MONITORING THE REPEATABILITY AND REPRODUCIBILTY OF A NATURAL GAS CALIBRATION FACILITY

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Abstract

The high flow system of the Iowa natural gas facility has been in place for 14 years. A number of programs are maintained to monitor the random effects. Traditional control chart techniques have been adapted for the measurements of pressure, temperature, gas composition and flowrate. Turbine meter calibration standards have traditionally been monitored using ultrasonic check meters. A new low flow system has recently been installed that makes use of ultrasonic meters as both calibration standards and check meters. This paper will describe the development and interpretation of some monitoring techniques for the various flowrate standards.

Introduction

The CEESI Iowa facility includes calibration standards and check meters, utilizing turbine and ultrasonic operating principles. The analysis in the present paper is organized based on several cases in which one meter is compared to another. In some cases a check meter is compared to a calibration standard, in other cases two calibration standards are directly compared. The observed variations in the output of a single meter could result from changes in either the flowrate of the meter, comparing two meters allows for eliminating the variations in flowrate.

In general both ultrasonic and turbine meters exhibit random effects that vary with flowrate; additional variation is observed as longer term random effects accumulate over time. A consistent analytical method has been adopted in order to separate the effects; the data are first grouped by flowrate each group in analyzed for variation over time. Each flowrate group contains enough data points to draw statistical conclusions, while the flowrate range is narrow enough to reduce variation with flowrate.

The present analysis is maintained to meet several objectives. First, the measurement community gains knowledge and experience based on the experimental data obtained by the Iowa facility. Second, CEESI uses the results to provide Type A estimates [1] of the random effects present when calibrating a meter. A check meter is effectively calibrated many times, the consistency of any one customer meter calibration can be quantified based on an analysis of the check meter calibration history.

Case 1

Four twelve inch ultrasonic check meters, from two vendors, have been in use since 2007. The oldest meter, identified as UM 730, has been producing data since 2007 while the newest meter (UM 137) data are from 2012. The other two meters have been removed from service.

The analysis completed thus far divides the UM 137 data into 31 intervals each containing between 200 and 400 data points. Figure 1 contains data obtained over the 15.8 - 18.0 m/s velocity range which are presented as being typical. A “Meter Factor” is defined as the ratio of flowrate indicated by UM 137 and the laboratory standard(s); the meter factor shift is the deviation from unity expressed as a percentage.

The dramatic shift in the data observed in May 2012 is the result of installing a new low flow system. The older data of Figure 1 (prior to May 2012) were obtained with the unit under test (UUT) installed upstream of UM 137. The inlet pipe conditions were constantly changing as a result of differences in the nominal UUT diameter. The variable pipe geometry resulted in velocity profile changes that in turn shifted the meter output.

When the low flow system was installed the laboratory was re-arranged so that UM 137 is always installed upstream of the test section. Since May 2012 the inlet conditions of UM 137 have remained consistent, the data of Figure 1 quantify the consistency. The newer data show a statistical interval identified by parallel lines that contains 95% of the data; the interval width is ±0.090%. This value accounts for all effects present in the calibration process that could result in random variation in the output of UM 137. The statistical interval indicates a slight positive slope; the value is 0.004% per year when expressed as a standard uncertainty. This small slope is not considered to indicate a significant drift of either the flow standards or UM 137.

The analyses summarized in [2] include data from UM 730 subjected to similar variable inlet pipe conditions. A correlation between nominal UUT diameter and meter factor shift was suggested; a similar analysis of current UM 137 data has begun. The standard deviation characterizing the more recently observed UM 730 random effects is similar in magnitude to the value associated with the pre-May 2012 UM 137 data. Two twelve inch turbine meters have served as check meters until damaged by UUT debris. Interestingly the ran-

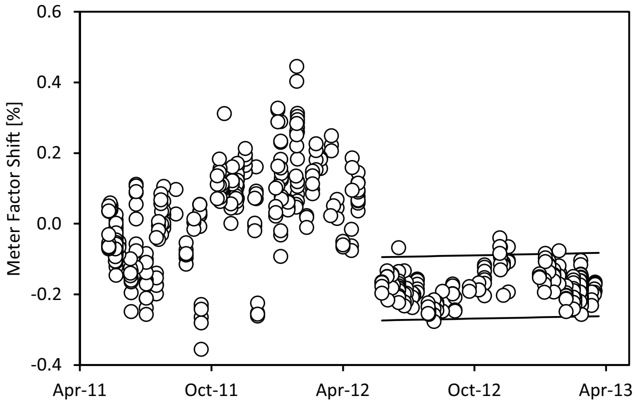

Figure 1: Historic UM 137 data, 15.8 - 18.0 m/s

dom effect standard deviations were consistently observed to be less than ultrasonic meters measuring the same flowrate. From these observation it is generally concluded that turbine meters are less sensitive to velocity profiles changes. This is likely attributable the axial flow diversion resulting from the large central blockage.

Data from the currently available flow intervals are summarized in Figure 2. The abscissa is velocity, the ordinate is the standard deviation from the post May 2012 data similar to that contained in Figure 1. It is well known that the random effects associated with ultrasonic flow measurement increase with decreasing velocity. The data of Figure 2 quantify the relationship for this particular meter.

Case 2

The Iowa facility has included a twenty inch ultrasonic check meter (UM 502) since 1999. The random effects are traditionally monitored using two control charts [3]. Recent control charts, covering the 9.1 - 11.9 m/s velocity range, are contained in Figure 3.

Each symbol in the control charts represents one day. The upper chart, here called the “within chart”, indicates daily standard deviations while the lower chart, the “between chart”, indicates mean daily deviations. The solid lines represent control limits; 95% of the data are expected to fall within the limits of the between chart or below the single limit of the within chart.

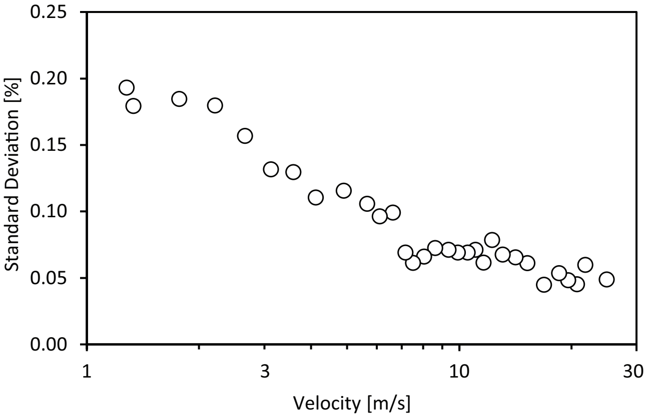

Figure 2: Observed Random Effects - UM 137

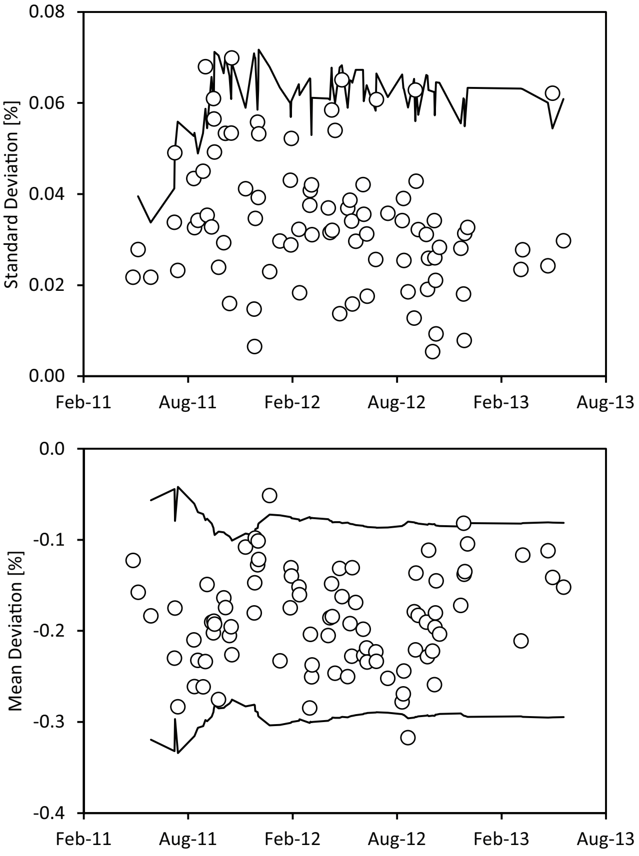

Figure 3: Control Charts for UM 502

The time interval represents roughly two years while the calibration history covers nearly fourteen years. A much longer time interval could be presented but would not be useful in estimating relevant random effects because the calibration standards are recalibrated every one or two years.

The data of the between chart are centered around a negative value. The output of the meter has never been corrected because the purpose in maintaining a check meter is monitoring consistency, not reporting the correct flowrate.

The within chart control limit is less steady than the between limits because it is calculated based on the number of data points obtained on each day. The daily data count varies considerably as a result of the narrow velocity range. The two between chart limits are calculated based on accumulated data and so become smoother over time. Days that yield a single data point are excluded from the analysis because a standard deviation cannot be calculated.

The construction of each control chart is based on a calculated standard deviation value. The between chart data result in a standard deviation (s_b) that accounts for random effects observed between calibrations. The within chart data result in a pooled standard deviation (s_w) that accounts for random effects observed within a single typical calibration. For the data of Figure 3 s_b = 0.053% and s_w = 0.040%; the combined value is s_r = 0.067%.

Summarizing data over time in the form of a control chart provides more potentially useful information than simply plotting a parameter over time such as in Figure 1. The control chart allows for separation of long term and short term random effects which can help reduce uncertainty. When comparing the results of several tests completed in the same day the uncertainty would not need to include long term random effects. Short term comparison testing is typically used to evaluate meter conditions such as fouling, inlet pipe configuration, ambient noise and component replacement.

Case 3

A new low flow system was installed in May 2012, a detailed description and uncertainty analysis are contained in [4]. The design allows for the simultaneous measurement of flowrate by two or more standards even though only one is in service for a particular calibration process. The direct comparison of data from two standards over time quantifies the stability of the two standards.

Case 4 compares the six inch (UM 587) and the three inch (UM 541) calibration standards. When used to calibrate a client meter the transition from the use of one meter to the other takes place between 7.0 and 7.1 kg/s. The three inch meter is used below this flowrate, the six inch above.

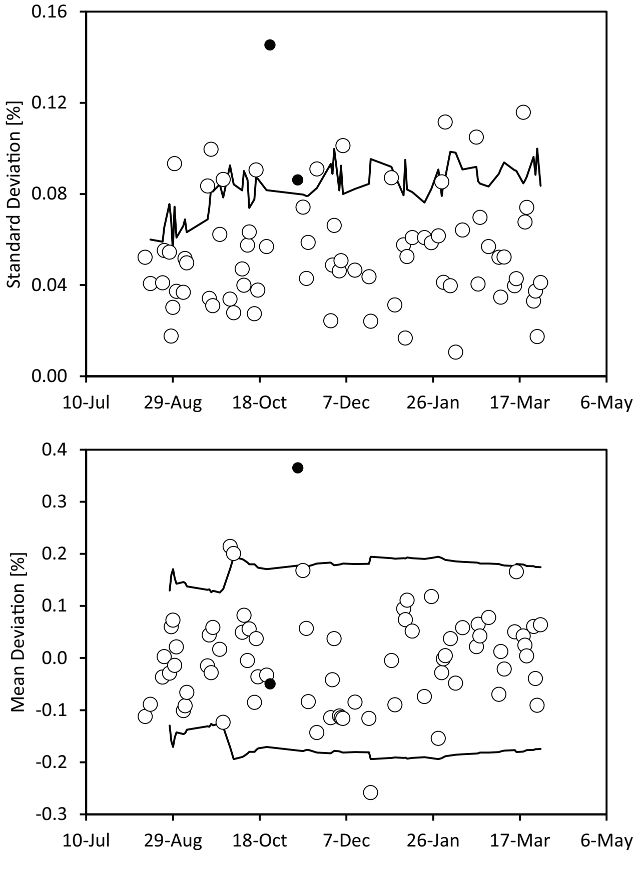

Figure 4: Control Charts for UM 587 - UM 541

The data that have been subject to analysis are divided by mass flowrate into nine intervals all but one containing approximately 500 data points. Control charts for data over the 4.5 - 5.6 kg/s range are shown in Figure 4. The y-axis value refers to the difference in reading between the two standards expressed as a percentage. The short and long term random effects are quantified by s_w = 0.062% and s_b = 0.087%. The combined value is s_r = 0.107%.

Each control chart shows two data points symbolized by closed circles. Each data point falls well outside the control limits and thus potentially indicates what is commonly labelled as an “out of control” condition (OOCC). In the interest of the current discussion the points have remained on the control charts but are not included in the calculations. The control chart statistics provide some assistance in evaluating potential OOCC. A point that appears on both charts is more likely to represent OOCC that one appearing on only one chart. The two points in Figure 4 each appear only in one of the two charts. When interpreting the charts it must be understood that the control limits are presented with a 95% level of confidence; one point out of twenty can fall outside the limits without being judged as OOCC.

The statistics of the control chart does not provide assistance in the further evaluation of OOCC, this process requires an understanding of the measurement process. In the present case UM 587 is operating below the flowrate range normally used for calibration; a potential OOCC may therefore have no effect on calibration. Also, when comparing UM 587 and UM 541 only one meter is in use as the calibration standard, the check meter may have caused the OOCC. In some cases a third meter serves as the calibration standard and both UM 587 and UM 541 serve as check meters. The evaluation of OOCC proceeds by plotting the data from the particular day identified by the control charts; an example based on orifice testing [5] represents a good example of the process.

The ability to detect and isolate OOC conditions represents a second advantage that control charts offer when compared to the simple time plot of Figure 1.

Case 4

One of the low flow calibration standards is a six inch meter utilizing an eight path design; the acoustic paths define two planes that are each oriented 60 degrees from the flow. One set of transducers is designated as the calibration standard (UM 587), the second set is designated as a check meter (UM 586).

The six inch meter data included in the analysis are divided into seven intervals each containing between 500 and 600 data points. Control charts based on data obtained over the 7.5 - 9 m/s velocity range are contained in Figure 5. The short time interval is the result of the low flow system only being in service since May 2012. The short and long term random effects are quantified by s_w = 0.056% and s_b = 0.031%. The combined value is s_r = 0.064%.

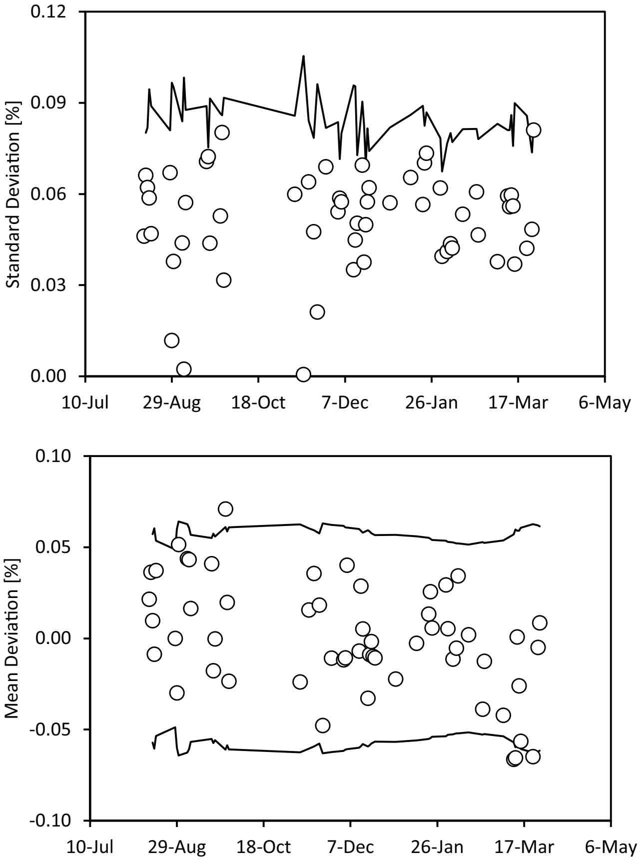

Figure 5: Control Charts for UM 587 - 586

The analysis of Case 3 provides less independence between the check meter and calibration standard than Case 1 or 2. In the previous cases the check meter is ultrasonic and the calibration standards are either ultrasonic (low flow) or turbine meters (high flow). Also, the check meter and standard(s) are influenced by independent installation conditions because they are not installed directly in series. The lack of independence between UM 586 and UM 587 will allow for some flow disturbances or distortion to equally affect both sets of transducers and thus go undetected. On the other hand, the availability of eight acoustic paths provides options to compare individual paths that are not possible with fewer acoustic paths. This is discussed in Case 5.

Case 5

Case 5 began with several observations. Data were obtained comparing two inch four path (UM 643) and two path (UM 785) meters installed in series as part of the low flowrate system. The four path meter serves as a calibration standard, the two path meter is a check meter. In reviewing the data it was observed that the two inch meter random effects were slightly less than those observed with the four path meter. This observation is counter-intuitive because a four path meter is generally considered to be better suited to custody transfer applications. It is noted that additional acoustic paths are preferable because the more complete sample of the flow area results in less sensitivity to velocity profiles variations. Profile insensitivity is more important to a typical user than a slight reduction in random effects; more paths are better.

As liquid ultrasonic meters increased in popularity difficulties were reported when applying conventional proving techniques to liquid ultrasonic meters. The natural turbulence present in flowing liquid results in random variations between successive pulse transmissions. As a result of turbulence related random effects an ultrasonic meter cannot demonstrate the same level of proving repeatability as a turbine meter. It is well known that the impact of a random effect can be reduced by obtaining additional samples, this principle is applied to the process of proving ultrasonic meters [6]. The same principle is applied to the uncertainty analysis of the Iowa facility [4]; additional samples are obtained at very low flowrates in order to maintain a target value.

These observations lead to a series of questions regarding the role of turbulence in the repeatability of a gas ultrasonic meter calibration. In particular, does turbulence represent an absolute limit to meter repeatability? A quick Monte Carlo simulation was designed to provide insight into the problem. Multiple series of twenty random numbers were generated to represent groups of time difference measurements. The ultrasonic vendors report that standard deviation values over the 2-7% range are typically observed when twenty time difference measurements are made in one second. The Monte Carlo simulation predicts expected random variations based on averaging multiple twenty point measurement groups. The Iowa calibration facility obtains samples for two minutes to define a single data point. The Monte Carlo predicted standard deviation values are within the same order of magnitude as the present results when data are averaged for a period of two minutes. The simulation seems to indicate that longer sample times might be required to reduce the random effects that make up the Iowa facility uncertainty.

Case 3 compares UM 586 and UM 587, the Case 5 analysis compares the same meters but separates the chord velocities. The average inner chord velocities are compared in one set of control charts while the average outer chord velocities are compared using a second set of control charts. The data included in the analysis have been divided into seven intervals each containing between 300 and 600 data point; the results are summarized in Figure 6. The random effects

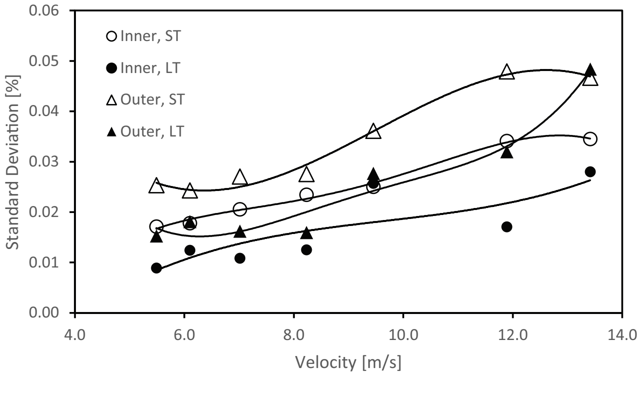

Figure 6: Chordal Random Effects, UM 587 - 586

increase with velocity, which is likely the result of increasing Reynolds number. The inner chord random effects are lower than the outer chords which is consistent with the observations discussed above. The long term (LT) random effects are consistently less than the short term (ST) random effects.

A variety of ultrasonic meter data are monitored by users to assure consistent meter conditions, they combinations of raw data are called diagnostic parameters. The Case 5 analysis illustrates the application of controls charts to the monitoring of a diagnostic parameter. The orifice plate data [5] applied control charts to monitor the profile factor, a particular ratio of chordal velocities. The use of control charts brings many of the previously discussed advantages to field applications.

Summary

The Case 1 data illustrate the value in plotting a parameter over time. The random effects were significantly reduced when the meter was relocated within the facility. The Case 1 data are summarized to illustrate the variation of random effects with velocity.

The Case 2 data illustrate the use of control charts to present more information to characterize random effects. The Case 3 data were obtained by directly comparing two calibration standards. The Case 4 and 5 data were obtained from an eight path meter where four paths comprise the calibration standard and four paths represent a check meter.

Several advantages of control charts were illustrated. Potential measurement problems can be easily isolated to a particular day. Long and short term random effects can be independently estimated. The basic technique can be applied to monitor diagnostic parameters in the field or check meters in a laboratory.

The Iowa facility uncertainty is based in part on a Type B component (u=0.075%) that accounts for random effects present between calibrations (1-2 years). The Case 1 data indicate a smaller value (u= 0.045%) obtained over approximately one year. The Case 2 data indicate a slightly smaller value (u=0.067%) obtained over approximately two years. The Case 3 and 4 data were obtained over approximately nine months and indicate slightly smaller (u=0.064%) and somewhat larger (u=0.107%) values. It is noted that the Case 4 results are based on a data obtained below the normal operating range.

Case 5 indicates significantly smaller values that are not relevant in contributing to the uncertainty analysis because the full flow field must be included.

Most of the Case studies are incomplete, additional analyses are underway. The results thus far indicate that a reduction in the Iowa facility uncertainty due to random effects is possible.

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