dirty and clean.

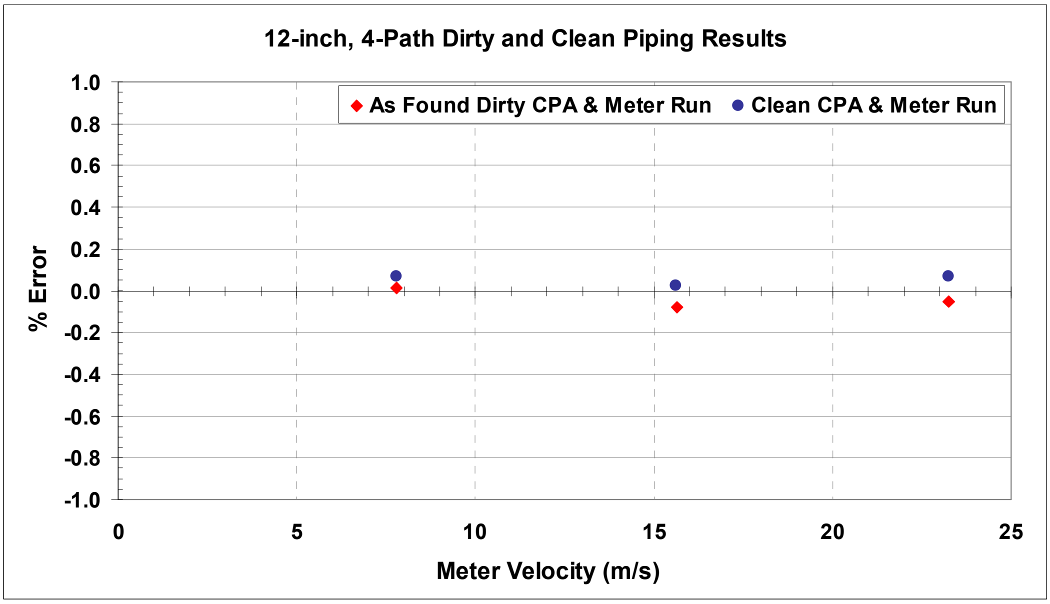

Figure 20: 12-inch, 4-path As-Found Dirty and As-Found Clean

The results of the 4-path meter as-found baseline are show 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 21 shows the difference between the two at each flow rate.

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

Figure 21: 4-path Dirty vs. Clean Differences

Figure 21 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 22 shows the results for the single-path during the same conditions.

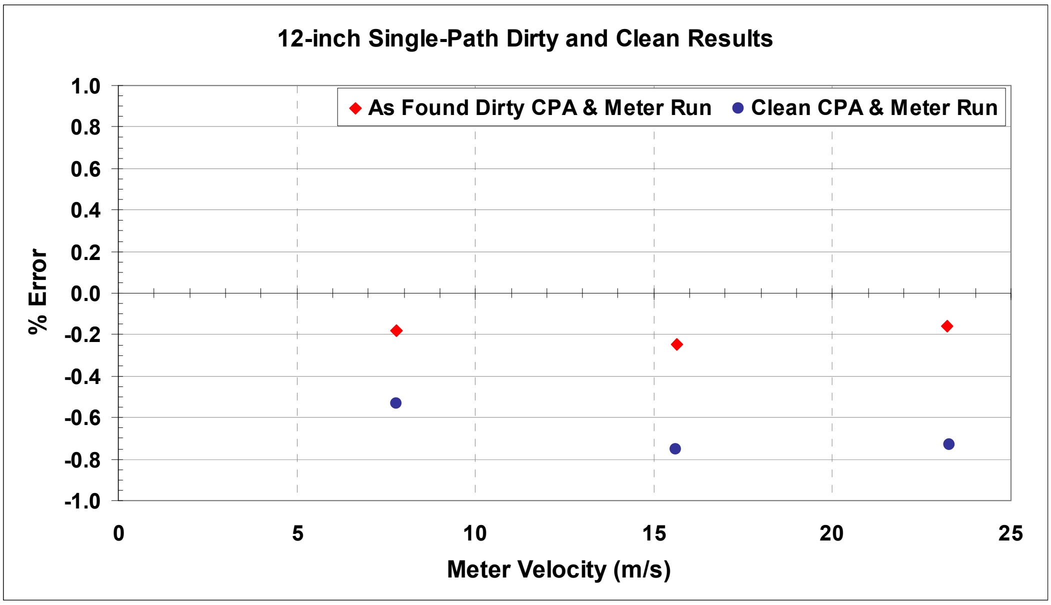

Figure 22: 12-inch, 4-path As-Found Dirty and As-Found Clean

In Figure 22 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 23.

Velocity	% Diff.
23.3	-1.30
15.7	-1.26
7.8	-0.88

Figure 23: 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 single path meter's response was easily seen. In the near future this entire meter assembly will be removed and once again tested but this time all the components will have been contaminated uniformly. The results of this will be published in a future paper.

3. 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 adjustable tolerance set 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 uncorrected volumes would suffice. Many users already have this capability built in to 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 taking full advantage of this meter design can be incorporated immediately without special flow computer programming.

The next phase of testing will be to determine how much the single-path meter will shift when installed in "real-world' conditions where contamination exists. Papers have been published [Ref 1 & 7] showing that the chordal design meter is relatively insensitive to contamination over time. It is expected the single-path meter will shift significantly during this period. The real question is "Can the use of the 4+1 CBM meter design be used to predict when the 4-path fiscal meter error exceeds a prescribed amount?"

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.

4. 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 users have been able to improve their measurement and reduce their UAF 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 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 of profile changes would not only have a significantly different impact on accuracy, but the effect would be in opposite directions, making the difference much easier to detect.

The benefit of the CBM 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 exceeds 75 times per second, thus virtually making the single-path insensitive to pulsation)
- Potential problems with the fiscal meter including transducers and electronics problems
- Full redundancy should there be a failure of the electronics

Today the cost of accuracy has never been more important. There are many applications where the accuracy of the measurement must be maintained to the highest degree possible. This CBM 4+1 meter design provides a "real-time health check" on the custody transfer meter. This significantly reduces the overall uncertainty of the measurement, and also reduces the O&M costs attributable to the technician by providing a timely (almost immediate) warning when a problem occurs.

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