The relevance of polynomial corrections and two different path layouts for master metering purposes in one gas ultrasonic meter

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On offshore applications space comes at a premium, and accuracy has always been looked upon as of great importance to the operator. One has seen the last decade a high improvement in meter accuracy in-situ where much of the credit is thanks to polynomial correction, and the introduction of meters with two different path layouts. The vendors have improved significantly, and our international standards, as well as NORSOK must undergo a new revision to meet the operator and NPD's standard as we speak. In this paper my main sources will be the standards ISO 17098, OILM R137, NORSOK I-104 and AGA 9 where the purpose is to discuss the relevance of polynomial corrections and two different path layouts for master metering purposes, and to see how the vendors have solved this in-situ accuracy challenge.

Ultrasonic meters has gained world-wide acceptance for fiscal applications the past several years, and has been presented in every major conferences showing their significant benefits in use including in the ones of greatest interest for Norway: NSFMW and NFOGM. 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 demand for gas world-wide will also increase the next 20 years based on the applications they are more and more commonly used in, and future prospects here in Norway indicates an even greater number of upcoming gas/condensate fields making the in-situ accuracy more and more important.

The most commonly used method to verify the ultrasonic meters operational accuracy/health today is often referred to as Conditional Based Maintenance (CBM), making the operator rely entirely on the understanding and interpretation of the meter's diagnostics. By adding an independent single-path, located in such a fashion as to traverse the meter in the center of the meter body to the 4-path layout[1)] we have a built-in diagnostics path in the meter. The result is a difference between the single path and the fiscal 4-path when the velocity profile changes. The main reason is due to the fact that a single -path meter is more sensitive to flow disturbance than the 4-path meter design[2)].

These include asymmetry, swirl and other profile changes that occur due to contamination or anything that causes a different profile entering the meter [2)]. A variety of installation effects were tested including two elbows in and out of plane upstream of the four meters by Terry Grimley in 1998. One could see that the multipath meters performed relatively well with errors attributed to the installation effects on the order of 0.5% or less, and single path meters errors in the order of 2-5%. As a conclusion of the tests it was clear that multipath meters could deal with the asymmetrical and swirling profiles far better than the single-path meters. But by placing the single-path pair of sensors in the center of the meter body that is the most sensitive location for flow measurement one could clearly see that the center-line path would shift far more than if located at any other position within the meter. This it was makes it an excellent check against the 4-path which experiences much less shift when the profile changes caused by for example partially blocked flow conditioners, or pipeline contamination [3)].

Since most conventional method of identifying potential measurement errors today is only checked on a monthly basis problem are about to occur, where it may be weeks before it is identified causing a substantial impact on billing. By using a CBM 4+1 method of comparing the output of a single-path meter to that of the fiscal 4-path meter, the performance of the two meters is validated every hour. In other words: if problems such as hydrate blocking in the flow conditioner occur, a potential measurement error can be identified by the system within one hour. First then there will be a need for a technician to investigate the meter or monitoring 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, saving the operator on a yearly basis maybe as much as 0.2-0.5%. But how can this be identified?

By blocking the flow conditioner during tests at CEESI Iowa high flow calibration facility done with a 12-inch 4+1 meter w/ CPA 50E flow conditioner it clearly shows the beneficial advantages one gets by having an independent single-path, located in such a fashion as to traverse the meter in the center of the meter body to the Westinghouse path layout. The velocities used for all tests where approximately 7 m/s, 14 m/s and 21 m/s [4]:

Figure 1

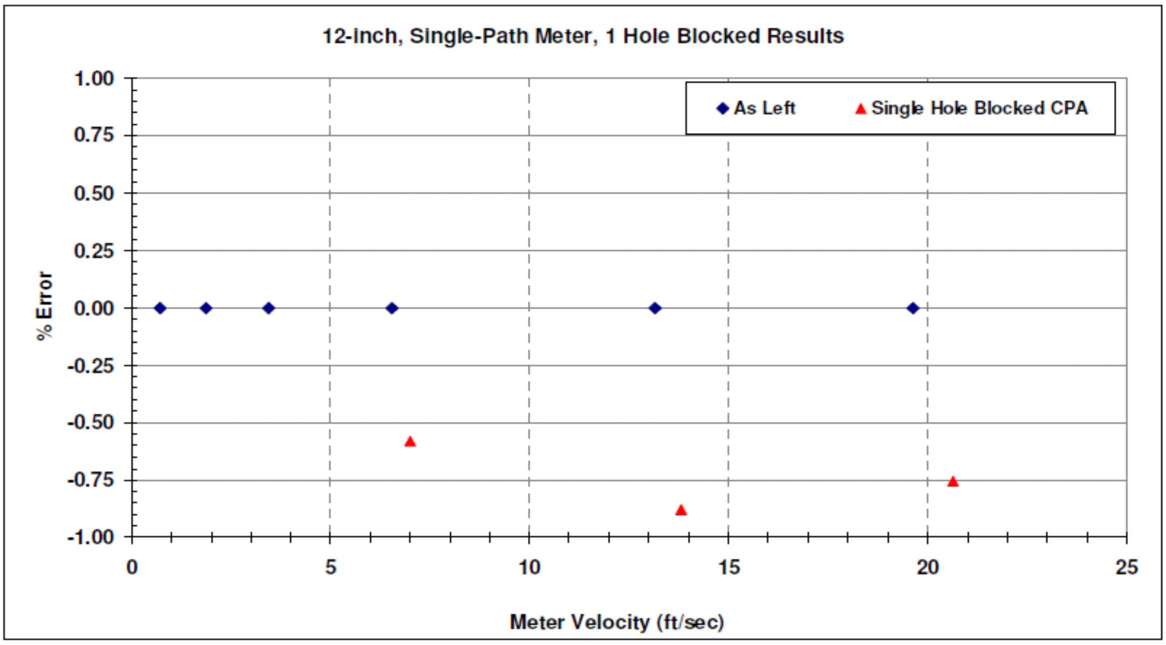

Figure 2: Single path Meter Result with 1 hole blocked

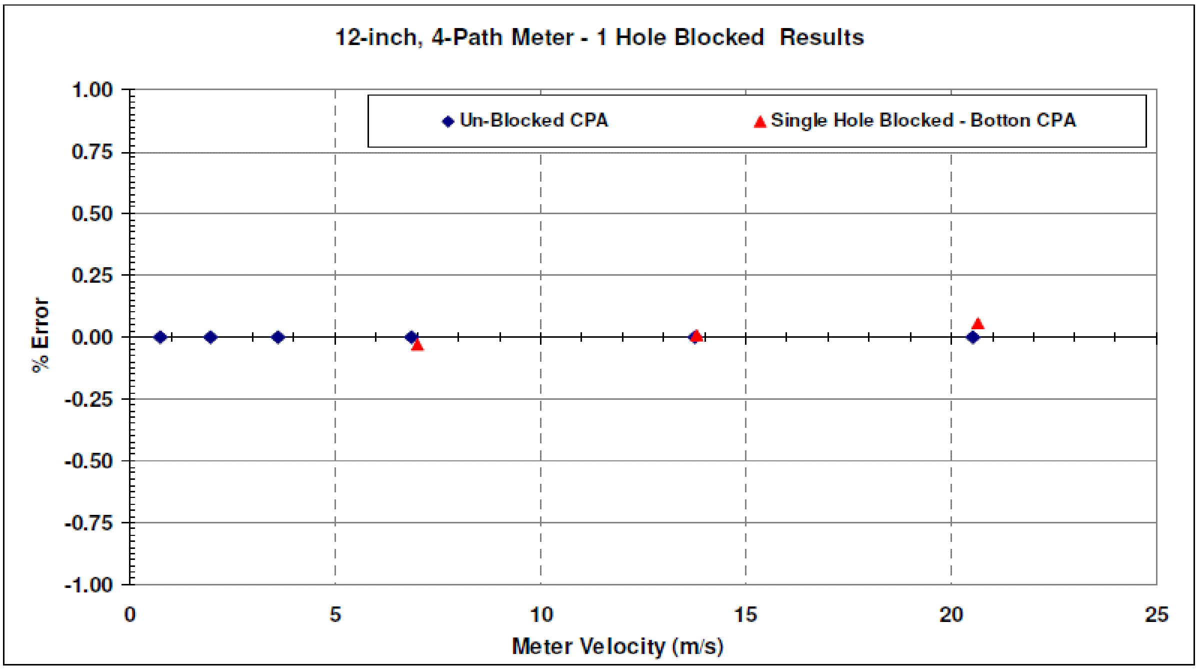

Figure 3: 4-path Meter Result with 1 hole blocked

Figure 3 shows there is no impact on the 4-path meter's accuracy, while the single-path meter, shown in Figure 2, 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.

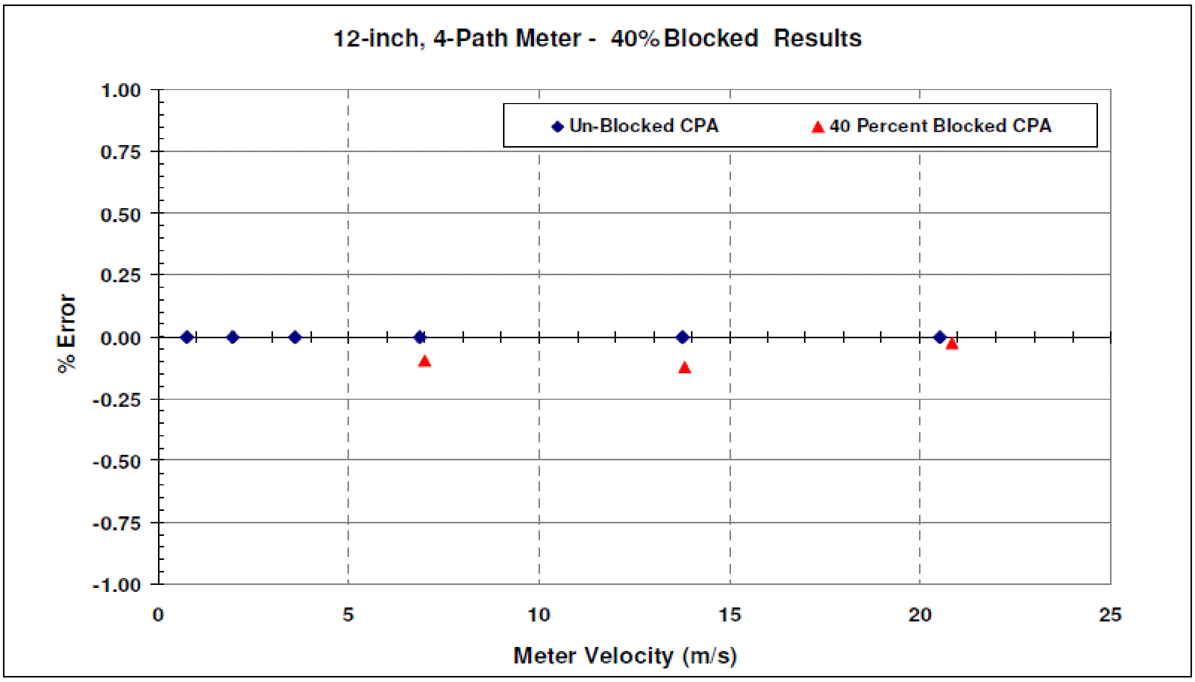

Figure 4: 4-path Meter Result with 40% blockage

According to AGA 9 (2006) meters larger than 12” have a maximum error prior to making any calibration-factor adjustment ±0.7% for $q_t \leq q_i \leq q_{max}$[10] and for small meters (less than 12”) ±1.0% for $q_t \leq q_i \leq q_{max}$. From OIML R 137 section 7.1 we find that An Accuracy Class 1 gas meter is tested during type evaluation with an uncertainty of 0.3 % (k = 2). In this case the test results can be accepted if the error is between ± (6/5 × 1.0 - 0.3) % = ± 0.9 % [5) 8) 11)]. It is also mentioned in AGA 9 section *6.4.3 Calibration Adjustment Factors* that the use of a polynomial algorithm, piecewise linear interpolation or other industry is an accepted method.

By looking further into OIML R 137 one can see that the number of degrees of freedom is the difference between the number of observations and the number of parameters or coefficients needed for the curve fit. For example, if a Straatsma polynomial is used with 4 coefficients, at least 10 measuring points are necessary in order to get a minimum of 6 degrees of freedom. This makes NORSOK I-104 [6)] calibration not “good” enough when wanting to have a meter calibrated with accuracy below ±0.5% for $q_t \leq q_i \leq q_{max}$ (small meters): *The turbine and ultrasonic flow meter shall be tested in the upper and lower part of the range, and at three points distributed between the maximum and minimum values. Five repeats shall be made for each point*. So how does this correction applied in the software affect the uncertainty for the meter?

From ISO 17089 [7)] section 6.3.5 Adjustment factors where linearization curves are applied, the following correction algorithm may be used:

$$q_{V,\,\mathrm{true}} = q_{V,\,\mathrm{actual}} \frac{100}{100 + E\left(q_{V,\,\mathrm{actual}}\right)}$$

Where

$q_{V,\,actual}$	is the raw metered quantity;
$E(q_{V,\,actual})$	is the error, as a percentage, associated with the flow rate;
$q_{V,\,true}$	is the value the meter should return with insignificant error, i.e. the reference meter quantity.

If a zero offset was established during flow calibration, it might be revised based on the results of the flow calibration to optimize the overall accuracy performance of the meter. The manufacturer should document such a change in this factor and alert the user that the zero flow output may have some intentional bias in order to improve the accuracy at $q_{V,\,min}$.

As polynomial correction improves the linearity of the error curve and corrects the WME to a lower value. The difference between the polynomial curve and the test flow rates “Dec. As found” is the remaining error after adjustment, represented in the error curve (“Dev. As left”). The calculation procedure mathematically shifts the polynomial to the zero line[9)]:

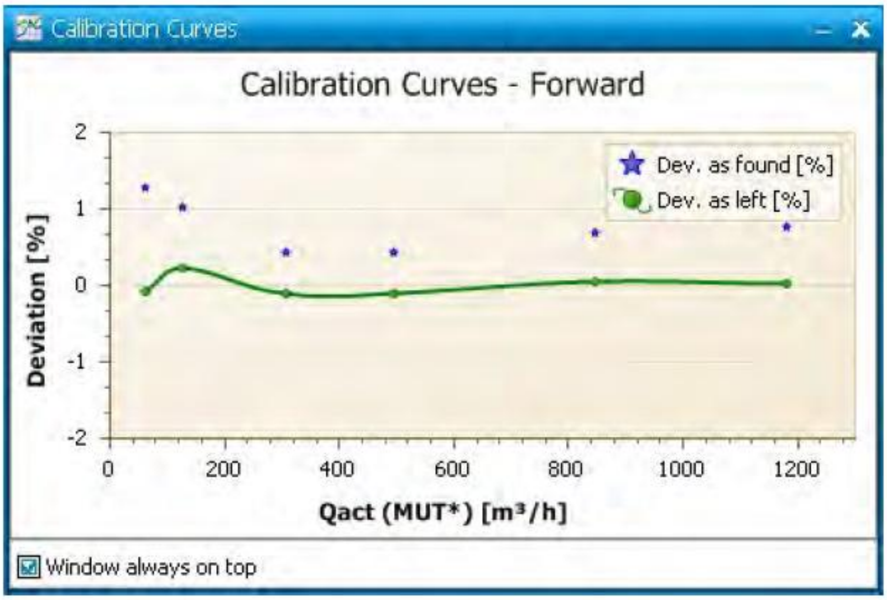

Figure 5: calibration Curve after and before polynomial correction.

CONCLUSIONS
As mentioned in the introduction the cost of energy is higher than it was several years ago, and it is not likely this trend will reverse in the near future. By implementing ultrasonic metering technology users have been able to improve their measurement and reduce their unaccounted for 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 either through polynomial correction, a USM with diagnostic information or both.

The benefit of having a 4+1-path meter design is that the flow computer is used to check the accuracy/health of the fiscal 4-path meter by simply comparing it to the single-path meter, making both meters agree if the velocity profile remains relatively constant.

By also implementing polynomial correction the accuracy will also increase in series to adjustment with constant factor and adjustment with piece wise linear error interpolation. This significantly reduces the overall uncertainty of the measurement giving more reliable in-situ accuracy and uncertainty limits of 0.1% can be achieved.

[1)] 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.

[2)] Terry Grimley, *Installation effects on two multi-path meters, and on two single-path meters, 1998*

[3)] John Lansing, *How Today's USM Diagnostics Solve Metering Problems,* 2005

[4)] Larry Garner & Joel Clancy, *Ultrasonic meter Performance – Flow Calibration Results CEESI Iowa*, 2004

[5)] OIML R 137 section 7.1, 2006

[6)] NORSOK I-104, 2005

[7)] ISO 17089, 2010

[8)] Directive 2004/22/EC, Appendix MI002, Class 1

[9)] TI_FL600_EN_V3-0

[10] q_t = gas flowrate at time t q_i = initial gas flow rate at time t q_{max} = maximum flow rate
[11] When a test is conducted, the expanded uncertainty (*k* = 2) of the determination of errors of the measured gas quantity shall meet the following specifications:
- for type evaluation: less than one-fifth of the applicable MPE
- for verifications: less than one-third of the applicable MPE.

If the above-mentioned criteria cannot be met, the test results can be approved alternatively by reducing the applied maximum permissible errors with the excess of the uncertainties. In this case the following acceptance criteria shall be used:
- for type evaluation: +/- (6/5 * *MPE* – *U*)
- for verifications: +/- (4/3 * *MPE* – *U*)

The estimation of the expanded uncertainty *U* is made according to the *Guide to the expression of uncertainty in measurement* (GUM, 1995 edition) [6] with a coverage factor *k* = 2.