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# Paper 2.3

# Proving of Multi-Path Liquid Ultrasonic Flowmeters

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## ABSTRACT

For fiscal and custody transfer operation, statutory requirements and good practice have led to in-situ proving of liquid flowmeters. Proving has been used not only to remove the installation effects, but also to demonstrate the continuing performance of the meter. The characteristics of positive displacement meters and turbine meters have made in-situ volume proving both necessary and cost effective.

Newer technology meters, such as coriolis and ultrasonic meters, have demonstrated greater short-term variability in their outputs, making them more difficult to prove by commonly used procedures. This characteristic makes it essential to look closely at the factors affecting this variability, and its implications for the proving process.

This paper identifies factors affecting the provability of multi-path chordal ultrasonic meters. It also presents proving data for such meters, for a range of meter sizes, at several independent certified hydraulic laboratories around the world, as well as data from meters at various field installations. These data show that repeatability is predictable and generally is controlled by turbulence statistics. The statistics are zero biased and subject to the flow conditions at the site. The understanding of the proving characteristics gained by this analysis leads to proving procedures whereby a specified calibration accuracy, such as the ±0.027% of the API Standards, can be achieved. The paper describes this process and demonstrates its application using field data.

## 1.0 INTRODUCTION

The development of ultrasonic transit-time flow meters began over 50 years ago. Early versions of these meters were at times disappointing in accuracy and reliability. While the basic principle remains unchanged today, the technology has evolved substantially. The major improvements have been in the areas of transducer design, signal processing and, even more importantly, in understanding the factors that influence the performance of these meters. Recent designs of multi-path transit-time ultrasonic flowmeters now routinely achieve an accuracy and reliability comparable to or better than older mechanical technologies (i.e., turbine and positive displacement meters).

Unlike older mechanical technology meters, ultrasonic flowmeters can provide information about flow characteristics within the pipe and the properties of the liquid (or gas). It is this information, along with the intrinsic possibilities of low uncertainty, low maintenance and large flow-range, as well as extensive diagnostics, that make these meters attractive. These features have pointed to the use of ultrasonic meters for fiscal / custody transfer applications. As these applications have traditionally required on-line calibration of the meters using meter provers, the proving characteristics of ultrasonic meters are receiving increased scrutiny.

### Proving of Fiscal / Custody Transfer Meters

Before discussing the use of provers with ultrasonic flowmeters, it is worth considering the reasons for proving meters.

- Proving can remove the effect of pipe fittings and installation hydraulics (reducers, planar and non-planar elbows, flow conditioner specifics) that may cause profile asymmetry, swirl, pulsations and high levels of turbulence, all effects that influence the majority of meters, often in an unpredictable way.

- In its simplest form, proving ensures that a meter, be it positive displacement, turbine, coriolis, or ultrasonic, is yielding a calibration uncertainty meeting the expectations of both parties to the custody transfer.

- Proving on site can eliminate effects from variations in fluid properties such as viscosity.

- When trended over long periods of time, proving results can give an indication when meters require maintenance.

- Finally, minimization of measurement uncertainty is becoming more important than ever as the economic value of liquid hydrocarbons increases. Proving has become mandatory with some national standards organisations. It is also likely to be desired by the users of ultrasonic flow meters as well.

We must therefore conclude that it would be beneficial for any meter used for fiscal /custody transfer purposes to be capable of being proved in-situ.

## Proving Ultrasonic Meters

For any meter, the validity and quality of the proving process is affected by several meter attributes:

- Its repeatability —Because the objective of the proving process is to establish a calibration factor with acceptable uncertainty in a small number of proving runs, the short term variability of the meter output - its repeatability - is a key element in achieving acceptable proving performance.

- Its rangeability—Depending on the application, proves may be required over a range of flow rates. To trend meter performance, and to ensure acceptable accuracy if flow rate varies during a transfer, it is clearly desirable that the calibration of the meter be insensitive to flow rate.

- Its stability—Trending of a meter's proving performance over the long term provides valuable information about its health. Additionally, because ultrasonic meters do not degrade mechanically, a stable performance base effectively enhances the uncertainty of subsequent proves.

- Its sensitivity to product properties—If the calibration performance of a meter is insensitive to a product's density and viscosity, then proves for a range of products effectively enhance one another.

This paper will focus on the repeatability and stability of ultrasonic meters. Additional papers on the rangeability and product sensitivity of ultrasonic flow meters are contemplated.

As with any new meter, and ultrasonic meters are new to this application, perceptions about their performance are beginning to develop, not all of which will prove to be valid. This state of affairs will persist until sufficient experience and data are accumulated upon which guidelines and rules of thumb can be developed. One of these perceptions is that the short-term repeatability of the meter will not meet the API standards for turbine meters. This perception appears to be true, and it will be seen that the repeatability of ultrasonic meters is a function of many features, prover size, installation conditions, prover type (compact or line prover) and, different from other meters, turbulence levels in the fluid. As there is an element of design influence on meter repeatability, as such, the data presented here relate only to the design of the Caldon ultrasonic meter (LEFM 240C).

## 2.0 FACTORS AFFECTING THE REPEATABILITY OF ULTRASONIC FLOWMETERS

Generally ultrasonic flow meters proposed for use in custody transfer applications measure fluid velocities along multiple acoustic paths. [1] For example, the acoustic paths of a Caldon LEFM 240C are arranged in the single plane forming four parallel chords as shown in Figure 1. This plane is oriented at an angle (the path angle) with respect to the centreline of the pipe. A photograph of an LEFM 240C installed at a crude oil batching facility is shown in Figure 2.

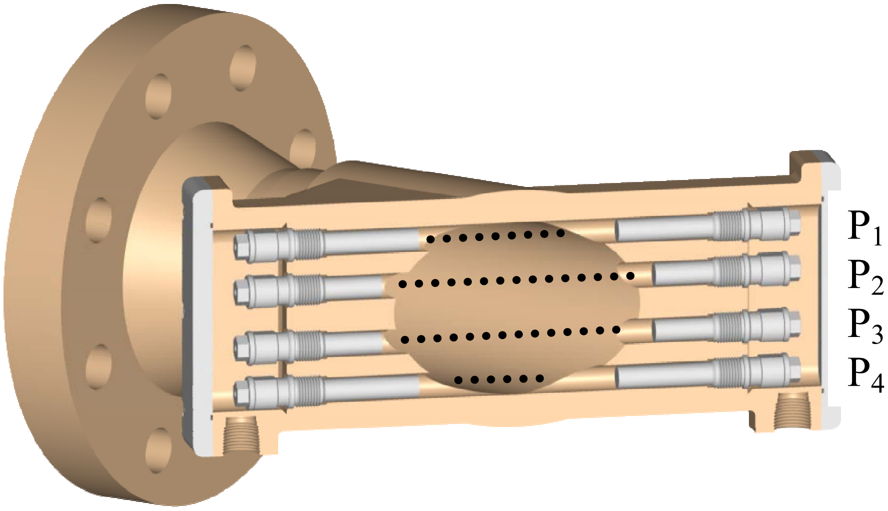

**Figure 1: Cut-Away of an LEFM 240C**

**Figure 2: Installed LEFM 240C**

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[1] The principles of operation of transit time ultrasonic flowmeters have been described in detail in the technical literature and will therefore not be covered in this paper. The reader desiring more information is directed to the Caldon Website.

All ultrasonic flow meters currently used in custody transfer applications determine fluid velocity along an acoustic path by measuring the transit times of pulses of ultrasonic energy travelling along the path in each direction. Ultrasonic flow meters are sampled data systems. That is, the transit time measured for a single pulse travelling in one direction along an acoustic path samples the fluid velocity and sound velocity along that path. These variables, and particularly the fluid velocity, vary in time because of turbulence, flow control operations and other factors. Hence a single sample does not establish the mean velocity. In Caldon systems, the velocities along individual paths, determined from a pair of transit time measurements (one with and one against the flow), are combined numerically by quadrature integration to form a single sample of the flow rate. This result too is affected by the statistics of the turbulence, though its effect is smaller than it is on a single path measurement. Thus, for a four-chord system like that in Figure 1 a set of eight-transit time measurement produces a measure of the flow. Multiple samples are necessary to refine the uncertainty of the measurement. It will be noted that the sampling characteristic of ultrasonic flow meters is fundamentally different than the characteristics of turbines and positive displacement meters, which integrate the flow field mechanically and tend to smooth time-wise flow variations by their rotational inertia.

It is now appropriate to tabulate the factors affecting the repeatability of ultrasonic flow meters:

- As noted above, the intensity of the turbulence encountered by a pulse as it makes its way along an acoustic path [2]. Typically, the root mean square value for local turbulence will lie in the range of 3 to 7% of the mean axial velocity [3]. The magnitude is sensitive to upstream hydraulics as will be discussed later. A mean velocity measurement along a single path will be below the 3 to 7% figure because of spatial averaging during the transit (typically ranging 2 to 4%).

- The sample rate of the ultrasonic flow meter A proving run takes place over a finite time period—for a ball prover, 10 to 20 seconds is typical. It would appear that the more frequently an ultrasonic flow meter samples the flow during the run period, the more precise the measurement of the calibration coefficient. This is true to a degree, but the uncertainty is also affected by the turbulence spectrum as described below. As a benchmark, Caldon meters typically sample and update the flowrate at a rate of about 60 Hz.

- The variations in fluid velocity due to turbulence – The effects of turbulence are random and multidirectional and can be characterized by a frequency spectrum that varies inversely with pipe interior diameter and directly with fluid velocity. The low end of the spectrum presents the greatest proving challenge—higher frequency disturbances tending to average out during a prove.

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[2] The focus of this paper is on the proving of ultrasonic meters with flow in the turbulent regime, that is, for Reynolds numbers greater than 10,000. Proving in the laminar or transition regions presents a different set of issues and will be discussed in a separate paper.

[3] Reference "*Boundary Layer Theory*" Seventh Edition, Schlichting (Chapter XVIII), McGraw-Hill

It should also be pointed out that the prover, compact or line, can affect the repeatability of the meter being proved. Assuming, that the prover is perfect (or has a negligible contribution to uncertainty and repeatability), then, from the discussion above, the repeatability will be a function of certain meter and application characteristics. In particular, it will depend on 1) the meter path configuration, 2) the sample rate, 3) the prover volume, 4) the turbulence, 5) the fluid velocity, and 6) the pipe diameter.

## Characteristic Statistics

It has been shown that for pulse output meters, the number of pulses required to obtain repeatability, as for example defined in the repeatability commonly used in prover calibrations, 0.05% from five runs, is dependant upon the pulse-to-pulse regularity. The worse the regularity the more pulses are required to obtain a given repeatability. Also, there is a finite limit to the achievable repeatability, which is a function of the number of pulses and the pulse-to-pulse regularity. The methodology of Mr. R. Paton [4] has been used to construct a typical set of curves for a normally distributed pulse output. Results are shown in Figure 3.

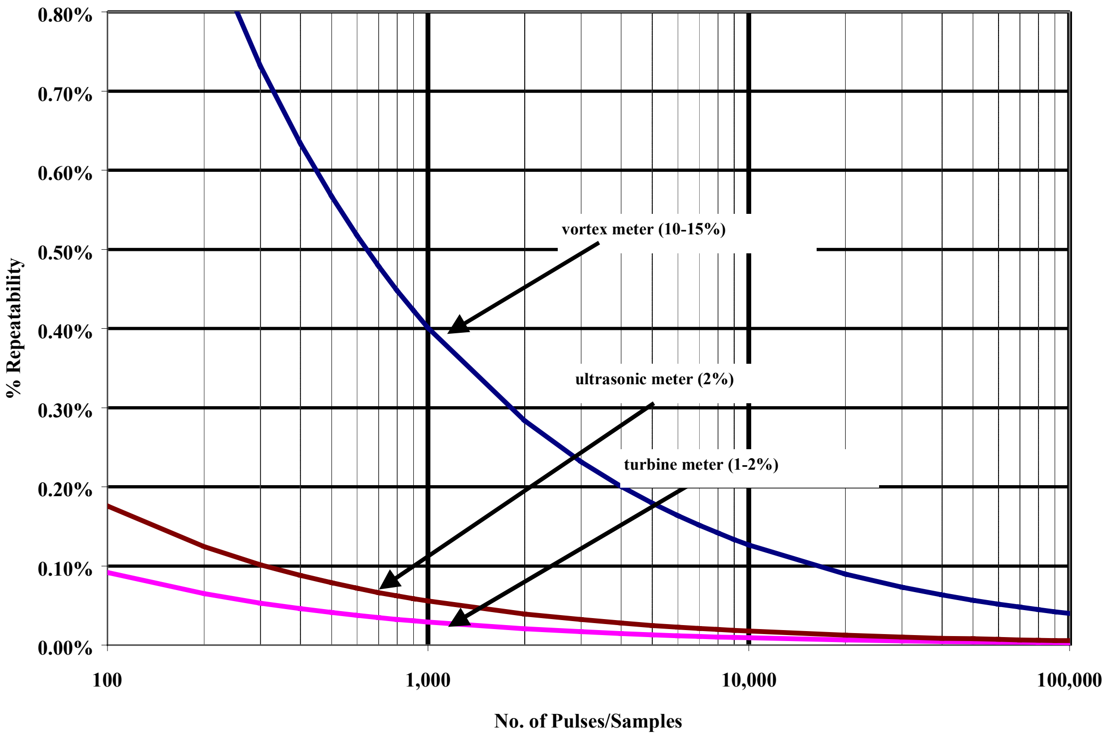

**Figure 3 – Predicted Repeatability vs. Number of Pulses/Samples for Varying Standard Deviations**

The data used to construct Figure 3 comes from the authors' experience for the three types of meters shown.

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[4] *The Predictions of Calibration Repeatability Using Compact Provers and Pulse Interpolation*, R. Paton

A good turbine meter will have a pulse-to-pulse standard deviation of better than 1-2%, although there is more complex variation due to inter-rotational irregularity. As can be seen the turbine meter has a natural ability to get to the repeatability requirements with a relatively small number of pulses. Further with a compact prover, pulse interpolation is a valid concept because of its predictive nature, requiring a good regularity of pulse output. A Vortex meter at the other extreme has a somewhat indeterminate regularity, but from the authors' experience has a pulse-to-pulse regularity standard deviation of between 10-15%. Referring to the curves it can be seen that many more pulses are required to obtain good repeatability and that for all practical purposes they never reach the theoretical 0.05% repeatability. In fact, our experience showed that 0.1% was the best repeatability of a conventional Vortex meter.

Included in Figure 3 is a “statistical” performance typifying the LEFM 240C. The 2% value shown on Figure 3 represents the standard deviation of a single flow measurement sample (60 Hz sample rate)– the value assumes that the LEFM produces one pulse per flow measurement sample, and that there is no pulse interpolation. The pulse/sample output from an ultrasonic meter is derived from converting each sampled flow measurement into pulses. The “jitter” or standard deviation is due to turbulence and hydraulic variability that in turn produce variability in the pulse output. As discussed above, increasing the sample rate will improve resolution, but not necessarily provability.

Note that Figure 3 can be interpreted in terms of a prover volume requirement. To achieve a desired repeatability in a set of calibration runs for a specific meter type, the prover is sized such that at the system flow rate, the meter produces the number of samples required for the desired repeatability. Thus, to achieve a repeatability of 0.05% for the ultrasonic meter, about 1500 flow measurement samples--are required. If the meter is sampling at 60 Hz, a volume equal to 25 seconds times the flow rate at which the proving is to be performed is required.

To achieve the repeatability typically required for a 5 prove set, Figure 3 implies significant increases in the prover volumes, with consequent cost and size penalty, or alternatively, to use a larger number of runs. Experience shows that proving of ultrasonic meters by both in-line and compact provers can yield repeatability comparable with turbine meters, but at other times, without an obvious external reason, the repeatability is inferior. It is probably safe to assume that this is due in most cases to the statistical nature of the process and/or to variations in turbulence levels.

## Multiple Proving Runs

Alternatively, the API MPMS Chapter 4.8 Table A1 provides a method for obtaining the desired calibration factor uncertainty--±0.027% (two standard deviations) without requiring large provers or an inordinate number of runs. The repeatability required to achieve +/- 0.027% uncertainty for a particular number of runs is shown in Table 1. The approach is substantially similar to that proposed by Folkestad.[5]

| **Runs** | **Repeatability (max-min)/min %** |
|---|---|
| **5** | **0.05%** |
| **6** | **0.06%** |
| **7** | **0.08%** |
| **8** | **0.09%** |
| **9** | **0.10%** |
| **10** | **0.12%** |
| **12** | **0.14%** |
| **13** | **0.15%** |
| **14** | **0.16%** |
| **15** | **0.17%** |

**Table 1: Summary of API MPMS Chapter 4.8 Table A1**

As will be shown from results presented herein, Caldon LEFM meters achieve acceptable and reproducible results by taking more runs as permitted by the API. This approach in our experience has yet to gain wide acceptance as a method for line provers, where 0.05% from 5 straight runs is the norm for turbine meters. For compact provers, however, the situation appears to be different, where the practice of increasing volume by taking a number of passes to make an individual run is common.

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[5] "*Testing a 12" Krohne 5-Path AltoSonic V Ultrasonic Liquid Flow Meter on Oseberg Crude Oil and on Heavy Crude Oil*", Folkestad, 19th North Sea Flow Measurement Workshop 2001

## 3.0 PROVING PERFORMANCE SUMMARY

### In-Line Proving of Ultrasonic Flowmeters

The following results presented are for a number of sites, including field installations as well as at three independent laboratories (SPSE, Trapil and Alden Research Laboratories). The data is more heavily weighted with lab data, which interestingly, is typically worse than field data (possibly due to control loop stability). The meter sizes are from 4" to 12" diameter and oil viscosities varying from 0.7 to 100 cS. Data is presented as a predicted required prover volume by using the following equation:

$$\frac{\text{repeatability}}{D_{(n)}\sigma_{\text{test}}} = \sqrt{\frac{\text{Volume}_{\text{test}}}{\text{Volume}_{\text{required}}}}$$

Here the factor $D_{(n)}$ relates the range (the maximum minus the minimum) of a limited sample taken from a large population to the standard deviation $\sigma_{test}$ of that population. $D_{(n)}$ = 2.33 for 5 samples and 3.078 for 10 samples.[6] $D_{(n)}$ = 2.33 for 5 runs and 3.078 for 10 runs.

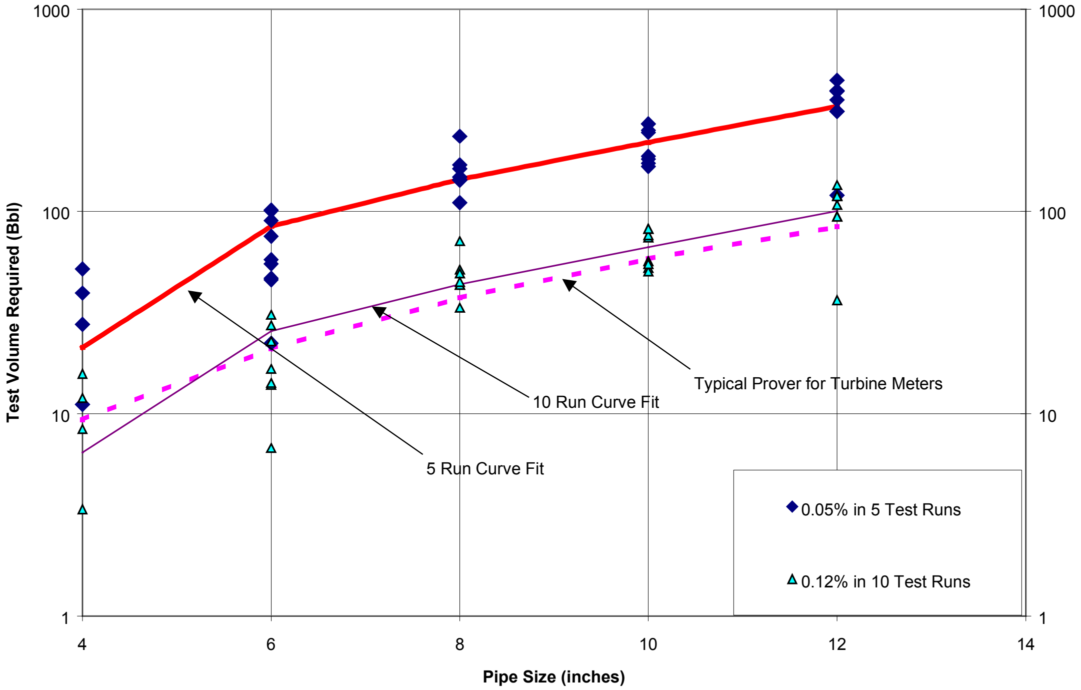

**Figure 4: Prover Volume for 5 Run and 10 Run API Required Repeatability vs. Meter Size**

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[6] John Mandel, *The Statistical Analysis of Experimental Data*, Dover

The results based on the data collected are shown in Figure 4. Also shown are the curve fits for the two proving criteria: that is, the prover volume required to achieve a calibration uncertainty of ± 0.027% in 5 proves and the prover volume required to achieve a calibration uncertainty of ± 0.027% in 10 proves. These curves have been synthesized using the repeatability equation given above.

The graph clearly demonstrates the improvement in repeatability by taking more repeat runs. Going from 0.05% in 5 runs to 0.12% in 10 runs reduces the required volume by a factor of 3.

Figure 4 also shows a plot of the typical volumes used for turbine meters (the dashed line). Here the prover size was computed for a prover to achieve 15,000 pulses from a typical turbine meter. The typical prover size line falls almost on top of the curve fit line of the 0.12% repeatability in 10 runs. However, for the ultrasonic flowmeter, the prover volume for the 0.05% repeatability in 5 runs requires a much larger prover than for equivalent size turbine meter.

The proving results of the Caldon LEFM 240C meters are summarized in Table 2. The number of runs and the acceptable repeatability shown in the two left most columns are the same as shown in Table 1. The numbers shown in the five other columns are the repeatability achieved by LEFM 240C meters from 4 inches up to 12 inches in diameter. The darker shading indicates the values that are within the required API specification. (It is noted, that there is always a probability that the meter will meet the API specification a percentage of the time even for the number of runs that are not shaded).

| | | Caldon LEFM 240C Meter Repeatability | | | | |
|---|---|---|---|---|---|---|
| Runs | Acceptable Repeatability | 4 inch | 6 inch | 8 inch | 10 inch | 12 inch |
| 5 | 0.05% | 0.08% | 0.08% | 0.10% | 0.09% | 0.10% |
| 6 | 0.06% | 0.09% | 0.09% | 0.11% | 0.10% | 0.11% |
| 7 | 0.08% | 0.09% | 0.10% | 0.12% | 0.11% | 0.11% |
| 8 | 0.09% | 0.10% | 0.10% | 0.13% | 0.12% | 0.12% |
| 9 | 0.10% | 0.10% | 0.11% | 0.13% | 0.12% | 0.13% |
| 10 | 0.12% | 0.10% | 0.11% | 0.14% | 0.13% | 0.13% |
| 11 | 0.13% | 0.11% | 0.11% | 0.14% | 0.13% | 0.13% |
| 12 | 0.14% | 0.11% | 0.12% | 0.14% | 0.13% | 0.14% |
| 13 | 0.15% | 0.11% | 0.12% | 0.15% | 0.14% | 0.14% |
| 14 | 0.16% | 0.12% | 0.12% | 0.15% | 0.14% | 0.14% |
| 15 | 0.17% | 0.12% | 0.13% | 0.15% | 0.14% | 0.15% |

**Table 2: Summary of API MPMS Chapter 4.8 Table A1 and Repeatability of Caldon LEFM 240C Meters for Various Pipe Sizes for Typically Sized In-Line Provers**

## Proving Ultrasonic Flowmeters with a Compact Prover

We are only just beginning to collect and organize data of calibration using Compact Provers, the results of which are encouraging with good success on several meters. Figure 5 shows a photograph of a compact prover used to calibrate an LEFM 240C. The method of calibration used includes taking groups of pulses, calculating the mean value of the group and taking that as one run.

**Figure 5: Compact Prover Test Configuration**

Figure 6 shows data collected at a particular installation that experienced difficulty when proving with a compact prover. The graph shows the effect of taking groups of passes to make up an individual run on two 6" meters, by plotting the data against effective proving volume, that is, the total volume produced by the passes for each run. The passes varied from one pass per run upwards. Repeatability was taken as maximum to minimum deviation in 5 runs.

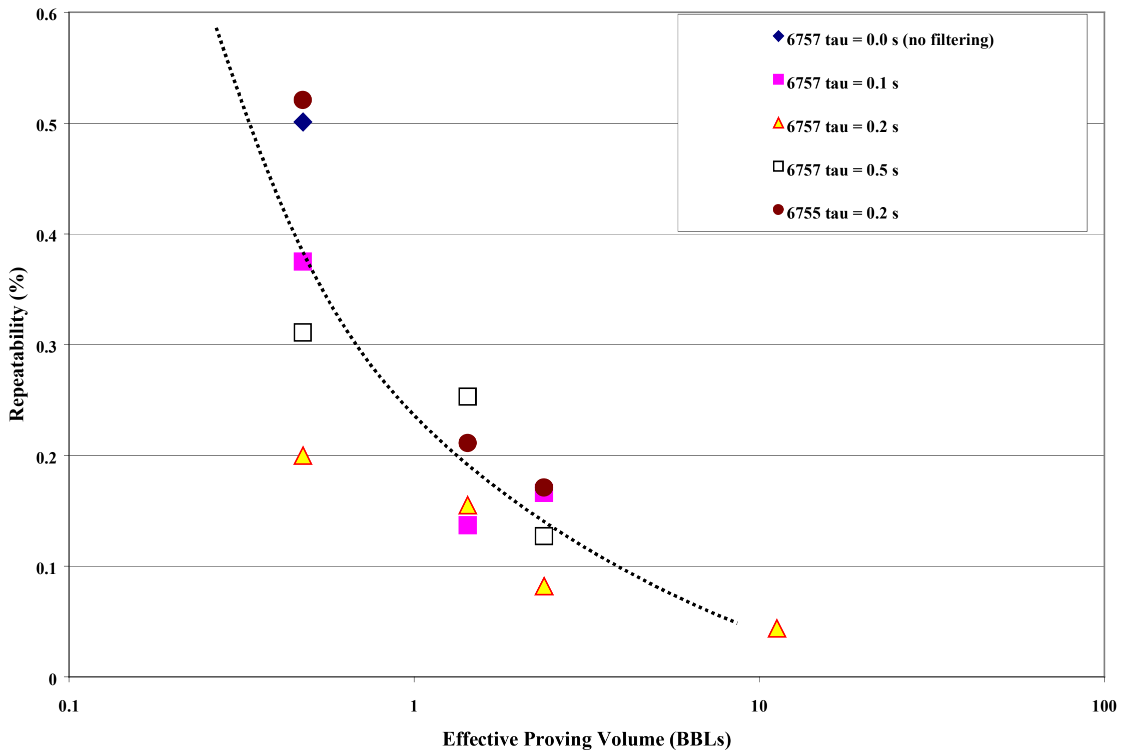

**Figure 6: Example of Repeatability (6 inch) Using a Compact Prover Configuration – Difficult Hydraulics**

In order to achieve better performance, the strainer immediately upstream of meter 6757 was removed. The meter subsequently proved using groups of 3 passes in 5 runs, as seen in Table 3.

| Hydraulics | Passes Per Run | Number of Runs | Repeatability |
|---|---|---|---|
| Strainer Upstream | 3 | 5 | 0.15% |
| Strainer Removed | 3 | 5 | 0.05% |

**Table 3: Meter 6757 Sensitivity to Upstream Strainer**

The data shown in Figure 6 was obtained with the compact prover upstream of meter 6755. When the prover was later installed downstream, the repeatability improved by a factor of 2, as shown in Table 4. Consistent with the proving results, there was also a clear decrease in turbulent intensity as measured by the meter (factor of 2.5).

| Arrangement | Passes Per Run | Number of Runs | Repeatability |
|---|---|---|---|
| Prover Downstream | 3 | 5 | 0.11% |
| Prover Upstream | 3 | 5 | 0.23% |

**Table 4: Meter 6755 Proving Data – Sensitivity to Prover Location**

While the success of several meters and the understanding of some installation effects are not conclusive and the number of results small, the indications are that a compact prover may be another solution for proving ultrasonic flowmeters other than just the line prover.

## Upstream Hydraulic Effects on Proving Ultrasonic Flowmeters

The preceding discussion made clear that turbulence will influence the repeatability of ultrasonic flowmeters, because of their inherent data sampling characteristics. But the magnitude of the turbulence intensity and its spectrum are influenced by upstream hydraulics. For the discussion that follows, we draw heavily on Caldon's nuclear flow measurement experience. Because there is no capability, in nuclear plants, to calibrate a meter *in situ,* a flow meter's calibration coefficient and the uncertainty in this coefficient must be determined beforehand. These requirements have led to measurements of calibration coefficients in full-scale models of the intended application and to quantifying the sensitivity of these calibrations to upstream hydraulics. The standard used in such calibrations is gravimetric—a weigh tank—and the statistics of the numerous weigh tank runs provide data on meter performance that can be used to project its performance with a prover.

A brief digression relative to the use of differing standard types: Numerous cross checks of calibration results obtained for specific meters, with a gravimetric standard against results obtained with a prover, show that, with like upstream geometries, the two standards produce essentially identical results. Additionally, the statistics of these results are comparable—for comparable sample periods the standard deviations are similar and the data are normally distributed.

Using both gravimetric standards and provers, the effects of various types of flow conditioners on repeatability (and on linearity) have been investigated.

It should be pointed out that, to date the investigations have been limited, and more work in this area is planned.

Non-Planar Elbows

The first item evaluated was the sensitivity to swirl producing hydraulics. For this evaluation, data from the calibration of an LEFM installed in nuclear feedwater line is used. This installation is also known to be a swirl producer, see Figure 7.

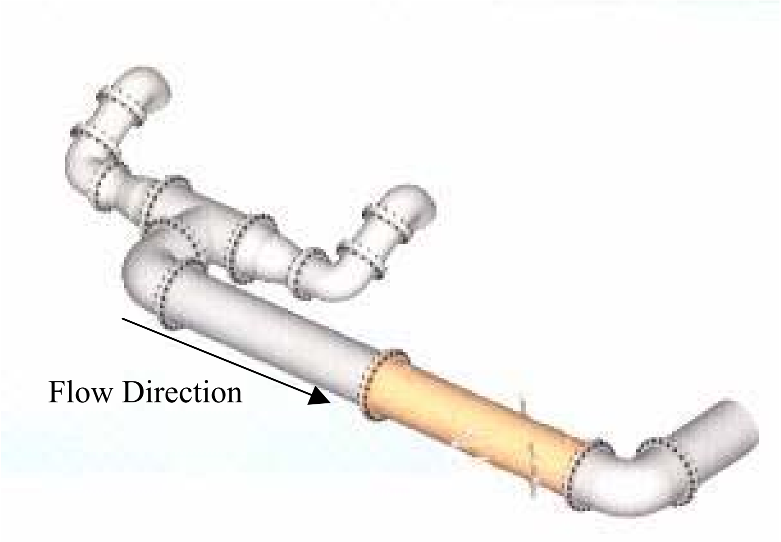

**Figure 7: Swirl Producing Installation Used to Evaluate Repeatability**

This installation used a 26-inch meter with two measurement planes each with four paths (i.e., the eight-path meter that is standard for nuclear feedwater systems). The velocity data obtained from the meter showed significant transverse velocities indicative of swirling flow, swirling at a rate of ~33 rpm when the axial velocity is at 17 ft/s (5 m/s).

We then performed special repeatability tests using a gravimetric standard for comparison (approximately 40 second tests). Two test configurations were evaluated, one with and the other without swirl eliminating flow straighteners upstream. The results for repeatability are shown in Table 5.

| Conditions | 4 Path (1) | 4 Path (2) | 8 Path |
|---|---|---|---|
| **Straightener (5D Upstream)** | **0.05%** | **0.04%** | **0.03%** |
| **No Straightener** | **0.22%** | **0.14%** | **0.05%** |

**Table 5: Summary of Repeatability of Swirling Hydraulics and Downstream Flow Straighteners**

It is clear that the transverse-flow degraded the four path systems' repeatability. It is also clear that even without a straightener the repeatability of the eight-path meter, with its natural cancellation of cross flows, remained within the required tolerance. As a result of this experience and others, the 8 path meter configuration is being investigated for the petroleum applications.

Reducing Tees

The next item evaluated was the repeatability's sensitivity to the elimination of flow conditioning when installing downstream of planar elbows and tees. For this evaluation, the repeatability of a 12 inch meter installed per API guidelines (10 L/D with a tube bundle) was compared to the repeatability of the same meter at the same site, but installed directly downstream of a reducing tee. The products tested were crude oils that were proved at regular intervals (each batch). The flowrate range was 2:1, the viscosity range was ~2 to ~60 cS.

| | **Installed per API Guidelines** | **Installed Immediately Downstream Reducing Planar Tee** |
|---|---|---|
| **Repeatability (5 runs)** | **0.10%** | **0.15%** |
| **Min Meter Factor** | **0.9952** | **0.9933** |
| **Max Meter Factor** | **0.9992** | **0.9970** |
| **Std Dev Meter Factor** | **0.08%** | **0.09%** |

**Table 6: Repeatability Comparison – Installed per API Guidelines as well as without any Flow Conditioning**

Table 6 shows that the repeatability degrades by 50% without flow conditioning. This is not surprising, since separation occurs at the bend and its effects on turbulence have not dissipated at the meter location. More impressively, Table 6 also shows, that the linearity of the meter is not degraded by the upstream hydraulics-- the calibration shift of 0.2% is predictable and due to the generally flatter axial profile downstream of the tee.

Flow Conditioning

The repeatability problem with a turbine flow meter is often addressed by flow conditioning—particularly if swirl is suspected. The sensitivity of an ultrasonic meter's repeatability to flow conditioning is less understood. Flow conditioner tests were performed with an 8-inch meter at Alden Research Laboratories using water as the test liquid. The repeatability reference standard was an independent turbine meter, buffered from the hydraulics by a tube straightener and straight pipe.

Table 7 documents configurations evaluated and the results.

| **Flow Conditioning - Description** | **Repeatability** |
|---|---|
| **Straight Pipe – 20 L/D** | **0.11%** |
| **Mitsubishi Plate Flow Straightener – Upstream 0 L/D** | **0.10%** |
| **Vortab Flow Straightener – Upstream 3 L/D** | **0.14%** |
| **V-Cone – Upstream 3 L/D** | **0.35%** |

**Table 7: Repeatability Summary for Various Flow Conditioning**

From the data shown, flow conditioners and obstructions (i.e., V-cone) near to the meter, that produce large-scale turbulence (shedding vortices) degrade repeatability. Likewise, the plate flow conditioner close to the meter slightly improved repeatability.

## Stability--Long Term Repeatability of Ultrasonic Flowmeters

The short-term repeatability of meters is important but ultimately the long-term repeatability, stability of the mean meter calibration is more important. Most turbine meters for example drift with time due to a combination of mechanical changes and tolerances and varying flow conditions. Because ultrasonic flowmeters are not subject to mechanical degradation, their calibrations are inherently more stable over time. This is clearly demonstrated in the tests shown in Figure 8, at Cushing, Oklahoma. A standard turbine meter, a helical turbine meter and Caldon LEFM meter were used in series for batch measurement of crude oil over a period of nearly 1.5 months. All meters were proved simultaneously at regular intervals. The flowrate varied from 7930 BPH to 14,025 BPH, the viscosity varied from 1.8 to 66.5 cS and the density varied from 0.79 to 0.90. As can be seen in Figure 8, the variation of the LEFM ultrasonic flow meter mean calibration over this time is more stable under all flow conditions than for either of the other two meters.

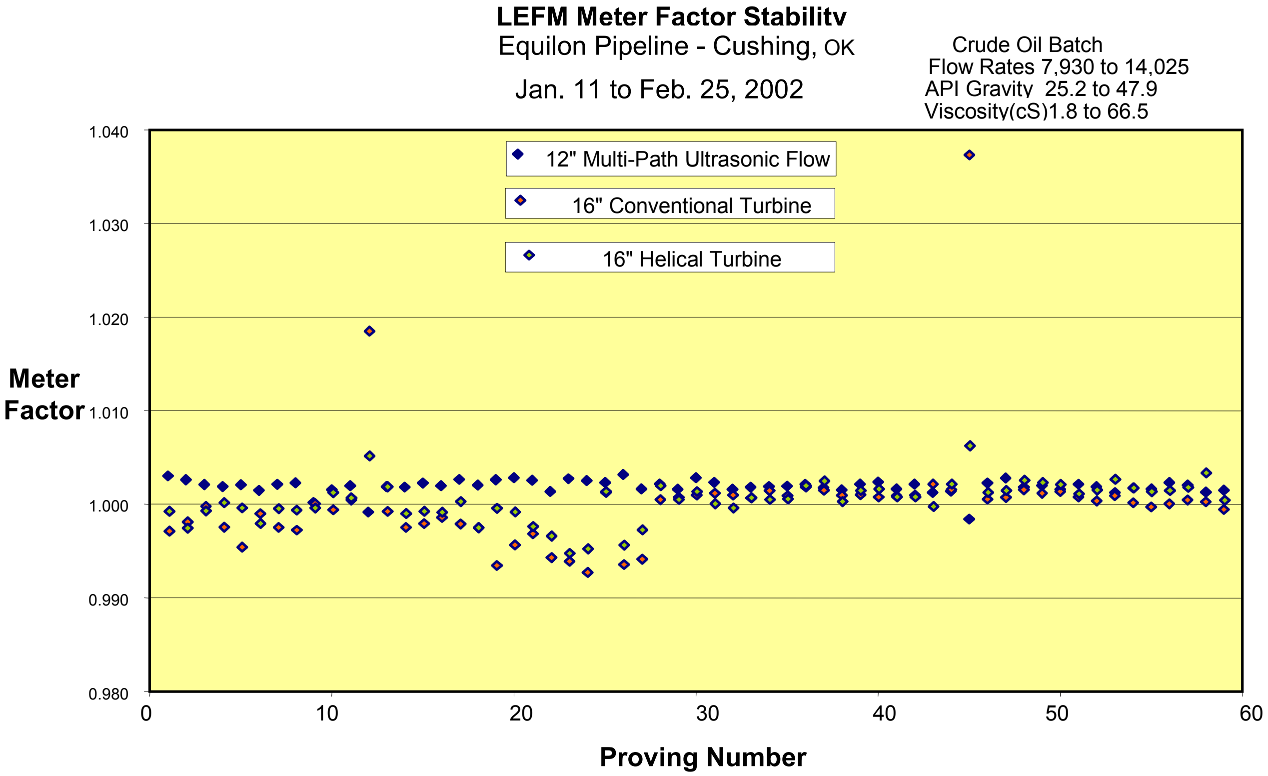

Figure 8: Long Term Repeatability – Ultrasonic, Helical and Standard Turbine

The remarkable stability exhibited by the LEFM 240C in Figure 8 is an attribute that eventually may play a role in proving practice for such meters. Effectively, by the 60th set of proving runs, the LEFM 240C calibration coefficient is known.

### Other Methods of Proving Ultrasonic Flowmeters

The most obvious solution to the problem of repeatable proving results is to use a master meter. This would allow proving over any length of time, using for example a prover calibrated turbine meter as a transfer standard. The turbine meter would be packaged with the prover and calibrated on the process fluid, before proving the meter. Pulses from the turbine would then be used to gate the ultrasonic meter output, choosing the appropriate number of pulses to give adequate repeatability. Caldon has results for this method, and in principle it should work in the same way that the method is used for coriolis meters (we do not have data from coriolis meters for comparisons). While the master meter approach will reduce the size of the prover, the downside is obviously addressing the uncertainty of measurement, due to the use of an intervening meter.

### Proving Ultrasonic Flowmeters – Future Work

The next issues that Caldon will be evaluating include the following:

- The impact of flow conditioning on meter performance (with respect to linearity and repeatability) – Tube Bundles and pipe reducers have already been extensively studied
- The compact prover and small volume prover evaluations teaming with an SVP manufacturer
- Adoption of some nuclear industry meter techniques (8-path meters and their natural turbulence reduction properties).

## 4.0 CONCLUSIONS

This paper looks at the proving of Caldon LEFM240C ultrasonic flowmeters. As the meter is relatively new to fiscal / custody transfer operation, data is only just beginning to come through. The points that are becoming self evident are:

1. Much of the output variability is due to turbulence in the flow. The higher the turbulence, the more variable the signal output.
2. The variability that can be adversely affected by upstream hydraulics can be alleviated by proper installation, such as 20 diameters of upstream straight meter run. Flow conditioners do not necessarily improve variability over straight pipe.
3. The results with in-line provers indicate that the Caldon meter needs to either use a larger volume prover than the conventional or to use more runs to achieve a standard deviation of 0.027% for repeatability.
4. The initial results with compact provers indicate good repeatability. There appeared to be no problem experienced with the change in flow at piston startup. We are planning tests, in cooperation with a compact prover manufacturer, that will better establish the parameters for proving with such provers.
5. We have only a little data using a master meter as a transfer standard. It would appear that this is a feasible method of proving, obviously, however, with a higher calibration uncertainty.

# References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.