North Sea FLOW Measurement Workshop

Paper 5.1

When Should a Gas Ultrasonic Flow Meter be Recalibrated?

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1 INTRODUCTION

How often and under what circumstances should a gas ultrasonic flow meter (USM) require recalibration? Within the Natural Gas Industry in most countries, there are currently either no standards requiring periodic recalibration or a standard based on arbitrary criteria. Removing an USM from service for recalibration is costly and inconvenient. However, the primary reason that a recalibration standard does not exist is the lack of definitive data regarding the long-term stability of installed USM's and data regarding the effect of replacing transducers, electronics and firmware.

The International Organization of Legal Metrology (OIML) document '*Guidelines for the Determination of Calibration Intervals of Measuring Instruments*' [1] states that "There appears to be no universally applicable single best practice for establishing and adjusting the calibration intervals of instruments." It also advises that "The drift determined by the recalibration of the instruments may show that longer calibration intervals may be possible without increasing risks, etc."

In order to improve the understanding of the stability over time of gas USM's, the Measurement Technical Committee of Pipeline Research Council International, Inc. (PRCI) funded a two-year study, which began in 2007. This program consisted of collection and analysis of the required data to allow formulation of a recalibration guideline through the following tasks:

1) Review and utilization of existing published technical papers that describe the results of recalibration of USM's;
2) Working with certified flow calibration facilities to obtain data on the long-term stability of the USM's that are used as permanent check meters in their facilities;
3) Obtaining data from USM manufacturers on the effect of changing the flow meter's electronics and/or transducers;
4) Obtaining historical recalibration data from certified flow calibration facilities, USM manufacturers and PRCI member companies;
5) Participation in selected recalibrations by PRCI member companies;
6) An extensive test program at a certified flow calibration facility.

At the conclusion of the study, a total of 34 USM recalibrations had been analyzed. Of these, 22 had been in service at least six (6) years when they were recalibrated. This data, plus that from permanently installed USM's at calibration facilities, allowed conclusions to be formulated regarding the stability of USM's.

If a USM has been installed for several years, there is a good probability that changes have been made to its electronics, transducers or firmware. As manufacturers bring out new models, there is a strong incentive to upgrade the existing USM's. This study yielded considerable data regarding the question of the necessity of recalibration following replacement of transducers and/or electronics.

2 SCOPE OF PRCI STUDY

The USM flow meters considered in this study were to be limited to those from the two dominant USM suppliers at the time (2007): Daniel and Instromet. The USM models were the Daniel Senior Sonic with the British Gas chord arrangement and the Instromet Q Sonic – 3 and Q Sonic – 5. Even though Sick Maihak was not initially part of this study, the PRCI committee agreed to include the data that they provided regarding the replacement of electronics and transducers.

Initially, a literature search was conducted to determine if data had been previously put in the public domain that could be used in this study.

This program specifically **excluded** an examination of the effect of material build-up in the USM (i.e., a dirty meter). However, the program did include a study of the effect of replacement of USM electronics or transducers.

Although it was not always possible, recalibration data was sought that met the following criteria:

- Recalibrations that were performed under the same conditions as the prior calibrations (pressure, flow rate, piping configuration, and flow conditioning);
- Both initial and recalibration tests were performed at the same Certified Flow Calibration facility;
- Recalibration data was available for the meter in the “cleaned” condition;
- If the electronics and/or transducers were to be replaced prior to recalibration, a recalibration run was desired before any replacement;
- Sufficient diagnostic data was available from both prior and recalibration tests.

The extent of this study was governed by the following factors:

- The amount of data available from the Certified Flow Test facilities relating to the stability of the permanently installed USM’s in the flow loops;
- Availability of historical meter recalibration data available from the flow test facilities, USM manufacturers and PRCI member companies;
- The number of recalibrations of PRCI member company meters during the program’s duration that met the above criteria;
- Data available from USM manufacturers regarding the effect of replacement of USM electronics or transducers.

3 ANALYSIS OF RECALIBRATION DATA IN THE PUBLIC DOMAIN

The first task in the Ultrasonic Flowmeter (USM) Recalibration Frequency Program was the analysis of recalibration data in the public domain. The data that was reviewed had been presented at technical conferences by users of USM’s. Some additional publications have addressed the stability of USM’s that are permanently installed in the flow calibration loops at Certified Flow Calibration facilities. The literature search yielded 7 publications that either addressed USM stability and/or factors that could potentially result in a change in performance of USM’s over time [2] – [8].

Only one of the selected publications reported on all aspects of interest for this study. Most of the data presented addressed the effect of material buildup on the interior of the flow meter. With only seven studies available, it was only possible to draw limited conclusions with application to the current study. These included the following:

- USM stability over a period of three years appears to be very good (<0.3%) from the limited data available. The primary cause of a shift in a USM’s calibration is buildup of a coating in the meter. When meters, flow conditioners and spools were cleaned, the calibration returned very close to the original.
- The USM system must be brought back to the prior calibration condition (i.e. cleaned) before the meter’s long-term stability can be determined.

- In the studies where the electronics were changed, no measurable change in the meter's calibration was observed.
- In the one study where transducers were changed, no measurable change in the meter's calibration was observed.
- Two of the studies reported that the effect of buildup in the meter body decreased as the meter size increased. This is expected, since the buildup represented a smaller percentage change in the meter's diameter.
- The effect of buildup on transducer faces appears to be less than on the meter body, especially if the transducers are recessed.

Table 1 – Summary of Data from Referenced Publications

REF #	STABILITY	CHANGE ELECTRONICS	CHANGE XDUCERS	CLEAN METER	CLEAN XDUCERS
2	**<0.25% over 3 years**	**No change**	**0.09%**	**0.4%**	**<0.1%**
3	**+/- 0.1% over 6 months (18" meter)**	**NA**	**NA**	**NA**	**NA**
4	**+0.1% to -0.2% over 18 months (16" meter)**	**NA**	**NA**	**NA**	**NA**
5	**0.3% over 3 years (16" meter)**	**No change**	**NA**	**0.6%**	**0.3%**
6	**Sixteen 12" meters checked over 4-months; changes were due to buildup**	**NA**	**NA**	**0.5% to 1.5%**	**NA**
7	**NA**	**NA**	**NA**	**0.04% 24" meter 0.36% 10" meter**	**NA**
8	**NA**	**NA**	**NA**	**0.2% 16" meter 0% 20" meter**	**NA**

4 REPLACEMENT OF USM ELECTRONICS AND TRANSDUCERS

A problem with an USM can occur because the meters themselves change over time for several reasons. Most manufacturers have a policy of continuous improvement, to stay competitive or because electronic components become obsolete and have to be replaced. Also, computers become more powerful, faster, have more memory and better digital signal processing. More input and output options become available. Transducers are developed for

different operating conditions of pressure, temperature, frequency and chemical compatibility. New software is developed to handle all the hardware changes and to provide more robust diagnostics.
If a meter has been installed for several years, there is a good probability that changes have been made. When components fail, they will be replaced and at the same time they may also be updated. As manufacturers bring out new models, there is a strong incentive for users to upgrade their meters.

The manufactures are interested in backward compatibility to ensure that an upgraded meter does not change its performance and does not need recalibration as part of the upgrade. Initially, it was anticipated that the manufacturers could provide recalibration data. It turned out that rather than recalibration data, the manufacturers had data on the effect of upgrading from one version of their USM electronics to the next. In addition, they were able to provide some data on the effect of replacing the ultrasonic transducers.

4.1 Electronics Replacement

Data for this portion of the study was obtained both from the manufacturers and from a series of tests conducted at TransCanada Calibrations (TCC). Figure 1 shows data provided for the Daniel Senior Sonic USM's when the Mark II electronics was changed to the Mark III version.

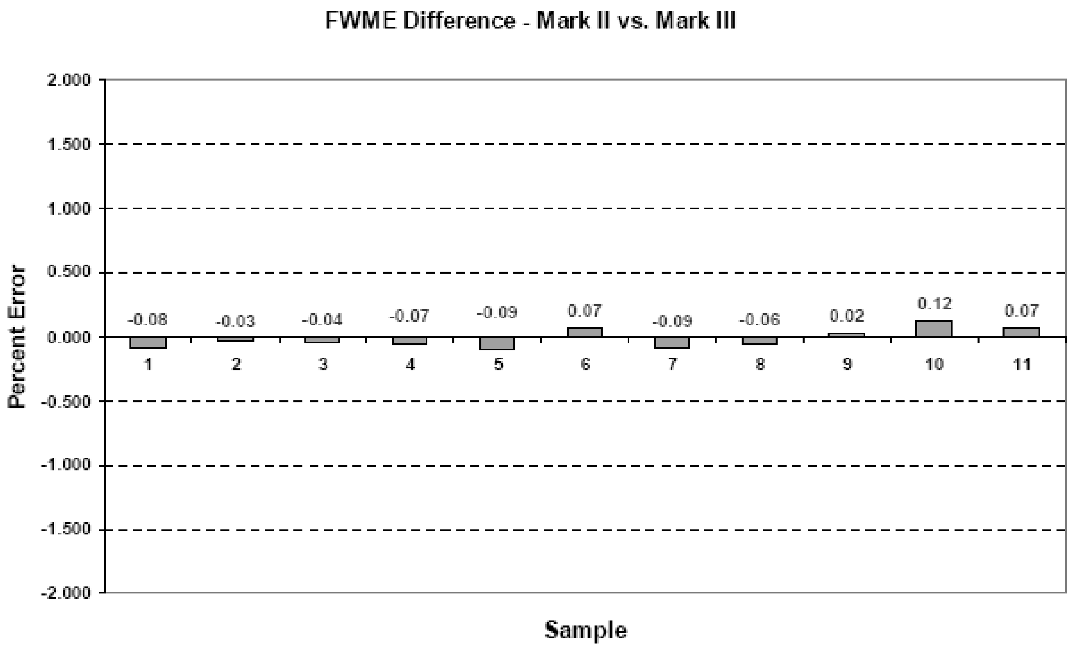

Figure 1 - Daniel Senior Sonic Electronics

In addition to the data furnished by Daniel in Figures 1, additional data was obtained in the TCC testing on a 12-inch meter. This was part of a series of tests paid for through this PRCI program. The results are shown in Figure 2.

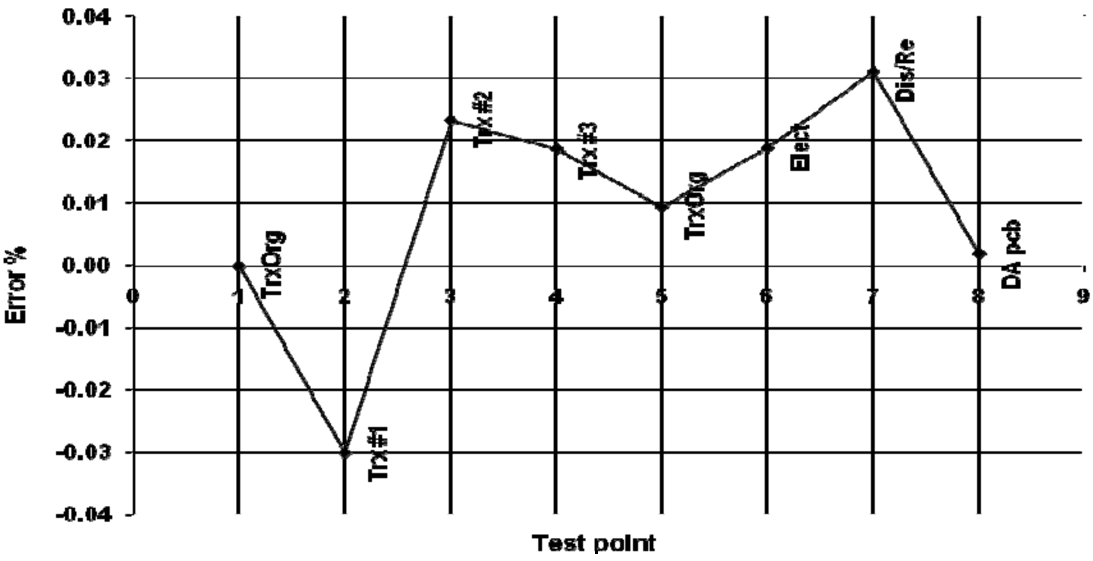

Figure 2 - Tests on a 12-inch Daniel USM at TCC

This test showed a change of less than 0.02% due to the change of the USM electronics.

Instromet furnished data taken with several different versions of their USM electronics, as shown in the following Figure.

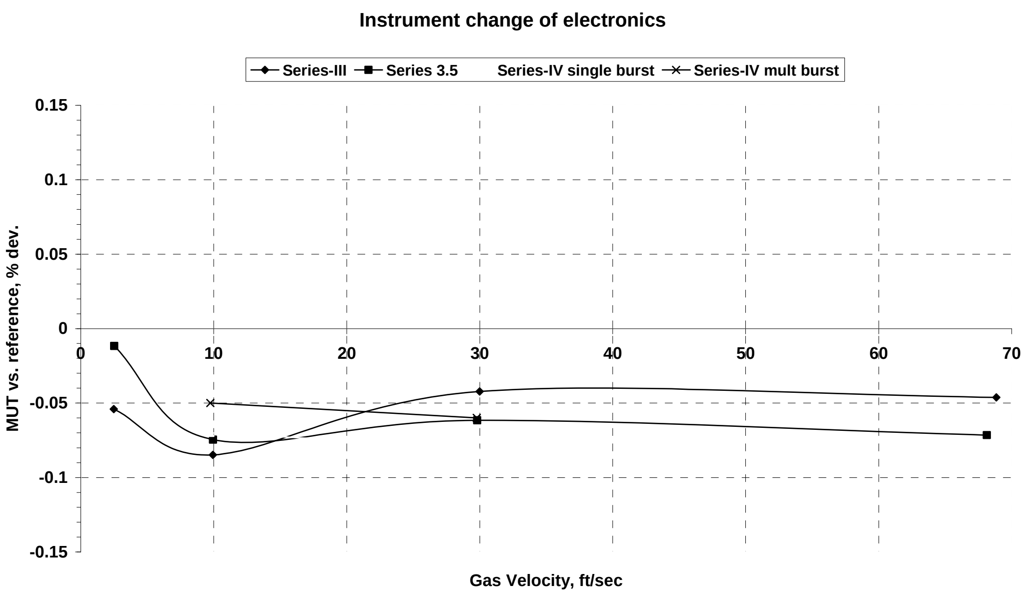

Figure 3 - Effect of Change of Electronics on an Instromet USM

In addition to the data furnished by Instromet in Figures 3, additional data was obtained in the TCC testing on a 12-inch meter. The results are shown in Figure 4.

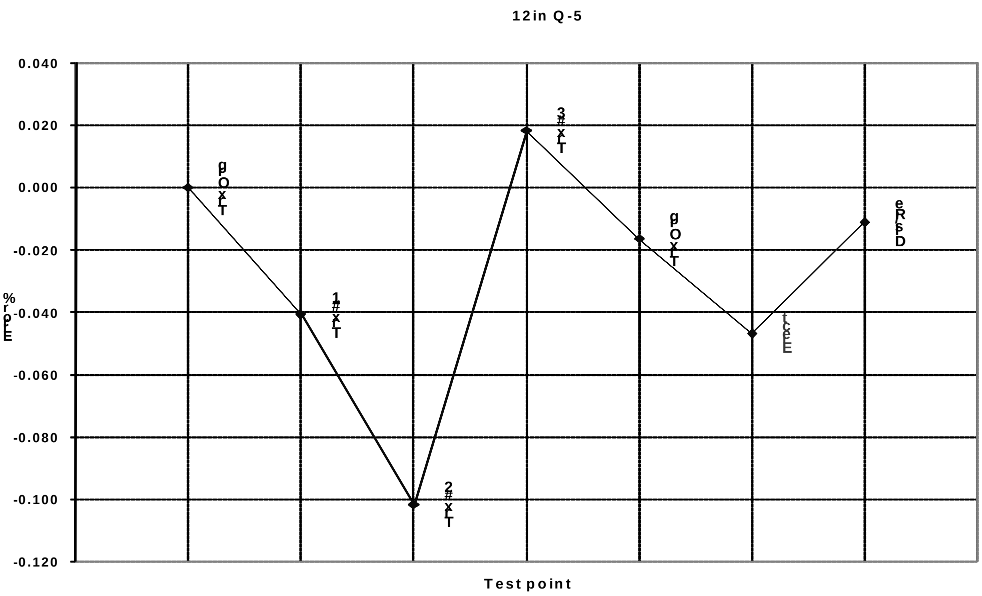

Figure 4 - Tests on a 12-inch Instromet USM at TCC

Changing the electronics on this meter yielded less than 0.05% change in the total recalibration.

Data furnished by Sick Maihak shows the effect of changing electronics on a 4-path USM. As seen from figure 5, there was almost no measureable change in either the Path Velocity Ratios or the SOS Difference between paths when the electronics were changed.

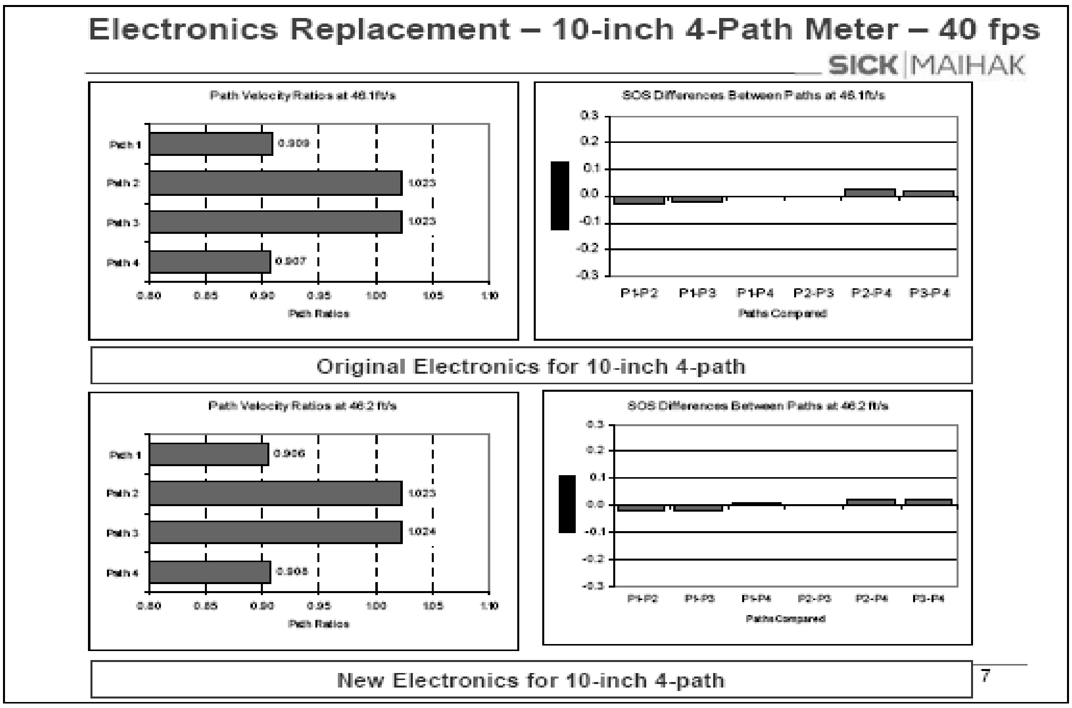

Figure 5 - Effect of Changing Electronics on a Sick Maihak USM

4.2 Transducer Replacement

When the ultrasonic transducers are changed, new values of path length and delay time are entered into the meter configuration. The VOS fingerprint is also compared with that for the old transducers, and if necessary the delay time can be adjusted to make them the same.

Daniel provided data showing the effect of changing from type T4 to type T11 transducers introduced a negligible effect on the USM's calibration. However, during the PRCI test program at TCC in February 2009, a pair of transducers was changed three times on the Daniel 12-inch meter. As seen in Figure 6, the maximum effect of these transducer interchanges was 0.03%.

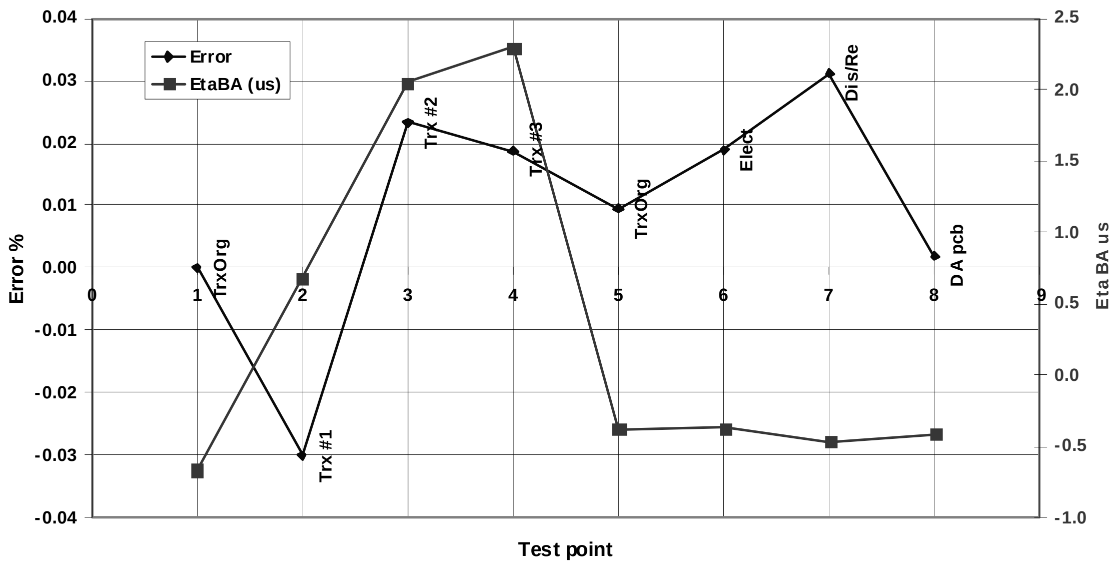

Figure 6 - Effect of Transducer Interchanges on a Daniel USM

During the PRCI test program at TCC, a pair of transducers was changed three times on an Instromet 12-inch meter. As seen in Figure 7, the maximum effect of these transducer interchanges was less than 0.05% except in one case it was 0.10%.

Sick Maihak provided test data of the effect of changing transducers of the same type on a 4-path USM. This data shows a maximum change of 0.05% when the transducers were changed in this meter.

Figure 8 shows the effect of upgrading from S1 transducers to the newer S2 version on a Sick Maihak meter. The Verification points were run with the S1 transducers and then the complete recalibration was run with the S2 units.

4.3 Component Replacement Conclusions

The data provided by each of the three USM manufacturers supported the following conclusions:

- When the USM electronics are replaced, either due to a failure or an upgrade, a recalibration of the flow meter is not required;
- When a USM transducer is replaced, either due to a failure or an upgrade, a recalibration of the flow meter is not required. This assumes that the characteristic parameters of the new transducer are correctly entered into the USM.

These conclusions are also supported by the tests on the Daniel and Instromet meters that were part of the PRCI tests at TCC.

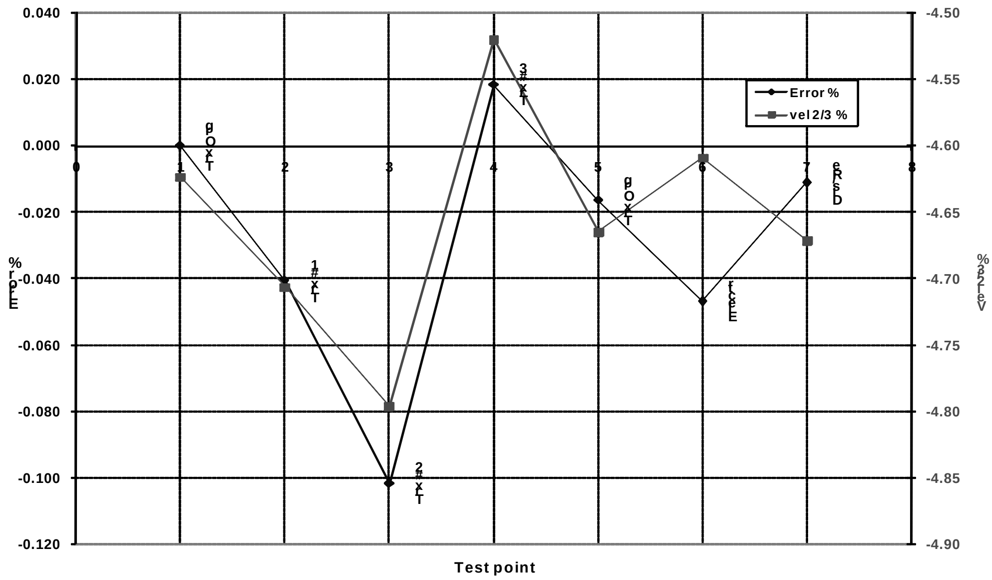

Figure 7 - Effect of Transducer Interchanges on an Instromet USM

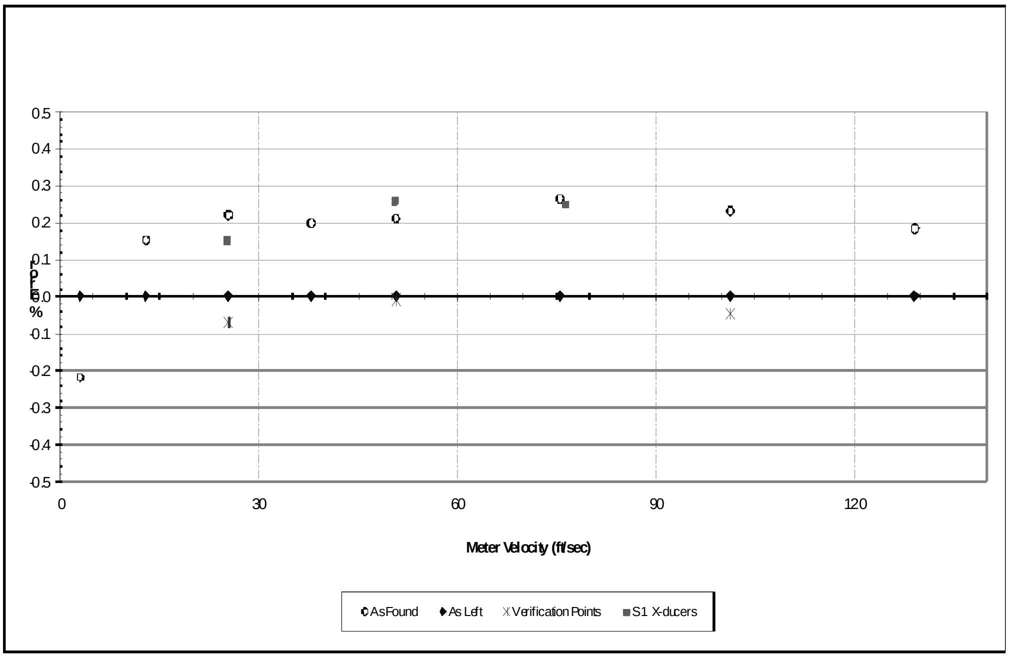

Figure 8 - Upgrade of Transducers in a Sick Maihak USM

5 DATA FROM CERTIFIED FLOW CALIBRATION FACILITIES

The intent of this portion of the study was to review data from the permanently installed ultrasonic meters used as check meters by the three North American natural gas flow laboratories: Colorado Engineering Experiment Station, Inc. (CEESI), Southwest Research Institute (SwRI), and TransCanada Calibrations (TCC). It was originally hoped that the meters would have records of transducer changes, firmware upgrades, electronics upgrades and any other service performed on the meters. As it turned out, since the meters are used as check meters, rather than certified reference meters, service was performed on an as-needed basis and service records were unavailable.

5.1 CEESI

Data was provided by CEESI for a single, 24-inch Daniel Model 3400 multipath check meter. The meter was installed in the facility in 1999. The meter is a check meter, used to confirm stability and overall performance of the facility via Statistical Process Control. It is not a certified reference meter used for meter calibration. Over 7,000 data points, representing 230 days during the period from August 2000 through May 2006 were provided.

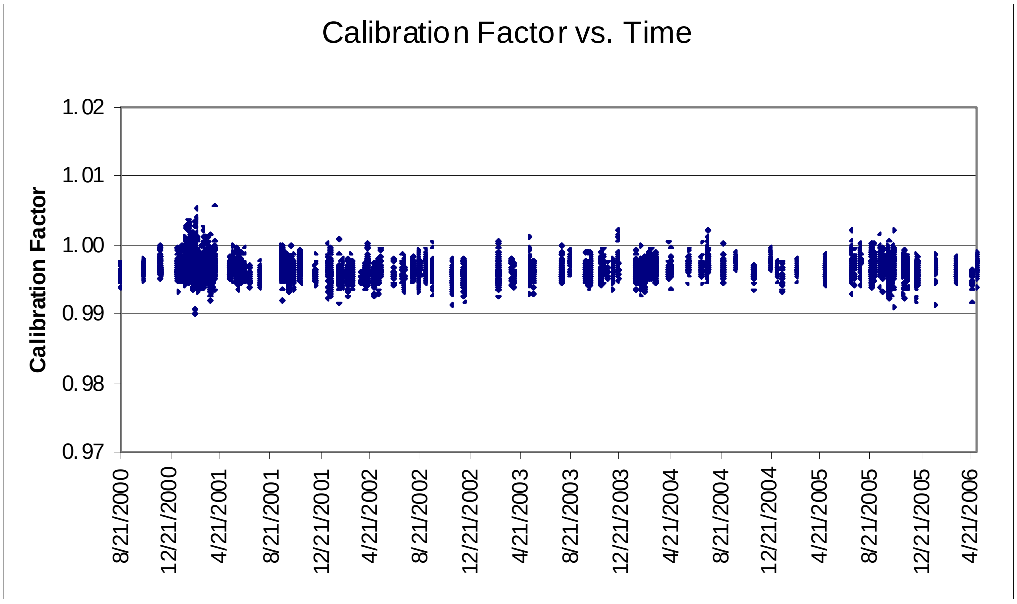

Figure 9 - Complete Data Set for the Daniel 24” USM at CEESI

The analysis of the CEESI data lead to the conclusion that during the time period studied (6 yrs), the Daniel 24” USM meter calibration factor appears to have shifted randomly and by very small amounts (less than 0.1 percent).

5.2 Southwest Research Institute

The Southwest Research Institute (SwRI) provided data from two ultrasonic check meters (Daniel 12-inch multipath) located nearby and upstream of the sonic nozzle reference meters in the High Pressure Loop (HPL). These check meters had been located in the HPL for over ten years. In the mid to late 1990’s, the meters’ electronics were upgraded to model MkII. During 2003-2004, Daniel Measurement and Control upgraded one meter’s electronics to model MkIII and used it as a beta test meter during the development of the MkIII. Since the meters were used as check meters to confirm stability and overall performance of the HPL, rather than as certified reference meters, dates of transducer and electronics changes were not recorded.

Over 9,000 data points, representing 152 days during the period from January 2003 through August 2007 were provided for each meter. Figure 10 shows the average daily calibration factor for the meter with the Mark III electronics. In general, the main determining factor in the size of the error bars is the range of test velocities on a given day. The largest error bars represent days in which the lowest test velocities were included in the calibration.

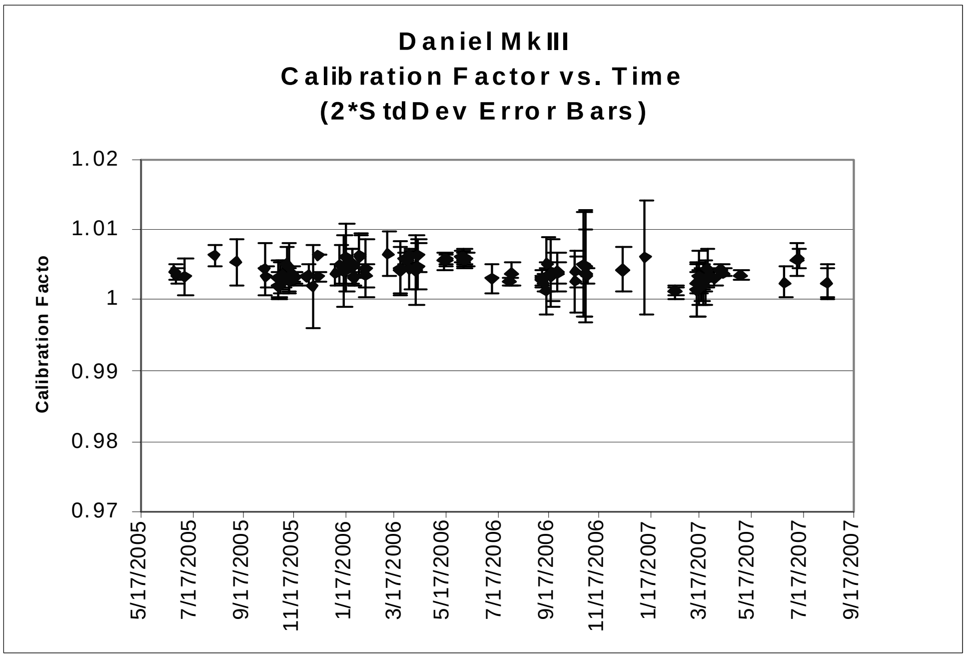

Figure 10 – Average Daily Calibration Factor at SwRI

The following conclusions can be drawn from the SwRI data:

- The calibration factors for the Daniel MkIII appear to have shifted downward by 0.16% from 2005 to 2007.
- The calibration factors for the Daniel MkII did not shift during the period from 2005 to 2007.

Based on the limited data available from both calibration facilities, the conclusion would be that in a clean, dry gas environment, ultrasonic meters are stable over a period of several years.

6 RECALIBRATION DATA

At the conclusion of this study, a total of 34 USM recalibrations had been analyzed. Of these meters, 22 had been in service at least six (6) years when they were recalibrated. It is not possible to present all of them in this paper, but a few are shown to illustrate some of the study's conclusions. The following recalibration examples were obtained from PRCI members either as historical records or from flow tests run during the duration of this program.

6.1 Recalibration Examples

In the example shown in Figure 11, the USM was calibrated and then re-calibrated 6 years latter in a different facility; each facility has an absolute uncertainty of ±0.25%. Hence the difference of 0.45% is statistically acceptable, but not very satisfactory. This was the largest deviation seen in this study between the initial and recalibration curves. This reveals that it would be better to calibrate and re-calibrate in the same flow facility.

There was another recalibration involving two different facilities, where there was excellent agreement. The data for the Q-5 meter shown in Figure 12 yielded a difference is only 0.03% over the 6 year period.

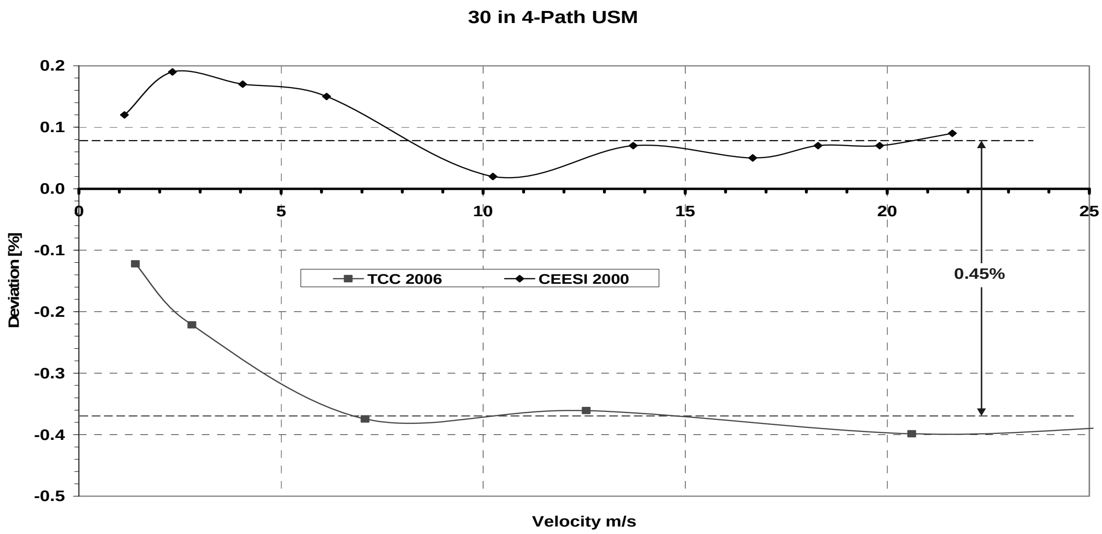

Figure 11 - Example of Recalibration at Different Facilities

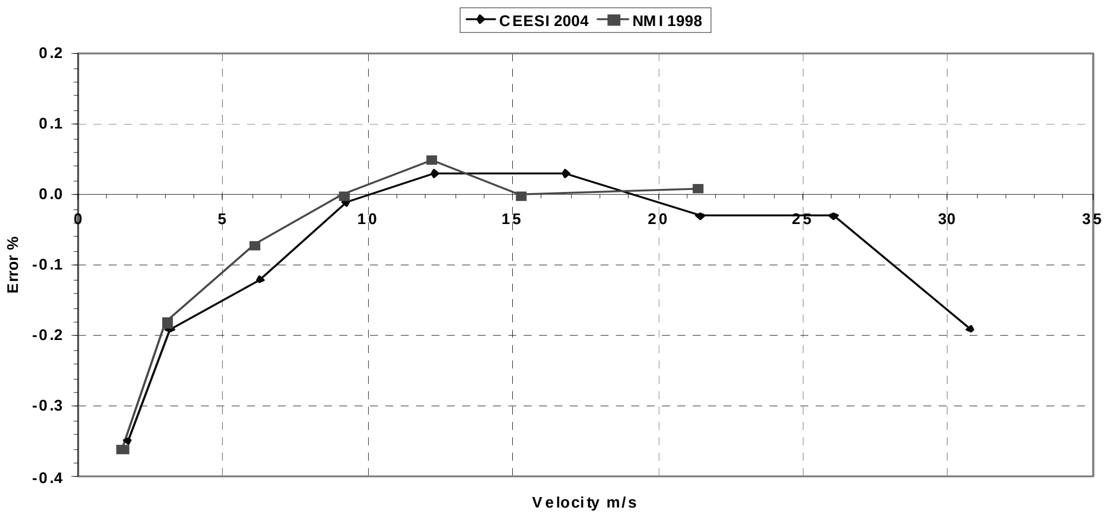

Figure 12 - Recalibration of a 16-inch Q-5 USM after 6 Years

Figure 13 shows a recalibration after only 2 years of a 16in 4-path meter. It was returned dirty from the field, calibrated dirty, cleaned and calibrated clean. The dirty meter shifted -0.078% from the original calibration. The cleaned meter shifted 0.014% from the original calibration. Both shifts were negligible.

This meter was shipped from the Far East to CEESI for re-calibration at considerable expense and inconvenience. It would have been possible to judge from the diagnostics that this was unnecessary! This is an excellent example of the potential savings that can be achieved if USM recalibration is based on meter diagnostics rather than an arbitrary time-in-service requirement.

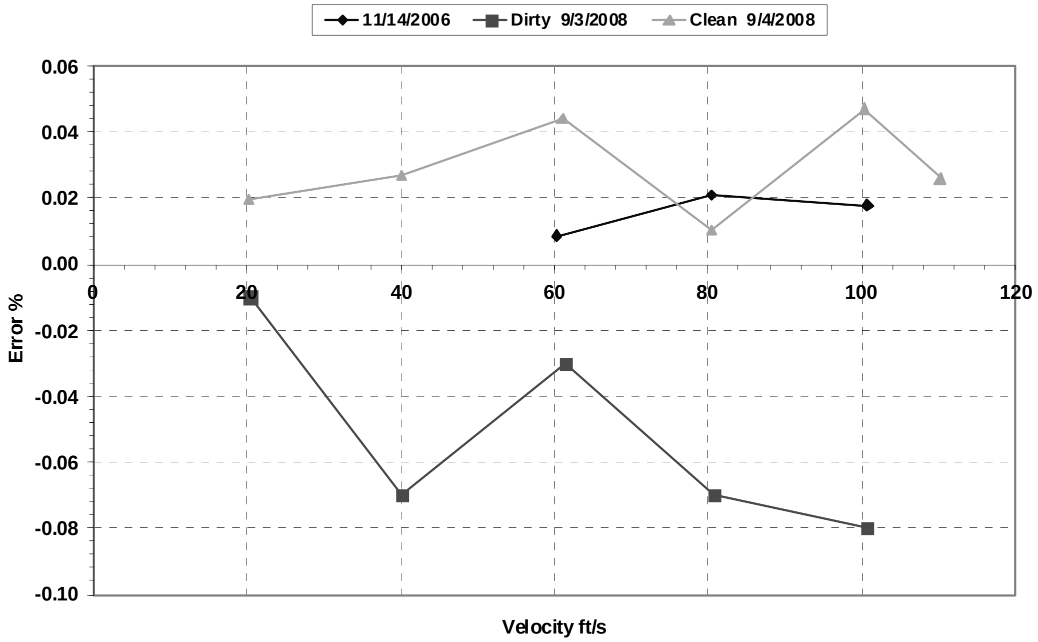

Figure 13 - Recalibration of a 16-inch 4-path USM after Two Years

6.2 Summary of Recalibration Data

Table 2 summarizes the recalibrations that were available for analysis for this program. There is data on 34 meters giving a total of 163 Meter*Years. However the longest time on a single meter is 7 years and the shortest 1 year. The 6-year data is due to the Measurement Canada rules and more such data should become available in the coming years.

One of the desired criteria for **qualified** recalibration data for this program was the availability of diagnostic logs for the original and for the recalibration flow tests. Unfortunately, field technicians are not generally aware of the value and use of the diagnostic logs and therefore do not routinely collect and retain them. Thus, in many cases, even if the logs were taken during the original calibration, they were not retained or could not be located.

7 PROGRAM CONCLUSIONS

Based on the analysis of the data available for this study, the following conclusions have been formulated:

- When the meter is cleaned & re-calibrated at the same facility, the calibration is within the uncertainty of the calibration facility for a period of at least six (6) years;
- The recalibration period may be considerably longer, but there is not enough data to support a larger number; however, there is no data to show that this is an upper limit;
- Changing the electronics and firmware does not require a recalibration;
- Changing the transducers does not require a recalibration;
- The need for recalibration is best based on the diagnostic logs than on the number of years that the meter has been in service, see reference [8];
- Instead of recalibration, an USM may only need to be cleaned if there is a change in its performance.

Table 2 - Summary of USM Recalibrations used in this Study

Model	Size	No	Calibration	Dates	Years	Meter*Yrs
Q-3	12in	1	Lab	2001 - 2008	7	7
Q-3	12in	6	Master	2001- 2004	3	18
Q-4	12in	8	Lab	2003 - 2009	6	48
Q-3	10in	1	Lab	2006 - 2008	2	2
Q-5	12in	7	Lab	1996 - 2002	6	42
Q-5	16in	1	Lab	1998 - 2004	6	6
Q-5	20in	1	Master	2005 - 2007	2	2
Q-5	20in	1	Lab	2002 - 2008	6	6
4-Path	8in	1	Lab	2001 - 2007	6	6
4-Path	12in	1	Lab	2002 - 2008	6	6
4-Path	16in	1	Lab	2006 - 2008	2	2
4-Path	20in	1	Lab	2000 - 2006	6	6
4-Path	30in	1	Lab	2001 - 2007	6	6
4-P+Q-5	16in	1	Series	2006 - 2007	1	1
4-P+Q-5	16in	1	Series	2006 - 2008	2	2
4-P+Q-5	20in	1	Series	2004 - 2007	3	3
Totals		34			70	163

8 RECOMMENDATIONS

Based on the analysis of the data obtained in this program, the following recommendations are presented:

- **Do not base the need for USM recalibration on time-in-service; use diagnostic tools**;
- Collect diagnostic logs on a periodic basis and note any significant changes;
- If the diagnostic logs indicate a performance change, clean the USM and re-check its performance;
- Continue to collect data on USM's recalibrations in order to possibly give an upper limit to their long-term stability.

9 REFERENCES

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10 ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the Pipeline Research Council International, Inc. (PRCI) for sponsoring this study and to its members for their cooperation in providing the recalibration data. The data provided by the flow calibration facilities and the USM manufacturers was a valuable component for the completion of this analysis.