Paper 2.2

Characterizing Ultrasonic Meter Performance Using A Very Large Database

Thomas M. Kegel
Colorado Engineering Experiment Station, Inc.

Richard L. Britton
Saudi Aramco

26th International North Sea Flow Measurement Workshop
21st – 24th October 2008

Characterizing Ultrasonic Meter Performance Using A Very Large Database

Thomas M. Kegel, Colorado Engineering Experiment Station, Inc.
Richard L. Britton, Saudi Aramco

---

1 INTRODUCTION

Ultrasonic meter calibration results are often the basis for gas volume uncertainty estimates. Current ultrasonic meter calibration processes do not completely identify many characteristics of ultrasonic flowmeters:

- short term random effects are not well identified due to limitations in the number of data points that make up a calibration
- long term random effects are not identified because a typical calibration only lasts a few hours
- performance characteristics correlated with line size are largely unknown if a user does not calibrate a range of meter sizes

This paper summarizes some analyses of a very large database of ultrasonic meter calibration results. The database has been populated during eight years of operation of an ultrasonic meter calibration facility. The analyses result in the quantification of meter performance separated into four categories:

1. Short term random effects expressed as a function of velocity of several “typical” ultrasonic meters. The time frame associated with “short term” is on the order of many minutes up to one hour.
2. Long term random effects expressed as a function of velocity of several “typical” ultrasonic meters. The time frame associated with “long term” is on the order of several years.
3. Random effects expressed as a function of velocity present in the “as found” data of multiple meters of the same size. These data are presented for a range of meters sizes.
4. Diagnostic parameters that relate to the development of initial calibration fingerprint curves and assist in monitoring long term meter performance.

The CEESIowa test facility went into operation in March 1999. During the intervening years a large calibration database has been assembled, much of the information is unique in the world. This paper discusses some results from “mining” that large dataset for information that is useful to the industry.

Two definitions of “data mining” can be found in [1]:

1. "The nontrivial extraction of implicit, previously unknown, and potentially useful information from data“
2. "The science of extracting useful information from large data sets or databases"

The data mining task is not complete, this paper organizes some of the results obtained thus far.

2 STATISTICAL PROCESS CONTROL

Much of the data discussed in this paper were obtained from three chordal path ultrasonic meters that are used as check meters in the Iowa facility. The nominal diameters are DN300 (12 inches), DN500 (20 inches) and DN600 (24 inches). Within this paper the meters are identified as SPC12A, SPC20 and SPC24.

Control charts based on a variety of check meters have been maintained on a regular basis since September 1999. This section provides a brief review of the process currently in place to organize and interpret data from these meters [2,3]. Figures 1, 2 and 3 of the paper are reproduced from [3] to aid in the discussion.

The development of the control charts begins with a curve fit of meter error and velocity. The conventional (AGA9 [4]) definition of meter error is the difference between flowrate values reported by the meter and the laboratory standard. In the Iowa facility nine twelve inch turbine meters are used as standards. While the AGA 9 definition is used in this paper, it is noted that the ISO VIM [5] states:

> "The error concept can be used when there is a single reference quantity value to refer to, which occurs if a calibration is made by means of measurement standard of negligible measurement uncertainty."

Current day ultrasonic meter calibration processes are characterized by meters exhibiting long term random effects that are smaller than the uncertainties of the laboratories. It is suggested that the use of the term "error" does not meet the ISO VIM definition.

Having defined a curve relating error and velocity; a residual is defined as the percent difference between a data point and the curve fit value. The standard deviation of the residuals defines a statistical interval that contains 95% of the data. Figure 1 shows a plot of residual vs. velocity for SPC24. Most measurement processes exhibit random effects that increase in magnitude for lower operating range values, the measurement of differential pressure represents a familiar example. The data of Figure 1 confirm such behavior for this ultrasonic meter based flow measurement process.

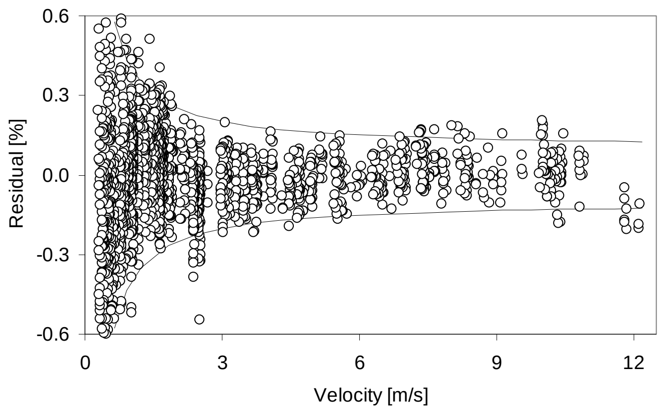

Fig. 1 – SPC24, Curve Fit Residuals

The statistical interval width is $\pm 2s$ where s is a standard deviation expressed in percent. Frequently s can be defined by an equation of the form:

$$s = a + (b/v) \times 100\% \qquad \text{[Eq 1]}$$

where v is velocity. Traditionally the coefficients a and b are selected until the interval appears to contain 95% of the data, a methodology is more qualitative than quantitative. One objective of current analyses is to better quantify the velocity dependence, a new approach is applied to data from Meter SPC24 in the next section.

The next step is the creation of the control charts. The residuals determined from calibration data obtained in a single day are compiled and the mean and standard deviation are calculated. Two control charts containing daily values of mean and standard deviation plotted against time are contained in Figures 2 and 3.

The dependence of meter error on velocity prevents directly comparing results obtained at different velocities on a percent basis. For example, a residual of 0.3% is acceptable at 1 m/s but not at 10 m/s. The data are normalized based on the confidence interval prior to creation of control charts therefore the ordinate values in the control charts of Figures 2 and 3 are presented as multiples of s.

The solid lines in Figure 2 are control limits calculated based on 95% confidence. The process can be stated to be operating in a state of statistical control if 95% of the data lie between the control limits. The control chart in Figure 3 has only one control limit because the standard deviation cannot have a negative value. Statistical control is demonstrated if 95% of the data points lie below the single control limit.

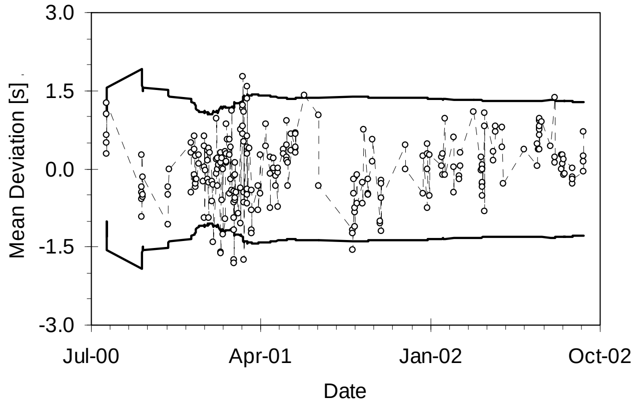

Fig. 2 – SPC24 Control Chart

The process of determining control limits requires the calculation of two standard deviation values [2]. The "within" standard deviation accounts for random effects observed during a single calibration day. The "between" standard deviation accounts for random effects observed between calibration days. These values can be interpreted to represent the short and long term random effects associated with the calibration process.

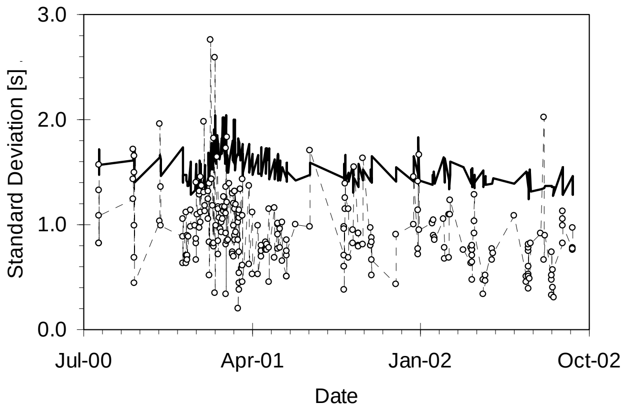

Fig. 3 – SPC24, Control Chart

Control charts are valuable in summarizing large data sets. Multiple data points obtained during one day are represented by two values. The control charts allow for a quick check of how consistent the current calibration is when compared to the accumulated history. The original application of control charts at CEESI was to allow a quick check of pressure transducer calibration results

Summarizing historical performance with a control chart is not as valuable in providing detailed meter performance information. One of the objectives of the data mining project is to investigate alternative analytical techniques to evaluate ultrasonic meter performance.

3 METER 1 – SPC24

The first meter under discussion, SPC24, was put into service in September 1999 as a check standard. This meter is permanently installed upstream of the test section and therefore subject to unchanging inlet conditions. No flow conditioner is installed. In January 2007 the transducers were replaced. The electronics remain unchanged except for some minor adjustments in December 2003.

Meter SPC24 is installed in series with every meter under test (MUT) calibrated in the DN600 (24 inch) test section. The data being analyzed consist of 7246 data points obtained between August 2000 and May 2006 over the velocity range of 0.5 to 24 m/s. It is noted that the velocity through SPC24 is defined by the MUT test plan. The data distribution is skewed towards lower values because the MUT is generally smaller than or equal to the check standard. This distribution is fortunate because more data are available to quantify the larger random effects present at lower velocity values.

The present analysis began by sorting the based on velocity. The sorted data were divided into 64 groups of approximately 100 data points each, each group of data represents a nominally constant velocity. The magnitude of random variations in meter error is dependent on both velocity and time. The analysis of a group of data points obtained at the same velocity allows for the isolation of time dependent effects. Typical results associated with a single group show in Figure 4, these data were determined over the 7.2 to 7.6 m/s velocity range. The ordinate is meter error while the abscissa is time, the symbols on the graph represent individual data points.

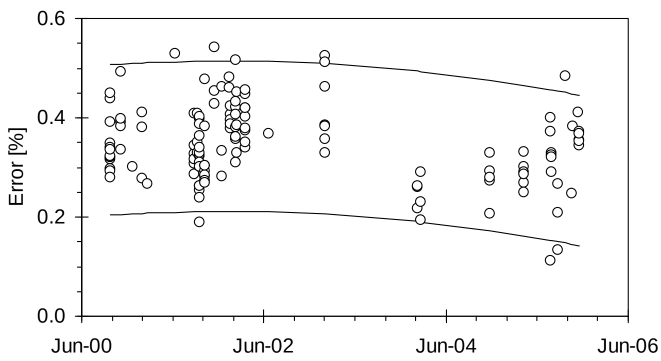

Fig. 4 – SPC24, Variation of Meter Error Over Time, Velocity = 7.2 – 7.6 m/s

The analysis continued with the fitting of a quadratic equation relating meter error and time and the determination of a residual for each data point. The standard deviation of the residuals is called standard error of estimate (SEE) [6]; for the present data SEE = 0.076%. The solid lines in the graph represent an interval of width ±2×SEE centered about the quadratic fit that contains 95% of the data points.

The data points in Figure 4 are uniformly distributed within the interval which indicates that the meter performance is reasonably consistent. A non-uniform distribution might indicate a second order effect requiring additional analyses.

The quadratic fit suggests a slight downward drift over time. A maximum error value of 0.363% is observed in early 2002 while a minimum value of 0.294% is observed in early 2005. The difference of 0.069% represents a potential drift rate of 0.023% per year.

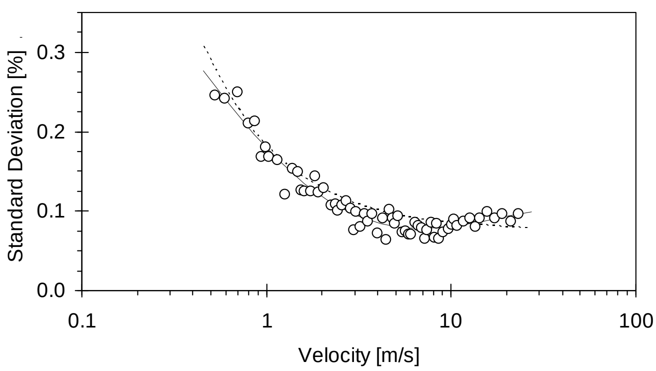

Fig. 5 – SPC24, Magnitude of Random Effects

Several conclusions can be drawn at this point. First, a potential drift or 0.023% per year represents a very small effect. Second, it is demonstrates that the analytical process is very sensitive. The interval width can be interpreted to represent a component of uncertainty. It is observed that a constant error value, a straight line with zero slope, could fit within the interval, the data could be interpreted to predict zero drift.

The analysis of Figure 4 was repeated at each velocity interval. The results are contained in Figure 5, the ordinate is standard deviation expressed as a percent of reading, the abscissa is velocity. The solid line is a fourth order polynomial fit of the data. The "best" performance, corresponding to the lowest standard deviation, is observed near the middle of the velocity range. The curve fit values over the 5.2 to 9.1 m/s range, for example, lie below 0.08%.

The dashed line in Figure 5 represents Equation 1 with a = 0.075 % and b = 1.05 [mm/s]. The term a in Equation 1 accounts for random effects that are consistent with velocity, sometimes called "percent of reading" effects. The term b accounts for the additional "percent full scale" effects that are commonly observed in most measurement processes. The result is the increase in standard deviation with decreasing velocity.

An alternative coefficient, b', can be defined as:

$$b' = b/L \qquad \text{[Eq 2]}$$

where L represents the effective spacing between transducer faces. While the determination of L is complex, the value is primarily dependent on meter geometry and can therefore be assumed constant. Equation 1 can be realized using b' with units of time illustrating that full scale effects arise from limitations in the measurement of time and effective transducer spacing.

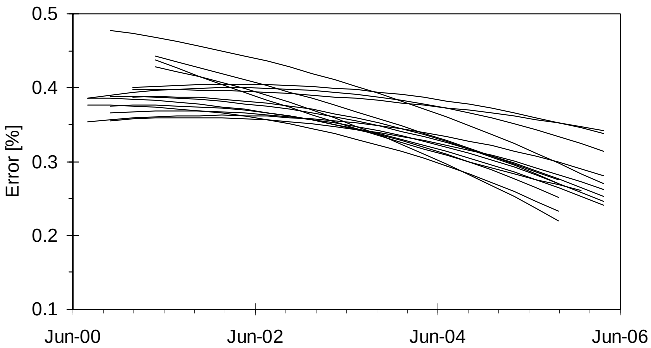

Fig. 6 – SPC24, Variation of Error With Time
Constant Velocity Curve Fits With Similar Shapes

The results of Figure 5 indicate a slight increase in standard deviation at high velocity. The magnitude of this change is approximately 0.02% between 10 and 30 m/s. This slight increase is the major contributing factor to Equation 1 not fitting the data as well as possible. A physical explanation for this observation is not currently proposed.

The results of Figure 5 are useful to CEESI in precisely quantifying the random effects required to normalize control chart data. The results are useful to the industry because the random effects represent an important uncertainty component associated with a "typical" ultrasonic meter. What is typical? Comparable results could be reasonably expected from another similar meter of the same size, perhaps a similar meter of a different size. One objective of the data mining effort is to determine the effect of diameter on the distribution and magnitude of random effects.

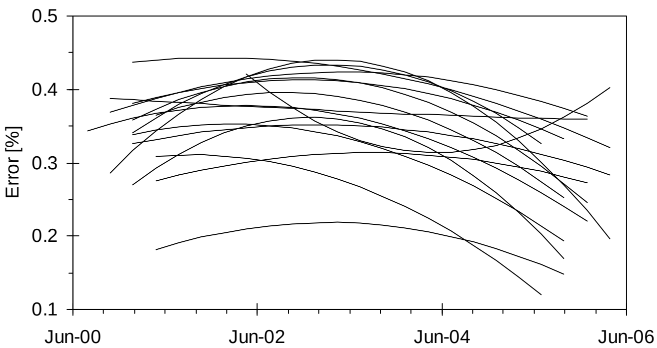

Fig. 7 – SPC24, Variation of Error With Time
Constant Velocity Curve Fits With Dissimilar Shapes

The quadratic fit of the data in Figure 4 predicts meter changes over time. Similar curve fits have been determined for data from a number of the velocity ranges, some of the results are summarized in Figure 6. The ordinate is meter error and the abscissa is time, each solid line represents the quadratic fit associated with a velocity range. The data shown represent 16 curves with similar shapes, similarity having been judged by eye. Figure 7 contains the remaining curves, the shapes exhibit a greater range of variation. All but two of the curves in Figure 6 fall in the 7 to 15 m/s range. All but four of the curves in Figure 7 fall in the 4 to 7 m/s and 15 to 23 m/s ranges. It appears that the meter exhibits more consistent long term behaviour in the middle of the velocity range than at either higher or lower velocities. A similar general trend has also been noted in Figure 5.

How are these results useful? Figures 6 and 7 quantify long term effects associated with this meter. These effects may be identified as drift, stability, or reproducibility; they may be considered random in nature. From the user's perspective, this information can help select a recalibration interval that balances cost and performance. The results provide CEESI an alternative tool to monitor consistency of the facility with greater detail than a control chart. Repeating from above, comparable results could be reasonably expected with another similar meter of the same size, perhaps a similar meter of a different size.

Historical analyses of meter SPC24 have included control charts of various diagnostic parameters, a detailed discussion including several examples are contained in [7]. That discussion included a case where meter SPC24 was installed downstream of an orifice meter and the resulting diagnostic (profile factor) clearly indicated abnormal conditions. The data mining effort includes available diagnostic data, currently the analyses have not resulted in additional conclusions concerning meter SPC24.

4 METER 2 – SPC20

The second meter under discussion, SPC20, was also put into service in September 1999 as a check standard. In October 2002 the electronics failed and a component was replaced. In February 2005 the transducers and electronics were replaced. This meter is permanently installed upstream of the test section and therefore subject to unchanging inlet conditions. No flow conditioner is installed.

Meter SPC20 is installed in series with every MUT calibrated in the DN500 (20 inch) test section. The data available for analysis consist of 15,250 data points obtained between April 2000 and July 2008 over the velocity range of 0.3 to 30 m/s. The present discussion is limited to the analysis of data obtained after the replacement of electronics and transducers in February 2005.

The present analysis parallels that underway for SPC24. The velocity sorted data were divided into 65 constant velocity groups each containing approximately 235 data points. The analysis to date consists of 14 velocity groups, the results are summarized in Figure 8. The ordinate is SEE associated with a constant velocity group while the abscissa is average group velocity.

Nine of the data points appear to follow a trend, a curve fitted to these data is shown as a solid line. The five data points with lower SEE values are not used in the curve fit.

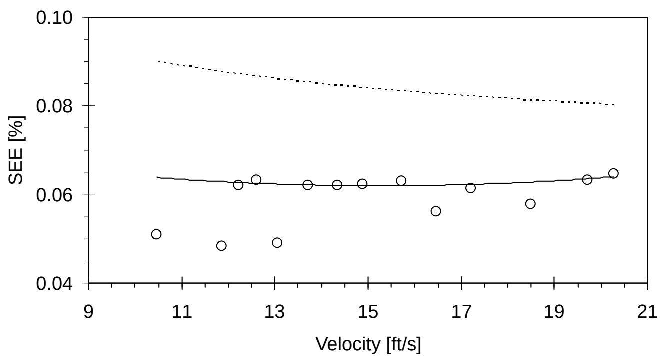

Fig. 8 – SPC20, Magnitude of Random Effects

The dashed line in Figure 8 indicates typical values in use immediately prior to failure of the electronics in October 2002. The difference between dashed and solid lines is the current vs. older electronics and transducers; clearly there is improvement as a result of the upgrade.

Meter SPC20 was subject to two historical events; failure of the electronics in October 2002 and full replacement of electronics and transducers in February 2005. Analyses of detailed data obtained in conjunction with these events would prove of value to the industry. A summary of older analyses concluded [8] that the control charts may have provided advanced warning of the electronic failure of 2002. The current results have not contributed new information to support this conclusion. The Iowa data acquisition system began collecting diagnostic data in September 2002, such data are therefore unavailable for the period preceding the electronics failure.

Meter SPC20 indicated a shift in performance with the new electronics and transducers in February 2005. At present that shift represents a single data point and will not be discussed in this paper. One of the future data mining activities involves collecting data from many re-calibrations that would better quantify the shift of a “typical” meter in response to changing transducers and/or electronics; data from SPC20 would be part of that study.

5 METER 3 – SPC12A

The third meter under discussion, SPC12A was first put into service in January 2003. It was primarily used by the manufacturer for research and development testing and the resulting data are proprietary. In March 2005 the electronics and transducers were replaced and the meter was put into service as a check meter.

Meter SPC12A was installed in series with most MUT calibrated in the DN400 (16 inch) test section between May 2005 and August 2006. A different check meter, SPC12B was installed for most of the calibrations completed between September 2006 and September 2007. The performance SPC12B will be the subject of future analyses. Meter SPC12A was returned to more continuous service as a check meter in October 2007. The present analyses are based on data obtained between May 2005 and August 2006.

As compared to SPC20 and SPC24, meter SPC12A is installed downstream of the test section. The pipe layout upstream of the meter therefore varies from one calibration to another. During the time interval of interest numerous calibrations were completed on DN150 (6 inch), DN200 (8 inch), DN250 (10 inch) and DN300 (12 inch) MUT, a few calibrations were completed on DN350 (14 inch) and DN 400 (16 inch) MUT.

Meter SPC12A inlet conditions vary depending on the MUT requirements. Some calibrations, for example, include two MUT installed in series, a configuration that would require additional space when compared to a single meter calibration. Other calibrations include the effect of elbows, tees and other pipeline fittings, such tests would potential introduce distorted or swirling profiles upstream of SPC12A. While the use of sufficient straight pipe plus a flow conditioner was always a goal, they would only be included if the test requirements were not

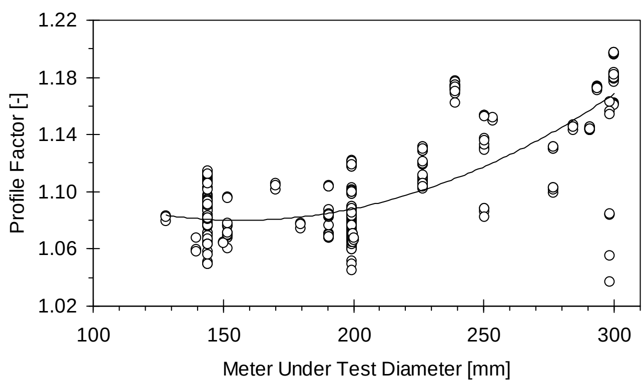

Fig. 9 – SPC12A, Profile Factor Variation with MUT Diameter Velocity = 6.7 – 7.6 m/s

compromised. The database for SPC12A provides a unique opportunity to gain insight into installation effects. For every calibration, the installed fittings have been recorded, these data have not yet been integrated into the database.

The mining of meter SPC12A data has included investigation of the profile factor, a commonly applied diagnostic parameter [7]. Results obtained over the 6.7 to 7.6 m/s velocity range are shown in Figure 9, the ordinate is profile factor while the abscissa is MUT diameter. The numerical value of profile factor is frequently interpreted to represent the velocity profile; a larger value corresponding to a more pointed profile, a smaller value indicating a flatter profile.

While random effects are clearly present, the data in Figure 9 appear to indicate a change in profile factor with upstream pipe configurations. The flow from a smaller to larger diameter in a commercial pipe reducer will result in a jet because the flow does not remain attached to the wall. The result, illustrated in Figure 10, will be a velocity profile that is more pointed than the fully developed profile associated with the Reynolds number and surface roughness. An ultrasonic meter exposed to the velocity profile of Figure 10 would be expected to exhibit a increase in profile factor. The trend in Figure 9 indicates the opposite effect, the profile factor decreases with MUT diameter.

Fig. 10 – Proposed Distorted Flow Profile

When a curve is fitted to a set of data the square of the correlation coefficient, R^2, indicates the degree to which the variation in the abscissa values is correlated with the ordinate values. The curve fit of Figure 9 is characterized by $R^2 = 0.56$ which means that 56% of the variation in profile factor is correlated with MUT diameter. The remaining 44% of the variation is either random or correlated with a different parameter. Identifying additional correlations remains an objective of future investigations.

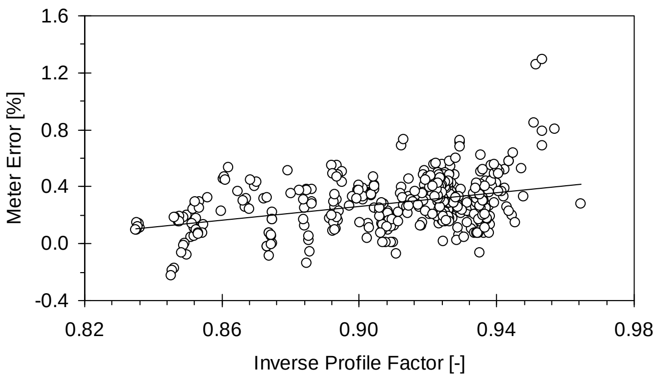

Fig. 11 – SPC12A, Meter Error Variation With Inverse Profile Factor
Velocity = 6.7 – 7.6 m/s

If the profile factor changes in response to upstream conditions, what impact does this have on meter error? Figure 11 shows a plot of the meter error and inverse profile factor. The solid line is a linear fit of the data characterized by $R^2 = 0.15$. It appears as if there is an effect, however small, of profile factor on meter error. The difference in correlation coefficient values (between Figures 9 and 11) indicates that the multipath velocity averaging is reducing the impact on meter error. The abscissa data are presented as the inverse of profile factor, as the data analysis proceeded the emerging data patterns seemed to indicate slightly better linearity with the inverse.

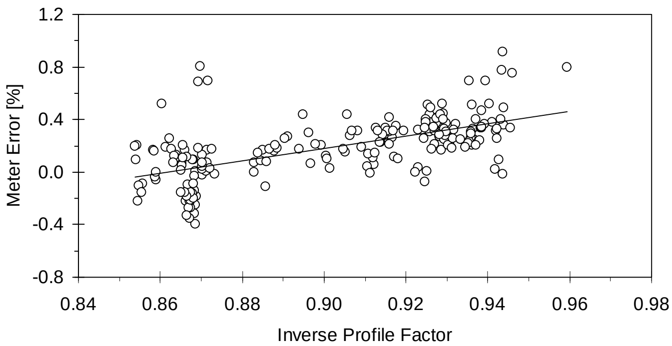

Fig. 12 – SPC12A, Meter Error Variation With Inverse Profile Factor
Velocity = 5.0 – 5.2 m/s

A similar plot is contained in Figure 12. The velocity range is 5.0 to 5.2 m/s and the linear fit is characterized by R^2 = 0.38. This plot, the result of a quick survey of the database, indicates the presence of data ranges that exhibit stronger correlation with profile factor.

The mining of meter SPC12A data needs deeper drilling. The analysis has not yet included complete descriptions of the pipe and fittings installed between SPC12A and the MUT. Including these data is expected to provide additional insight into the underlying fluid dynamics.

As with SPC20 and SPC24, the velocity through meter SPC12A is dependent on MUT size. This effect is more pronounced with SPC12A, a DN150 (6 inch) MUT will result in a velocity ratio 0.25. The smallest typical MUT size in the DN500 (20 inch) is DN350 (14 inch) which results in a velocity ratio of 0.70. The smallest typical MUT size in the DN600 (24 inch) test section is DN550 (22 inch) which results in a velocity ratio of 0.92. The variable velocity ratio imposes an additional constraint on the analyses.

6 INVESTIGATION OF METERS UNDER TEST

Analyses of meters SPC12A, SPC20, and SPC24 are based on large quantities of data obtained with single meters. The analyses described in this section are intended to represent smaller quantities of data obtained from multiple similar meters.

The first results under discussion were obtained from as ensemble of 23 chordal design DN250 (10 inch) MUT. The analysis began with a curve fit of meter error and velocity for each MUT, the curve fit residuals for all 23 MUT are shown in Figure 13. The solid lines represent a statistical interval of ±2*s* in width where s is defined by Equation 1 with *a* = 0.048% and *b* = 1.06 [mm/s]. When these results are compared to Meter SPC 24, the same value for *b* is observed. It appears that the basic relationship between random effects and velocity is the same for both meter sizes.

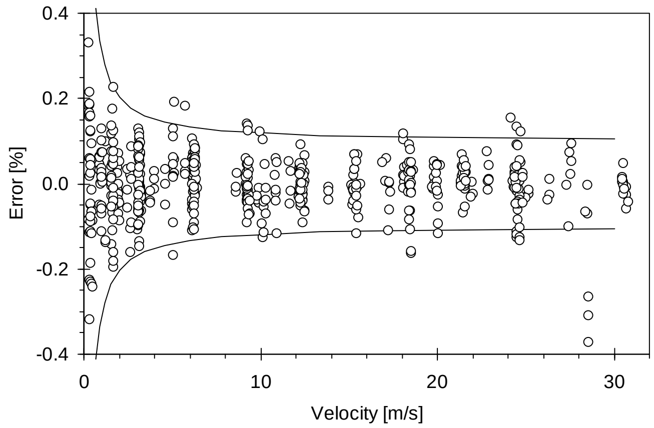

Fig. 13 – DN250 MUT Ensemble Meter Error Curve Fit Residuals

The *a* value for the meter ensemble (*a* = 0.048%) is significantly less than that for Meter SPC24 (*a* = 0.075%). One natural conclusion might be that the DN250 design is more repeatable than the DN600 design because the *a* values represent short term random effects. The difference between the meters is that a new curve fit is developed for each new set of ensemble data, while a single curve fit is applied to the data

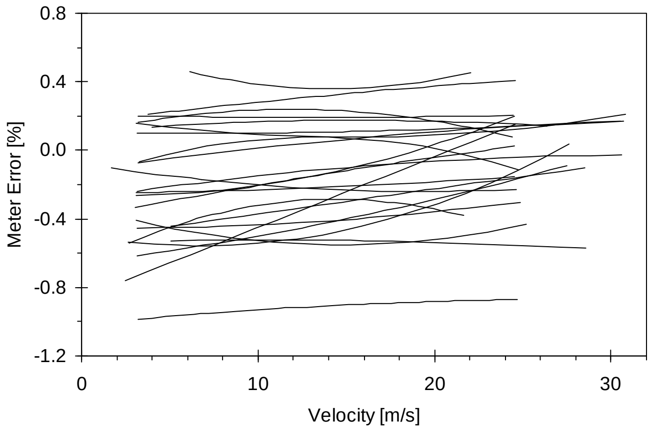

Fig. 14 – DN250 MUT Ensemble Meter Error Curve Fit Values

from Meter SPC24. Comparable performance from the large meter might be observed if the data were fit to a new curve every day.

The curve fits relating meter error and velocity are shown in Figure 14, each line represents one MUT. The data all lie within +0.46% and -1.0%; this range of values combined with values from Figure 13 provides one method for estimating the uncertainty of an un-calibrated ultrasonic meter. The uncertainty in a calibrated meter combines the values from Figure 13 with an uncertainty associated with calibration process. The uncertainty of a calibrated meter is always less than an un-calibrated meter. One of the curves of Figure 13 appears to be an outlier; in addition to generally reducing uncertainty, the calibration process will identify outliers.

A similar graph appears in Figure 15 where the curves fit profile factor data. These data illustrate that a curve relating profile factor and meter error is unique to each meter [7]. It has been proposed that diagnostic parameters can form a potential fingerprint to be monitored as an indicator of meter performance. A suggested application would be to record a fingerprint during calibration and then immediately upon installation in the field. Differences between fingerprints would identify potential changes to meter performance resulting from initial installation. Continuous monitoring of the fingerprint over time could provide indication of future meter problems.

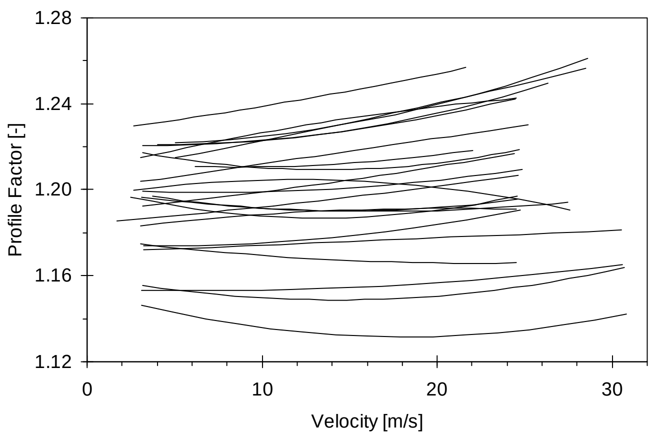

Fig. 15 – DN250 MUT Ensemble
Profile Factor Curve Fit Values

While identifying a relationship between profile factor and meter error is valuable; it does not provide a useful fingerprint because meter error is unknown in the field. Diagnostic data from individual meters in the ensemble are being evaluated for potential “field useable” fingerprints. One potential example is illustrated in Figure 16, the ordinate is the difference between measured and calculated speed of sound values. The calculated value is based on gas composition measured by a chromatograph and an equation of state [9]. The data were obtained over a range of velocities between 3 and 25 m/s. The solid line is a quadratic fit of the data characterized by $R^2 = 0.77$. Once installed, it would be a simple matter to periodically obtain data points and evaluate how well they fit the curve fit. One objective in continuing this investigation will be to evaluate how common this, or other, fingerprints are among similar meters. A second objective will be to evaluate the typical uncertainty associated with a fingerprint curve.

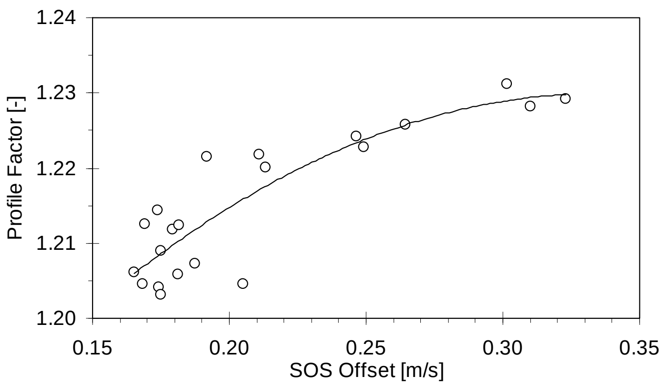

Fig. 16 – Selected DN250 MUT
Profile Factor vs. Sound Speed Fingerprint

7 SUMMARY AND FUTURE WORK

This paper has presented some results from an ongoing project to mine the CEESIowa calibration database. A summary of the results presented includes:

1. The process of characterizing two large meters (DN500, DN600) is well underway. Short and long term random effects have been defined, the long term values cover a period of several years. One of the meters shows an improvement in performance as a result of new electronics.

2. A third smaller meter (DN300) is exposed to a broader range of installation conditions. The analyses are more complex but the potential value of the results is high. The analyses thus far have identified meter sensitivity to installation conditions, additional detailed data have not yet been included.

3. Analysis has begun in the investigation of ensembles of similar meters under test. The discussion is based on a limited number (23) of DN250 meters. The effect of calibration has been demonstrated and some promising diagnostic tools identified.

As the project continues, the following activities are planned:

- Continue to the analyses already described, most are incomplete.
- Integrate additional diagnostic parameters into the database for the check meters. The speed of sound, in particular might yield some promising results.
- For the DN300 meter provide a summary of random effects as they vary with velocity and time.
- Begin analysis of a second DN300 check meter, a chordal design meter from a different manufacturer.
- Expand the ensemble MUT analysis to other meter sizes.
- Expand the MUT analysis to investigate meters returned for re-calibration.

8 REFERENCES

[1] http://en.wikipedia.org.

[2] T. KEGEL, Statistical Control of the Measurement Process, 6th Pipeline Conference, Merida, Yucatan, Mexico, 2001.

[3] T. KEGEL, Quality Control Program of the CEESI Ventura Calibration Facility, FLOMEKO, Gronigen, The Netherlands, 2003.

[4] AGA Report No. 9, Measurement of Gas by Multipath Ultrasonic Meters, American Gas Association, (2007).

[5] International Vocabulary of Metrology – Basic and General Concepts and Associated Terms, International Stand, International Organization for Standardization, (2006).

[6] R. DIECK, Measurement Uncertainty, Instrument Society of America, 2007.

[7] T. KEGEL, K. ROBERTS, and N. NGUYEN, How Often Do I Need to Recalibrate My Ultrasonic Meters; A Series of Life Cycle Studies, Southeast Asia Hydrocarbon Flow Measurement Workshop, Kuala Lumpur, Malaysia, 2007.

[8] T. KEGEL, Measurement Assurance Program of the CEESIowa Calibration Facility, Southeast Asia Hydrocarbon Flow Measurement Workshop, Singapore, 2004.

[9] AGA Report No. 10, Speed of Sound in Natural Gas and Other Related Hydrocarbon Gases, American Gas Association, (2003).