A Proposed Ultrasonic Meter Recalibration Interval Tool

Thomas Kegel [tkegel@ceesi.com]
Colorado Engineering
Experiment Station, Inc (CEESI)
Nunn, Colorado, USA

Stephen English
[stephen.english@atmosenergy.com]
Atmos Energy Corporation
Dallas, Texas, USA

Abstract

This paper describes data, discusses analytical results and presents a mathematical model that relates recalibration shift, meter size, velocity, and recalibration time interval. The results can be applied as a tool to assist in determining an appropriate recalibration interval for an ultrasonic meter. The database supporting this project is a result of twelve years of history in the operation of an ultrasonic gas flow calibration facility. The database includes 95 recalibration events, recalibration time intervals from less than one year to nine years, meter sizes from DN100 to DN500, and gas velocities between 3 and 30 m/s.

Introduction

The application of ultrasonic gas meters has been steadily increasing following the publication of the first edition of AGA Report 9 in 1998. Neither the first nor second editions of AGA 9 specify a recalibration interval. While custody transfer meters used in Canada require a five year recalibration interval, most other regulatory agencies have no specification. In the United States, recalibration time intervals would be included in a contract, but most contracts are silent on this topic.

The absence of clear guidance is due in part to the lack of significant recalibration data with accompanying analyses. The project summarized in this paper represents a contribution to the industry's understanding of the factors that contribute to ultrasonic meter recalibration shifts.

Previous Publications

The topic of meter recalibration has begun to appear in various publications, this section provides a brief survey of the available literature.

Reference 1 discusses several topics from the perspective of a calibration laboratory. Calibration data analyses are based on long term data from ultrasonic check standards used in the laboratory. The check standards indicate random effects characterizing repeatability and reproducibility that increase as velocity decreases. The observed random effects are separated based on velocity and time, the resulting analysis quantifies long term variation.

Reference 2 provides a discussion from the perspective of an ultrasonic meter user. Several case studies are described where meters are removed from service and recalibrated. Data presentation and discussion include the effect of meter cleaning and component replacement as well as shifts observed upon recalibration.

Reference 3 describes data from 35 meters re-calibrated in a flowlab. The objective was to investigate the effects of recalibration interval on the performance of ultrasonic meters. Results indicated that ultrasonic flowmeter performance changes over with time, data were presented as a function of recalibration time interval and velocity. The present study is a continuation if this work.

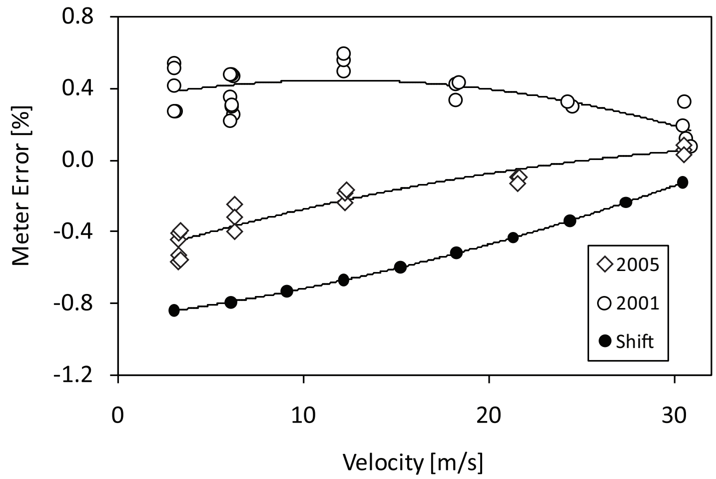

Figure 1: Sample Ultrasonic Meter Recalibration

Reference 4 summarizes the results of a two year study. The recalibration data of 34 meters were reviewed, 22 of the total had been in service at least six years when they were recalibrated. The details of selected calibrations are discussed to illustrate project conclusions. Related topics covered in the paper include diagnostics, component replacement and cleaning.

Analysis Method

The analysis method of the present study is described based on the sample calibration data shown in Figure 1. The meter error is defined as the percent difference between the flowrates indicated by the meter and calibration standard. This particular meter was first calibrated in 2001, the data represent the performance of the meter "as received". In 2005 the meter was recalibrated, the data represent the performance of the meter with correction coefficients restored to the factory settings.

The "shift" curve which characterizes the difference between the two calibrations is defined by a second order polynomial. It represents the average value of the meter error fitted over the velocity range. The shift curve does not account for the random effects observed in association with the two calibration curves. Numerical values of calibration shift are calculated at 3.28 m/s (10 ft/s) intervals, they are symbolized by closed circles in Figure 1. These numerical values, called "velocity points", become data points that are used in the analysis to categorize velocity based effects.

Table 1: Database Scope

Nominal Diameter	Recalibration Events	Velocity Points
100	3	24
150	6	44
200	31	213
250	13	80
300	18	127
400	14	97
500	10	62

This process described above was repeated for multiple ultrasonic meter recalibrations. Care was taken to properly interpret the data sets. The same set of coefficients was confirmed to be present during both calibrations. If a meter was cleaned, only the clean data were compared. The status of any component replacements was noted.

Database Scope

The database used in the present analysis represents most of the ultrasonic meter recalibrations completed at the CEESI facility. The analysis comprises 95 "recalibration events" where an event is defined as one meter returned for one recalibration. The same meter can be recalibrated several times each recalibration represents a different recalibration event. In the current study nineteen meters were recalibrated at least twice. Bidirectional meters result in two recalibration events, one each for the forward and reverse directions. The current study includes four bidirectional meters. The distribution of recalibration events and velocity points are contained in Table 1.

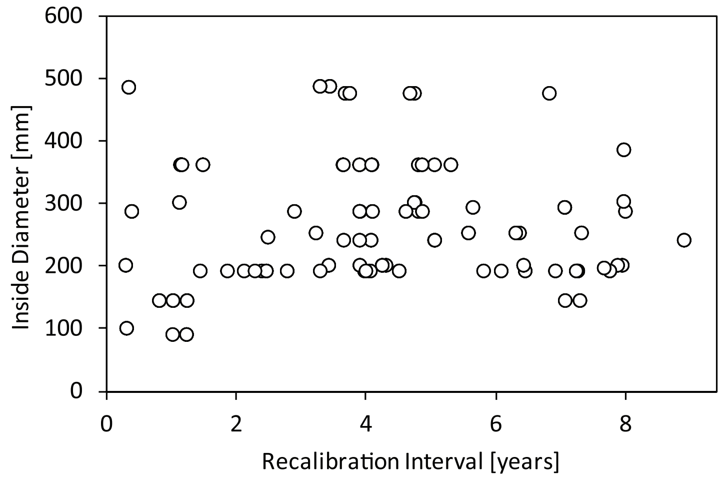

Figure 2: Database Scope

A different view of the database scope is shown in Figure 2. The abscissa represents the recalibration interval expressed in years and the ordinate represents meter inside diameter expressed in millimeters. The recalibration intervals ranged to nine years, the data are reasonably evenly distributed based on meter size. The entire database consists of 646 data points.

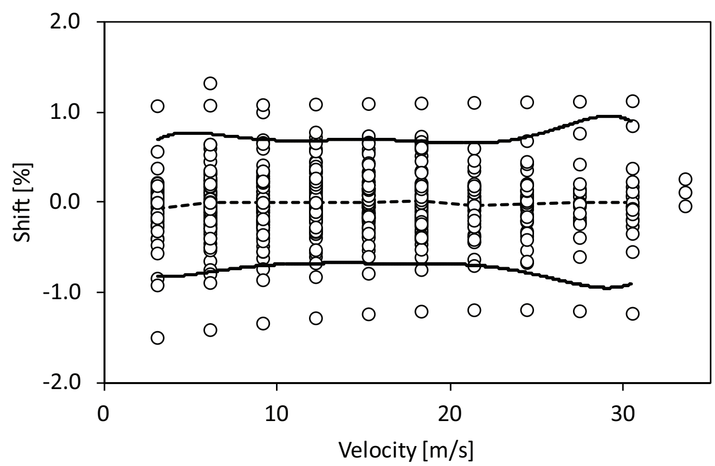

Figure 3: Recalibration Shift as a Function of Velocity

A majority of the meters were from a single manufacturer (Daniel) while a few were from a second manufacturer (Instromet). This is a reflection of the calibration business rather than the result of a selection process. Those manufacturers that entered the market more recently are not represented, likely as a result of the fact that the meters have not yet been returned for recalibration in significant quantities. Once again, this was not the result of a selection process.

Summary of Results

It is proposed that the recalibration shift is dependent on the meter size, velocity and recalibration interval. In this section the relationships between these variables are explored.

Results summarizing the effect of velocity are contained in Figure 3. The individual symbols represent the 646 velocity points that make up the database. For each of the ten velocities a mean value is calculated, the ten values are identified by the dashed line. The mean values are within ±0.06%, meaning that ultrasonic meter recalibration data are equally likely to indicate a positive or negative shift.

Three data points were obtained at a velocity of 33.5 m/s. They appear on the graph of Figure 3, but are not included in subsequent analyses.

The standard deviation associated with the data points corresponding to each velocity is also calculated. The calculated values are used to define a statistical interval that contains 95% of the data. The two solid lines in Figure 3 represent that statistical interval centered about the dashed mean line. The interval width is consistent through the velocity range, increasing slightly at higher velocity. The consistency in the interval width suggests that the recalibration shift does not vary significantly with velocity. An ultrasonic meter user might not need to consider velocity as a variable in making recalibration decisions.

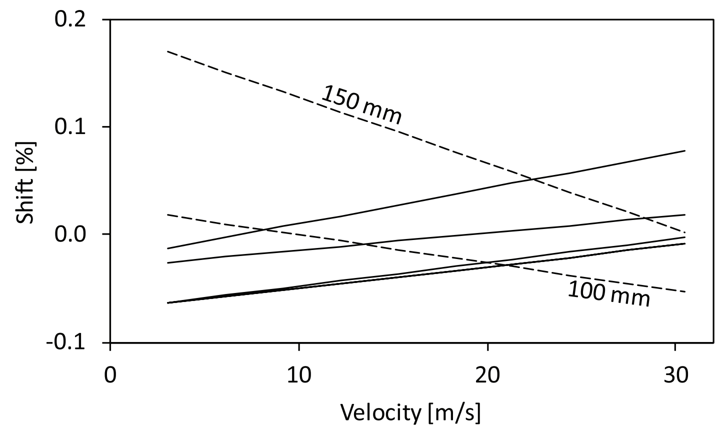

Figure 4: Average Recalibration Shift as a Function of Line SIze and Velocity

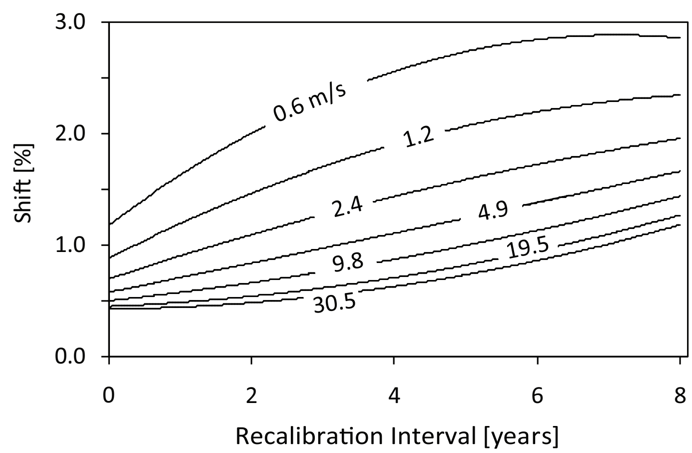

Figure 5: Summary of Results From Reference 3

The data points in Figure 3 are not separated by meter size. It is possible that the data for one meter size may be shifted in one direction, while those representing a different meter size are shifted in the opposite direction; behavior that would not be apparent in the graph. With this possibility in mind the analysis shifted to data sets sorted by line size. For each meter size a linear fit is determined that relates recalibration shift and velocity, the fitted lines are contained in Figure 4. The five solid lines correspond to meters sizes between DN200 and DN500. Meters of these sizes exhibit similar behavior characterized by a gradual increase in recalibration shift with gas velocity. The two smallest meter sizes exhibit a gradual decrease in recalibration shift with velocity. All of the data fall within ±0.1% except for velocities less than 15 m/s measured with the DN150 meters. It is concluded that the recalibration shift does not vary significantly with line size.

Some results from Reference 3 are summarized in Figure 5. The ordinate represents the absolute value of the recalibration shift, the abscissa represents the recalibration interval, and the solid lines represent different velocities. Clearly the recalibration shift increases as the velocity decreases. It appears as if Figures

3 and 5 are contradictory in regards to the velocity effect. The reason for the differences lies in the analytical methodologies. The previous study included the repeatability of the calibration results, it is well known that the random effects increase in magnitude as the velocity decreases. The present study only considers the recalibration shift of the average values; the random effects resulting from repeatability are not included.

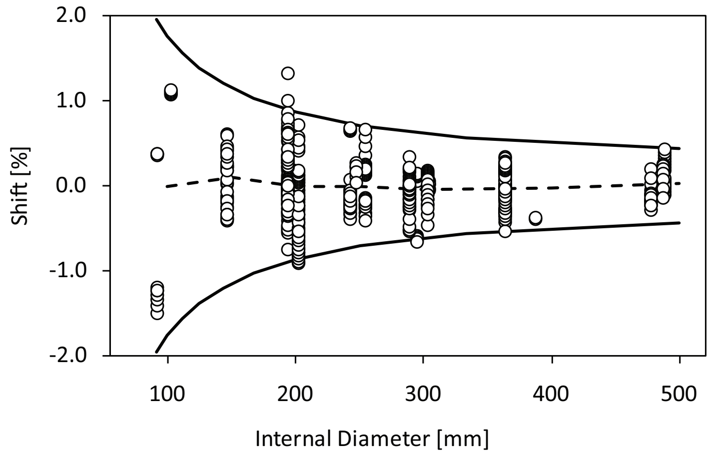

Figure 6: Recalibration Shift as a Function of Meter Size

The second variable that might affect recalibration shift is meter size, summarized results are contained in Figure 6. Once again the individual symbols represent the 646 velocity points that make up the database. The analysis is similar to that applied to the data of Figure 3; mean and standard deviation values are calculated for the data corresponding to each of the seven nominal diameters. The solid lines identify a 95% confidence interval. The lines are represented by:

$$S_1 = \pm\left(0.25 + \frac{600}{d^{1.3}}\right) \qquad \text{[Eq. 1]}$$

where S_1 represents the recalibration shift and d represents the inside diameter in mm. Clearly the recalibration shift magnitude increases as the meter size decreases. This apparent trend is useful to an ultrasonic meter user that may be evaluating the recalibration schedule for meters of several sizes. For example, they may elect to recalibrate smaller meters more frequently than larger meters.

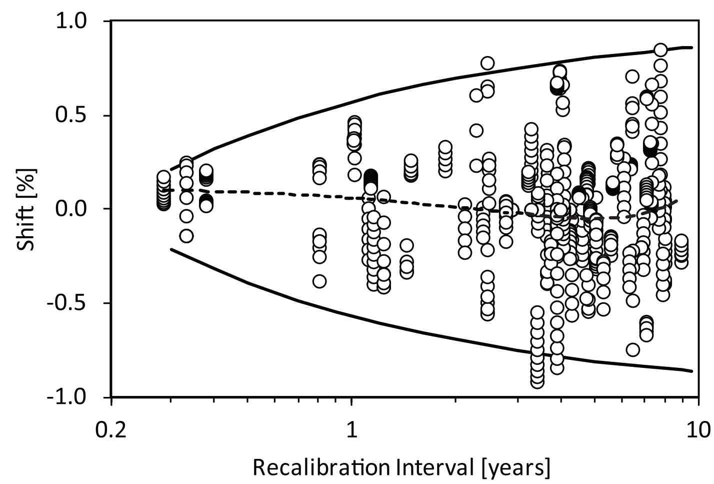

Figure 7: Recalibration Shift as a Function of Recalibration Time Interval

The calculated mean values are shown in Figure 6 as a dashed line, the values are all within ±0.1%. As described above, the analysis continues by separating the 646 data points based on velocity to identify asymmetry within the database. The mean values corresponding to the nine 3.1 - 27.5 m/s velocity values are each within ±0.08% while the mean values corresponding to the 30.5 m/s mean values are within ±0.18%.

From the analysis thus far it is concluded that the recalibration shift is symmetric to within ±0.1% for most values of velocity and diameter. The DN150 meter and 30.5 m/s data are symmetric to within ±0.2%.

The third variable that might affect recalibration shift is recalibration time interval. Results summarizing this effect are contained in Figure 7**.** The individual symbols represent 628 velocity points from the database. Not shown are data from two of the DN100 meters as well as the two lowest velocity data points from one of the DN200 meters. These data fall points outside the ordinate scale, they are readily identified in Figures 5 and 6.

As shown in previous graphs, the dashed line represents the mean of the entire data set as the shift varies with time interval. The mean values remains within ±0.1%, thus further re-affirming the symmetry of the shift data. The solid lines represent a manually developed estimate of the 95% confidence interval. The lines are represented by:

$$S_2 = \pm\left(1.0 - \frac{0.43}{t^{0.5}}\right) \qquad \text{[Eq. 2]}$$

where S_2 represents the recalibration shift and t represents the recalibration time interval in years. The shape of the confidence interval indicates a fairly rapid initial increase in recalibration shift that gradually decreases over time.

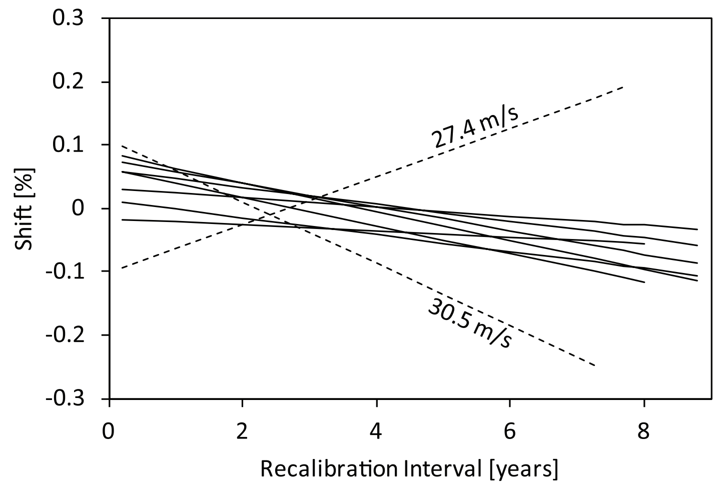

Figure 8: Average Recalibration Shift as a Function of Velocity and Recalibration Time Interval

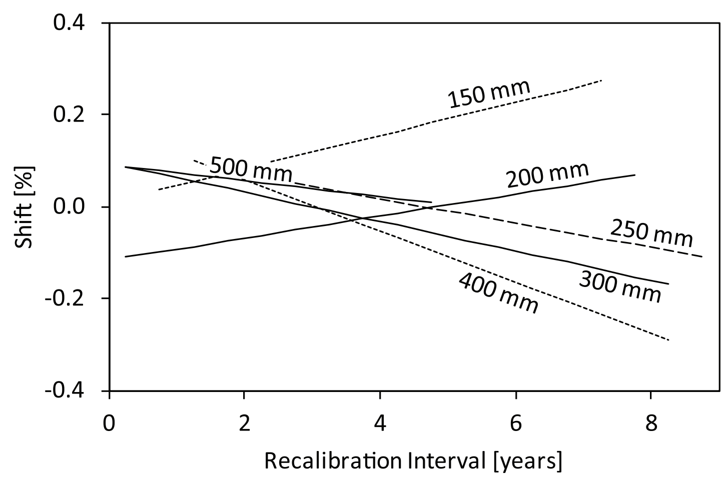

Figure 9: Average Recalibration Shift as a Function of Meter Size and Recalibration Time Interval

As discussed above, asymmetries associated with velocity and meter size are not evident in Figure 7. To identify asymmetry the data were first organized by velocity, and then mean values were determined as a function of recalibration interval. The results are shown in Figure 8. Eight of the ten linear fits are similar, a slight downward slope is observed. The recalibration shift trends slightly negative, the average slope is 0.013% per year, a ten year recalibration interval might result in average shift of -0.13%. The two highest velocities exhibit much larger amplitude slopes. This observation may also be noted in Figure 3 where the highest velocities are accompanied by an increase in statistical interval width. All the data of Figure 8 fall within ±0.2% except for intervals greater than 6.3 years for operation at 30.5 m/s.

The data are then organized by meter size and mean values determined as a function of recalibration interval. The results are shown in Figure 9. The available data for the DN100 size are not shown because they are based on only three meters subject to similar recalibration intervals. The data of Figure 9 indicate more variation than previous graphs. The two smallest meter sizes indicate that the recalibration shift trends slightly positive. The average slope is 0.030% per year, a ten year recalibration interval might result in average shift of +0.30%. The four largest meter sizes indicate that the recalibration shift trends slightly negative. The average slope is -0.033% per year, a ten year recalibration interval might result in average shift of -0.33%. All the data of Figure 9 fall within ±0.2% except for intervals greater than 5.25 years for DN150 meters and 6.65 years for DN400 meters.

The discussion continues by writing a general form of Equation 2:

$$S_i = \pm K_i \left(1.0 - \frac{0.43}{t^{0.5}} \right) \quad \text{[Eq. 3]}$$

where the subscript i refers to the data from a particular meter size, S_i represents recalibration shift and K_i is a constant. It was observed that as the meter size increases, the constant K_i decrease to maintain the 95% confidence interval. In other words, a plot similar to Figure 7 that contains data for only one meter size will show the solid lines closer together. As the meter size increases from DN200 to DN500, K_i decreases from 1.0 to 0.6. This is the same behavior that leads to the interval width reduction with meter size observed in Figure 6.

In summary, the meter user might choose to exercise additional caution when measuring the higher velocities indicated in Figure 8. Meanwhile, Figure 9 shows that all meter sizes will exhibit recalibration shifts over time that are similar in magnitude.

Over the years the electronic components of ultrasonic meters have been improved. For a variety of reasons some users will upgrade the electronics on existing meters while some will chose not to. The present analysis includes the effect on recalibration shift of replacing electronic components. The status

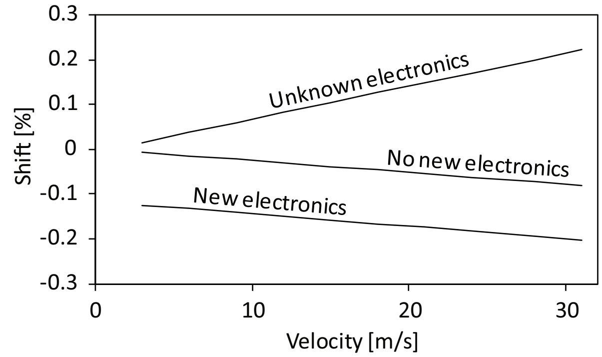

Figure 10: Average Recalibration Shift as a Function of Electronics Status and Velocity

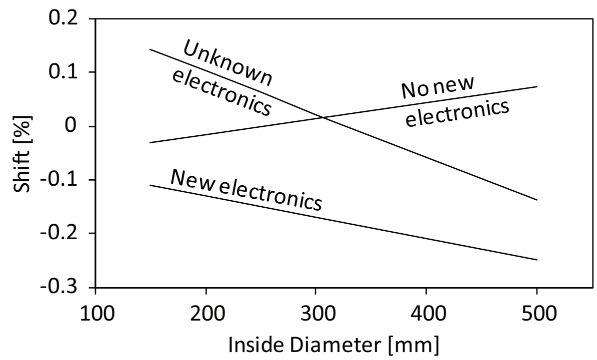

Figure 11: Average Recalibration Shift as a Function of Electronics Status and Meter Size

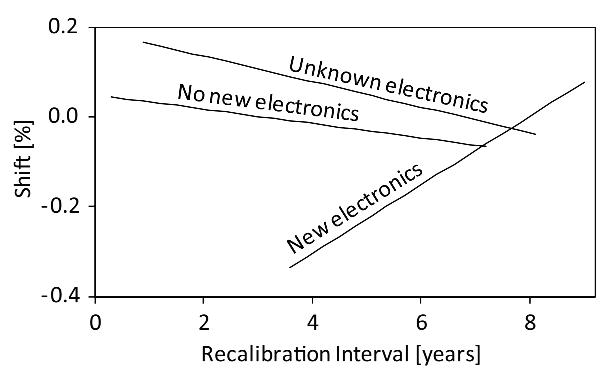

Figure 12: Average Recalibration Shift as a Function of Electronics Status and Recalibration Time Interval

of electronic components was not always known based on the information available for the present study. Out of the total of 646 data points, 296 did not involve new electronics, 115 included new electronics, and the status of 235 were unknown. It is noted that data points in the unknown category might include field replacement. It is further noted that with many older calibrations the serial number of the electronics was not recorded and therefore the status would be unknown.

To investigate the effect of electronic component replacement the data were divided into three categories based on knowledge ("yes", "no", "unknown") regarding the replacement of electronic components. Linear fits were determined of recalibration shift as it varied with velocity, internal diameter, and recalibration interval; the results are contained in Figures 10-12. Note that the linear fits cover different recalibration interval ranges, this is a result of grouping the data points.

There appears to be an effect associated with whether or not the electronics have been replaced. In all three graphs the "no new" curve is centered at the zero shift position; all the data fall within ±0.08%. The "new" curves fall consistently low, the overall average for all three graphs is -0.15% while the range goes from -0.34% to +0.08%. The trends of the lines show no particular pattern between the graphs. Overall the data all lie within ±0.2% except for the case where new electronics are installed in conjunction with a recalibration time interval of less that 5.1 years.

Predictive Model

The entire database was fit to a curve of the form:

$$S_p = c_0 + c_1 v + c_2 d + c_3 t \qquad \text{[Eq. 4]}$$

where:

S_p = average predicted shift [%]
v = velocity [m/s]
d = inside diameter [mm]
t = recalibration time interval [years]
$c_0 = 5.308424\times10^{-2}$
$c_1 = 4.255990\times10^{-4}$
$c_2 = -8.919045\times10^{-5}$
$c_3 = -1.099365\times10^{-2}$

It is noted that Equation 4 only predicts the average trends. Any one meter can exhibit recalibration shifts within the confidence intervals shown in Figures 3, 6 and 7. The S_p values all lie within ±0.08% when applied to the entire database.

Uncertainty Considerations

Much of the discussion concerns observations of small effects, either recalibration shifts or trends. The significance of an observed effect must be judged within the context of the measurement uncertainty. In particular the present study has compiled data of numerous comparisons of the form:

$$S = A - B \qquad \text{[Eq. 5]}$$

where S is the recalibration shift and A and B are calibration events. The uncertainty of S can be expressed as:

$$u_S = \sqrt{u_A^2 + u_B^2 - u_C^2} \qquad \text{[Eq. 6]}$$

where:

u_A = uncertainty associated with calibration A
u_B = uncertainty associated with calibration B
u_C = correlated effects between calibrations A and B

Correlated effects represent uncertainty components that remain unchanged between A and B. A simple example would be the equation of state used to calculate the natural gas compressibility. The equation will not change between A and B and the uncertainty of S will be reduced by the uncertainty in the equation of state. The present study is based on calibrations completed in the CEESI Iowa calibration facility with an estimated uncertainty of $u_A = u_B = 0.23\%$. The process of estimating u_C is complex because it will vary with recalibration time interval, velocity and meter size. The details of this process are beyond the current scope of the project, but will be considered for future work.

In the absence of a detailed uncertainty analysis, it is likely that the uncertainty in S will likely exceed $u_S = 0.2\%$ and thus many of the observations discussed above will fall within the uncertainty.

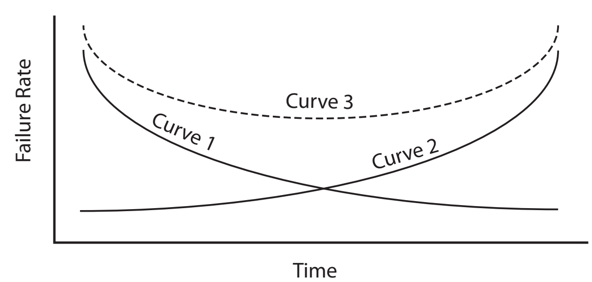

Figure 13: The Bathtub Curve

General Observations

Reliability engineering models can be based on a "bathtub curve" that might be relevant to the current analysis. A simple example is shown in Figure 13. Curve 1 corresponds "infant mortality" failures while Curve 2 corresponds to "wear out" failures. Curve 3, the bathtub, results from combining Curves 1 and 2. The shape of the statistical interval width suggests Curve 1 in Figure 13. Perhaps components of the ultrasonic meter change in time in the manner of Curve 1. Perhaps similarly to the wear in period for a set of new bearings.

Supposing that the bathtub curve describes ultrasonic flowmeter performance, the current study has not identified any trends that indicate the presence of a Curve 2 type wear our behavior. It is possible that sufficient recalibrations with long time intervals have not yet been recorded. The authors of Reference 4 came to a similar conclusion.

The statistical interval of Figure 6 shows the variation is recalibration shift decreasing as the line size increases. A fixed time measurement shift, a change in the clock, might be responsible for the observed trend. The fixed time shift becomes a smaller percentage of the time measurement that increases with meter size. Further analysis based on this observation has not currently been completed.

In general the two highest velocities seem to exhibit more drift than the lower velocities. Users that operate meters at higher velocities (over 27 m/s) might want to consider more frequent calibration.

Larger meters seem to have lower recalibration shifts that smaller meters. The present study included data from DN100 meters that was often removed from the analyses. The DN100 data was limited in scope (3 meters) and range (of recalibration time interval).

The authors of Reference 4 concludes the absence of an effect due to electronics replacement. The current study seems to indicate an effect, though it might be small enough to fall within the uncertainty.

The analysis of Reference 3 identifies an increase in amplitude corresponding to year three when recalibration shift is plotted against recalibration time interval. The present study also shows a similar increase in magnitude between years 3-4 with lower shift values between years 4-7. It is noted that all the data from Reference 3 is include in the present study, some similarities can therefore be expected.

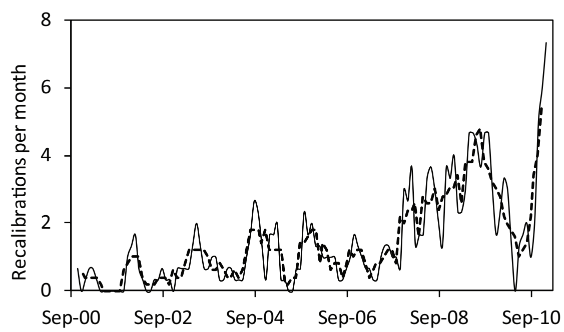

Figure 14: Monthly Recalibrations

Future Work

On a daily basis calibrations continue in the Iowa facility. Figure 14 shows that recalibrations have been gradually increasing. These data represent increased knowledge and will be added to the database.

While the present database is quite large, some recalibration events have not been included. Future plans include filling in these gaps.

The authors of Reference 4 propose that diagnostic parameters represent a powerful tool to predict the need to recalibrate ultrasonic meters. Inclusion of available diagnostic parameters is planned for the future.

The details of how correlated effects influence the uncertainty of the recalibration shift is considered for future work.

References

1. Kegel, T. and Britton, R., "Characterizing Ultrasonic Meter Performance Using A Very Large Database," 26th International North Sea Flow Measurement Workshop, 2008.

2. English, S. and Clancy, J., "Ultrasonic Meter Recalibration Program," Seventh International Symposium on Fluid Flow Measurement, 2009.

3. Trostel, B., Kegel, T. and Clancy, J., "Ultrasonic Flowmeter Calibration Intervals," Flomeko, 2010.

4. Hall, J., Zanker, K. and Kelner, E., "When Should a Gas Ultrasonic Flow Meter be Recalibrated?" 28th International North Sea Flow Measurement Workshop, 2010.

5. http://en.wikipedia.org/wiki/Bathtub_curve