

Paper 4.1

Installation Effects and Diagnostic Interpretation Using the Caldon Ultrasonic Meter

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INSTALLATION EFFECTS AND DIAGNOSTIC INTERPRETATION USING THE CALDON ULTRASONIC METER

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1 INTRODUCTION

The Caldon chordal flowmeter is a descendant of a multi-path meter conceived in 1966 by the Oceanic Division of the Westinghouse Electric Corporation. The Westinghouse meter was the first practical multi-path ultrasonic transit-time meter. Its 4 path configuration was selected to minimize the influence of installation conditions. The fundamental principle of the design is to integrate the axial velocity profile numerically, using Gaussian quadrature integration. The method specifies the optimum positions for the acoustic paths (the paths traveled by ultrasonic pulses from one transducer to another) and also the weighting factors for the velocities measured along each path, such that errors in calibration due to changes in velocity profile are minimized.

The resultant design was initially used to measure flow through large water pipes, and later to provide multiple line balances on the Trans-Alaska oil pipeline, where the meters have been in continuous use for nearly 30 years. When Caldon acquired the product and refined it, they found a market in the Nuclear Power industry measuring feedwater flow, where they have installed a large number of meters. It is from this area that the data presented in this paper were taken.

There is a growing demand for large—16 to 32 inch—custody transfer meters in petroleum applications, particularly offshore. Providing the means to prove these meters, if it is practical at all, is extremely expensive, both in equipment and space. Does the feedwater measurement experience point the way to a solution of the oil measurement problem in large pipes? The significant requirements of the feedwater flow measurement are as follows:

- The uncertainty requirement for the feedwater volumetric flow measurement is in the range of ± 0.20 to $\pm 0.25\%$. Feedwater flow is a critical measurement in the calculation of reactor thermal power—a measurement that balances nuclear safety requirements against the objective to maximize the power output of a nuclear plant.
- There is a need to validate the calibration on the large (16 to 32 inch diameter) meters used in nuclear plants without the ability to “check” the meters directly on site. That is, it must be possible to demonstrate on line that in fact the meter is operating within an uncertainty of ± 0.20 to $\pm 0.25\%$. The temperature and pressure of nuclear feedwater—230 C, 8 MPa—rule out the use of provers or other standards.
- The installation conditions, because of the space constraints, lead to complex upstream piping configurations and thus require the meter to deliver its accuracy with distorted and, in some instances, varying velocity profiles.
- Because of the constraints of nuclear safety, self-checking as well as the ability to audit meter operation, to ensure that the meter remains within its design uncertainty, is essential. That is, it is required that the meter not only *be* accurate but that it be possible to *demonstrate* that it is accurate.
- Because of the economic objective to maximize thermal power, the reliability of the feedwater flow measurement is absolutely paramount. If failures do occur, it is necessary that the meter be robust—that it be able to continue to operate with its accuracy degraded as little as possible, and for its performance in this degraded condition to be well defined and displayed.

All of these features read across to the measurement of petroleum and its products. Furthermore, water has similar fluid properties to petroleum and its products. It is a

Newtonian fluid; its viscosity varies with temperature and lies below that of crude and refined oils but above gasoline, other distillates, and liquefied gases. Hence a meter's response to changes in profile due to changes in Reynolds number or other hydraulic factors is similar for water and petroleum products--there is a good "read across".

This paper discusses the methods used to provide the capabilities listed above, including the calibration practices as well as the diagnostics that have been developed to ensure that the meter remains within its design basis.

2 DISCUSSION

2.1 What Can Go Wrong with an Ultrasonic Meter?

It is often noted that transit time ultrasonic meters have no moving parts and that, consequently, they are not subject to the wear mechanisms that can degrade the performance of turbine and positive displacement meters. This does not mean ultrasonic meters cannot fail, however. Nor, perhaps more significantly, does it mean that they are not subject to mechanisms that can, gradually or abruptly, degrade their performance. The degradation mechanisms can be subtle. It is therefore highly desirable that an ultrasonic meter be fitted with means to detect the onset of a degradation mechanism and to alert the user, allowing them to take appropriate action before the mechanism leads to a significant reduction in performance. In nuclear applications the provision of means for error detection is essential, since there is no prover by which the meter can be independently checked. The discussion that follows will focus on the degradation mechanisms and the means whereby Caudon nuclear flowmeters detect them. Outright failures of an ultrasonic meter (for example, a failed transducer or power supply) are generally readily detected and corrected.

What are the phenomena that can cause the accuracy of transit time UFM's to degrade? Fundamentally, the calibration of a chordal transit time UFM measuring volumetric flow is affected by (1) the hydraulics of the fluid system in which the meter is installed, (2) the geometry of the flow element—its dimensions and path angles, (3) the quality of the signals produced by the pulses whose transit times are measured, as detected by the instrument, and (4) the clock that is used to measure the transit times. Expanding on each of these topics:

2.1.1 Hydraulics

All flow meters are sensitive in one way or another to hydraulics. The calibration of external UFM's, turbine meters, and chordal UFM's are, to varying degrees, sensitive to the shape—the roundness or bluntness—of the axial velocity profile. Transverse velocity, particularly swirl, can affect flow nozzles and turbine meters and, to the extent that it projects onto the chordal paths, transverse velocity can also affect some chordal UFM's. Specifically, Goertler vortices—the two kidney shaped vortices that are formed downstream of a single bend that is preceded by a long upstream straight, can impact the calibration of a 4 path chordal UFM by several tenths of a percent. Local velocity patterns and the character of the turbulence can affect cross correlation meters, and in some circumstances, chordal ultrasonic meters as well. And fluid properties, most notably kinematic viscosity, can affect the shape of the axial velocity profile as well as phenomena such as boundary layer separation brought about by a flow disturbance. Viscosity also affects the propensity of the measured fluid to leak by the measuring mechanism of a mechanical meter—the turbine meter rotor or the pistons of a positive displacement meter.

The issues that must be faced in nuclear feedwater UFM's and that will have to be faced in using a large UFM for custody transfer without proving it in place are:

- How do you know that the offsite calibration data are applicable?
- How do you prove that to a skeptical customer?
- What is the uncertainty of the meter, as applied?

It is worth mentioning three other properties of the fluid that can impact the performance of UFM's in petroleum service:

- The presence of a significant fraction of water in the product,
- The presence of precipitated wax or asphaltenes in the product (which is usually crude oil in this case)
- The presence of Drag Reducing Agent (DRA) in the product

The first two can disrupt or otherwise degrade the transmission of ultrasound, sometimes causing the meter to stop functioning altogether but in other situations causing the meter's performance to degrade. Can these situations be reliably detected? Can one select an operational configuration for the meter that minimizes the impact of water and wax? DRA can dramatically alter the profile seen by the UFM; what is the effect on its calibration? A detailed discussion of these subjects is beyond the scope of this paper. However, it remains appropriate to ask: Can a UFM whose performance is degraded by one of these factors inform the user of that degradation in a way that allows him to take appropriate action?

2.1.2 Meter Dimensions

Chordal UFM's for nuclear feedwater service are calibrated in a certified calibration facility against a traceable standard. Hence errors made in the measurement of meter dimensions and path angles are embedded in the calibration coefficient and have no impact on the meter's accuracy in the field. However, the meter dimensions change in the field (because of the thermal expansion of the flow element) and, over the longer term, internal dimensions can change, due to the deposition of corrosion products on, or the erosion of the interior surface of the flow element. How does one account for these changes, and how accurate is that accounting? Similar problems apply to the use, without calibration of chordal UFM's in oil service. In this service, in addition to corrosion products, wax can alter the effective interior diameter of the flow element.

2.1.3 Signal Quality

The transit time UFM's of this paper determine the fluid velocity projected onto their chordal paths by measuring the times of flight of pulses of ultrasonic energy between the transducers that define each path¹. The repeatable and accurate detection of a received pulse is critical to the measurement of transit time, and good signal quality is essential to this process. Signal quality is determined by two properties of the received signals:

- (1) The reciprocity of the pulses traveling the chordal path in the upstream and downstream directions, and
- (2) The ratio of the signal as received to noise, both random and coherent.

Degradation of either these properties will lead to degradation in the accuracy and linearity of the UFM. Such errors will be present, to some degree, when the meter is calibrated, and again, when the meter is in the field, although in the field they will not, in general be of the same magnitude or sign as in the calibration lab. The errors must therefore be measured and accounted in both places, and for the nuclear feedwater application, assurance must be provided that they *remain* within the bounds assigned to them.

2.1.4 Clock Accuracy

In Caldon UFM's, transit times are measured by counting the pulses from a high frequency clock, for the duration of the pulse transit. Clearly wander in the clock frequency will lead to errors in the flow measurement. Accordingly, for nuclear feedwater flow measurements, Caldon includes an automatic clock confirmation, using an independent clock, and alerts the user, if the test fails.

¹ The principles of operation of Caldon's chordal flowmeters are described in a technical paper, TP-44, available on Caldon's website.

2.2 Large Meter Calibration Practices

For most nuclear feedwater installations the meter is calibrated in a model of the pipework. This hydraulic modeling is also usually extended to take into account possible variations that might occur in service, such as changes in upstream lineup, increased or decreased wall roughness, etc. Many of these pipe configurations are convoluted and similar to those in the oil industry, particularly off-shore. Figure 1 is photograph of a typical calibration test arrangement taken at Alden Research Labs in Worcester, Mass. The calibration test, in this case, is for one of four 18 inch meters that were later installed in a large Pressurized Water Reactor plant. The UFM flow element is in the foreground.

Calibration runs for a nuclear flow element are performed using a weigh tank as a standard with an uncertainty of about $\pm 0.1\%$. To obtain precision—that is, to reduce observational uncertainties due to random errors in the measurement equipment and the standard—multiple runs are performed over a range of flow rates, for each hydraulic configuration. Varying the flow rate in a specific hydraulic configuration allows the meter's sensitivity to Reynolds Number to be measured, independent of configuration. Testing the meter in multiple hydraulic configurations allows the meter's sensitivity to profile to be determined independent of Reynolds Number. As we have noted, the calibration of chordal UFM's depends on the shape of the axial velocity profile, which is determined not only by Reynolds Number but by the inertial effects of the upstream hydraulic configuration and by the relative roughness of the pipe wall.

Figure 1 Calibration of a Chordal UFM for Nuclear Service in a Full Scale Hydraulic Model

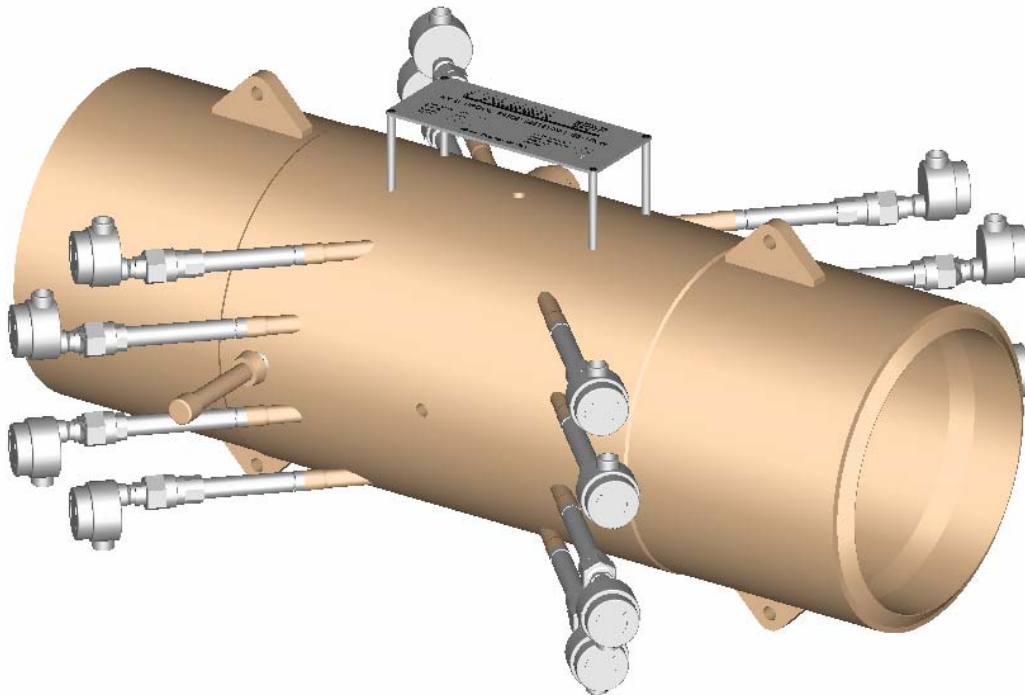


As was noted earlier, the calibration of 4 path chordal meters can be sensitive to transverse fluid velocity, since such velocity components can project onto the chordal paths. Transverse velocity components can change over time if, for example, they are brought about by the

distortion produced by a flow regulating valve. Changes in relative roughness can also produce changes in the magnitude of transverse velocity components.

To eliminate this sensitivity to transverse velocity, nuclear applications requiring the highest accuracy employ an 8-path arrangement, shown in Figure 2, below. The paths are arranged so as to form, effectively, two separate meters each having 4 paths lying in a plane, the two planes lying at plus and minus 45° with respect to the nominal flow axis. Each of the two meters numerically integrates the velocities projected onto its chords. The arrangement is such that transverse velocity components that project onto the chords of one of the two meters are effectively cancelled by the measurements of the second meter, while the axial velocity components reinforce each other. The 8 path arrangement also provides the robustness required of the nuclear measurement; the meter can tolerate any single failure and still deliver an accuracy close to what it delivers with all components operational.

Figure 2 8-Path Chordal UFM for Nuclear Service



The 8 path arrangement also delivers low and predictable sensitivity to changes in axial profile. Figure 3 shows calibration data for the meter of Figure 1 versus Reynolds Number, a hydraulic factor that can affect profile. Each point represents a collection of weigh tank (calibration) runs taken at a specific flow rate in a specific hydraulic configuration. The slide also shows the theoretical sensitivity between the UFM calibration and RN. The data essentially confirm that the sensitivity of this flow element to RN is consistent with theory.

The figure also shows the range of Reynolds Numbers seen by the flow element in the plant during power ascension after (the green bar bell). Note that there is overlap between the lab data and the plant data—with respect to Reynolds Number, extrapolation is not necessary. This is an issue with nuclear plants—the Reynolds Number at high power is typically 10 to 20 million, while the highest achievable Reynolds Number in a calibration lab is 3 to 4 million. But the large turndown of the chordal meter makes extrapolation unnecessary.

The axial profile, as it affects chordal meters, is best characterized by its flatness, which Caldon quantifies by the ratio of the axial velocities measured on the shorter (outside) chords of the UFM to the axial velocities measured on the longer (inside) chords. Figure 4 shows the calibration data of Figure 3 plotted against the flatness measured by the chordal meter. The data represent a wide range of hydraulic conditions. For this calibration series, the character of the axial and transverse velocity profiles seen by the flow element was varied by changing

the fraction of the total flow delivered by the three feeders to the header of Figure 1 and also by performing a set of calibration runs in straight pipe. Figure 4 also shows the theoretical relationship of calibration to flatness—the dotted line—as well the flatness encountered in the plant from 30% to 100% power. The response of this flow element to changes in flatness is, as with Reynolds Number, generally in accordance with theory. But, unlike the Reynolds Number case, extrapolation is required here, and the uncertainty of that extrapolation must be (and is) accounted in the overall uncertainty of the nuclear flow element.

Figure 3 Profile Factor Vs Reynolds Number

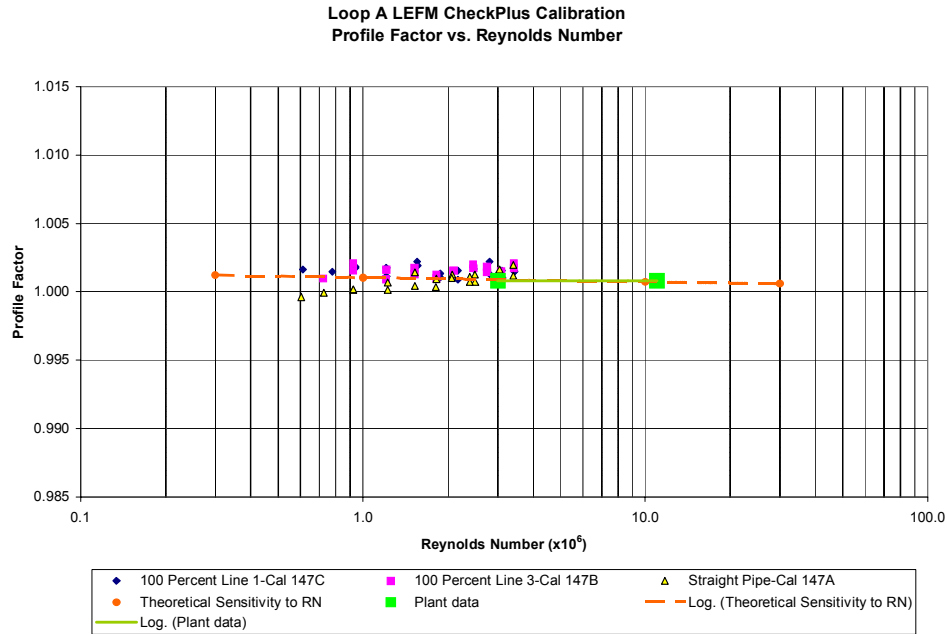
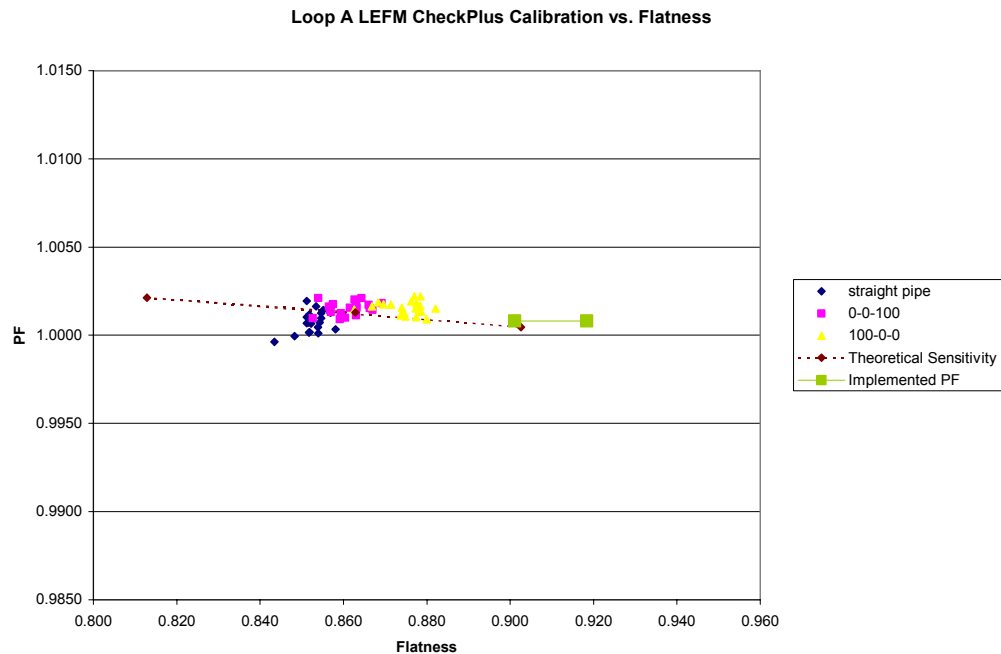


Figure 4 Calibration Vs Flatness



Can nuclear calibration practice be applied to large meters for petroleum service? We believe that it can. Specifically we believe that the accuracy of large weigh tank facilities like Alden Research Labs, with its ability to model complex fluid system configurations and to vary those configurations parametrically can deliver a chordal UFM whose accuracy in the field is in the 0.15 to 0.2% range. Perhaps as important, because the chordal meter provides information with which to characterize the axial and transverse velocity profiles that it is seeing, one is able, in the field, to *verify* that the calibration data are applicable.

3.0 DIAGNOSTICS

A listing of all of the diagnostics provided in Caldon nuclear or petroleum flowmeters is beyond the scope of this paper. What follows is a description of the features provided in nuclear meters that will detect the *gradual or subtle* degradation of meter performance—features that would be essential in a flow meter used for custody transfer of petroleum products without on site proving. Many of these features are available in Caldon's 4 path meters for petroleum service, but they have not been used, as of yet, to validate the use of the meter without proving.

3.1 Hydraulics

As stated in the preceding discussion, 8 path chordal flowmeters are insensitive to variations in transverse velocity components like swirl, but changes in the axial velocity profile can cause their calibrations to change incrementally. The meter's chordal arrangement allows a quantitative measurement of the axial profile—its flatness, as noted earlier, the ratio of the average axial velocity measured by the outside chords to the average axial velocity measured by the inside chords. In nuclear flowmeters, an alarm on flatness is provided. The alarm annunciates if the flatness varies more than a preset value (typically 0.05) from a setting established using its calibration data and data taken when the instrument is commissioned in the field. A variation in flatness of 0.05 translates to a change in meter factor of 0.1%. A change in flatness of 0.05 is unusual in nuclear service but such changes have infrequently been observed. Similar changes have been observed in the profiles of the crude oil in the Trans Alaska Pipeline—larger changes have occurred in this pipeline when a significant increase in the concentration of Drag Reducing Agent occurs. Tighter settings of the flatness alarm may be appropriate for petroleum service. Additionally, for multi-product service or where DRA may or may not be used, adjustable flatness alarm settings and meter factors may be appropriate. Conceptually, such features could be automated, but, with their current experience base, Caldon considers the risks of automated features to exceed their benefits.

3.2 Dimensions

The dimensions of flow elements in nuclear service do not change rapidly. Nevertheless the 8 path UFM's used in this service are provided with two features that allow the detection of dimensional changes, either by erosion or by the deposition of corrosion products.

(a) The fluid sound velocity is measured for each path, and compared with the average of the other paths. If the sound velocity for an individual path differs from the average by more than a preset amount, it can be indicative of a build up of corrosion products on the face of the transducer for that path. In petroleum service a change of this kind can also be indicative of wax deposition, which also affects signal/noise ratio (discussed below).

(b) Each flow element is provided with a circular machined "target" at the center its exterior surface. This target is used for periodic measurements of wall thickness, using an ultrasonic thickness gage. The user trends the thickness data, which allows him to detect a change that exceeds the allowance for such changes in the UFM's uncertainty budget. A similar feature would also be appropriate for a large UFM in custody transfer service.

3.3 Signal Quality

Accurate and reliable measurements of the transit times of pulses of ultrasonic energy are, of course, essential to the performance of a chordal UFM; high quality received signals are keys to accurate time measurements. Caldon nuclear UFM's measure the two principal mechanisms whereby signal quality can degrade: the magnitude of noise that is present when a pulse is detected and the absence of reciprocity in pulses traveling a chordal path in opposite directions. An individual pulse that fails to meet preset criteria for these mechanisms is rejected. An occasional substandard pulse can be tolerated but if the condition persists the accuracy of the overall flow computation can be compromised, and an annunciation informs the user. Conditions that are precursors to degradation of the detection process are also alerted. For example, the magnitude of the received signal is controlled by adjusting the gain of the receiver such that, when averaged over a few seconds, the pulse height is constant. This feature is not intended to keep up with pulse height variations due to turbulent scattering, but will keep up with pulse height variations due, for example, to changes in product viscosity or temperature, or due to changes in the transducer itself. If for example wax deposits gradually build up on the face of the transducer assembly, the amplitude of the ultrasonic signal will be reduced and a compensating increase in receiver gain will be required. At the outset, the signal to noise ratio of the received signal may meet specifications, but if the build up continues, eventually it will not. Accordingly an alert is provided when the gain of the receiver approaches the end of its range, or the SNR degrades to below the acceptable range. The presence of this alert, in addition to the other signal quality protective measures, assists the user in diagnosing failures, a subject that will be expanded upon in the next section.

3.4 Clock

As noted previously, in Caldon UFM's the accuracy of the transit time measuring clock is automatically checked against an independent clock, and if the check fails, the condition is annunciated. In the nuclear 8-path meter, two transit time clocks are provided, one for each measurement plane, so that, should one fail, operation can continue using the remaining four paths.

4.0 APPLICATION OF DIAGNOSTICS

The diagnostics provided with nuclear UFM's serve several functions for the user:

- Taken together, they are a comprehensive set of vital signs that allow the user at any given time confidently to prove that the meter is operating within its specified accuracy. In a petroleum application a hard copy of these data could constitute a record of meter performance when a batch is being delivered
- When trended over time, they permit the user to anticipate inadequate performance
- They can be used, separately or together, to troubleshoot problems that may arise in meter performance. In a petroleum application, problems can arise that were not foreseen when the meter was specified. For example, volatile high ends sometimes offgas from a crude oil when line pressure drops after pumps are turned off. Gas can collect in transducer apertures, degrading the transmission and reception of signals when the flow is stopped and for a short period after flow recommences. The signal quality diagnostics, provided for each path in each direction, will clearly identify problems of this kind.

The vital signs also provide a convenient means for government authorities and customers to audit the performance of the UFM. Records of the vital signs taken for a batch whose custody is being transferred, per item (a) above, and records of trends, per item (b) above constitute a paper trail whereby the user can demonstrate his diligence.

4.1 Diagnostics: a Case Study

The method currently used to deal with calibration uncertainties in large meters is to use the master meter method, whereby a second meter is placed in series with the main operational meter and used as a check meter for the operational meter. The case described below deals with a calibration problem in a 4 path meter that is illustrative of the benefits that would be obtained with an 8-path meter. It also illustrates the effective use of the diagnostics provided with chordal UFM's.

There was a shift in the calibration of the meter in question at start-up, which at the time was unexplained. Data logging of the meter diagnostics allowed the following analysis, and subsequent explanation of the changes.

Figure 5 shows the data. Startup occurs before the beginning of the time scale in the figure. The initial calibration value following startup (shown in red) was markedly different from the prior history of this meter. The figure shows a later shift in calibration coincident with a change in flow rate, when the meter factor (shown in blue) returns to a value consistent with prior history. The change appears to be a step. Something happened to change the calibration at startup; then a second thing happened to return it suddenly to its historical value. After reviewing the diagnostic data, the reason for the changes in calibration was found.

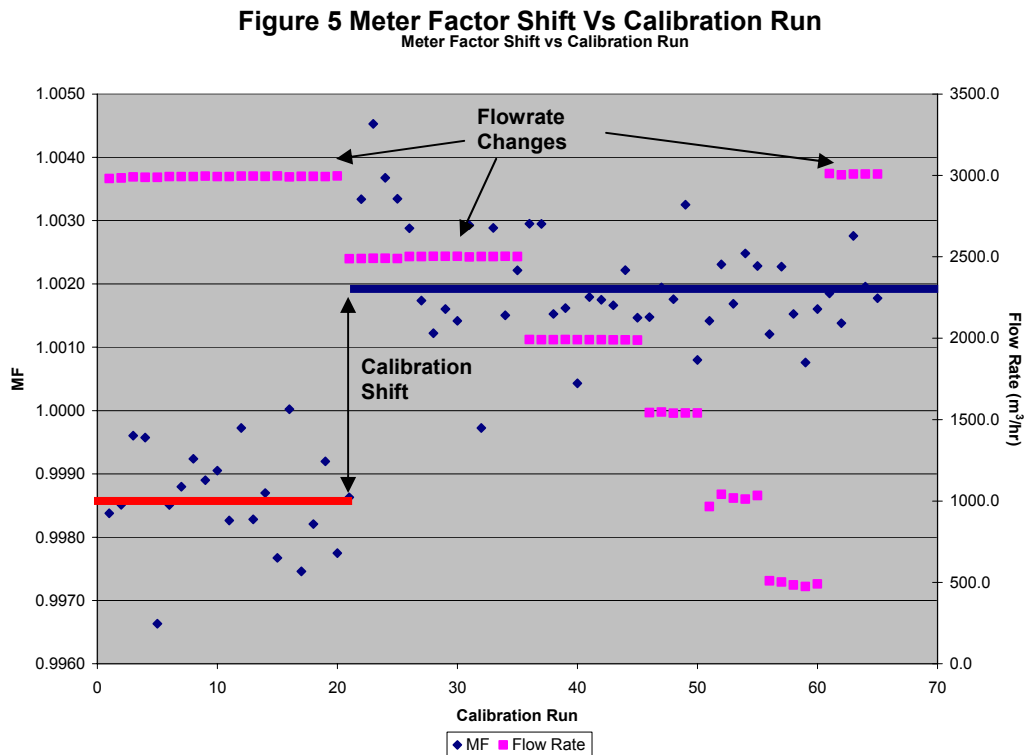
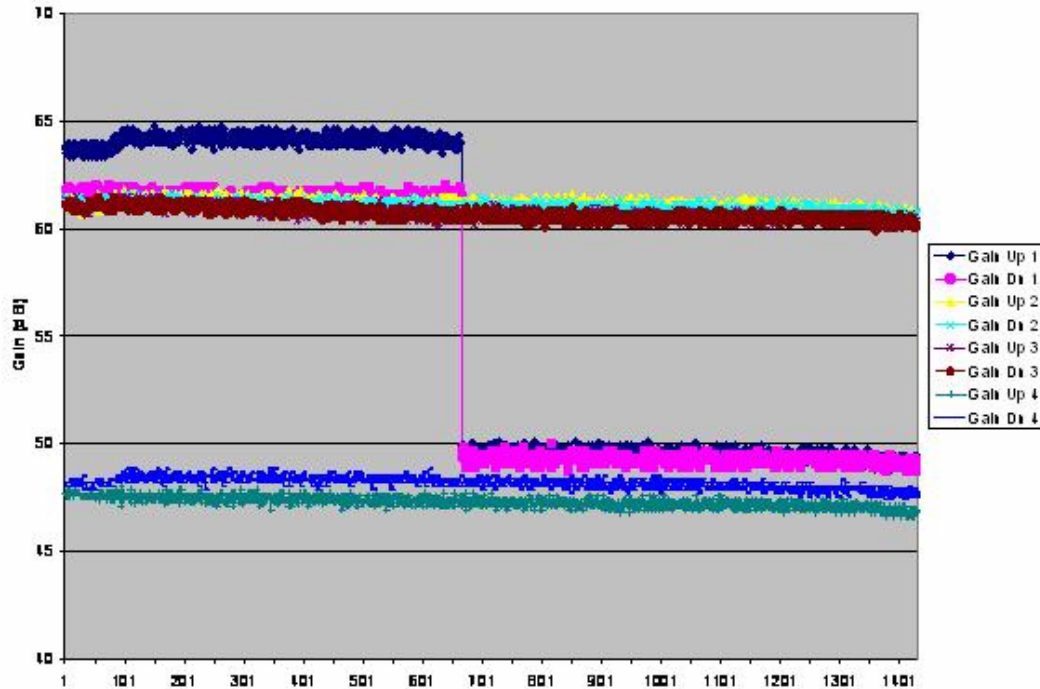


Figure 6 is the log of the Gain (electronic receiver sensitivity) in each direction for all of the chordal paths. The figure shows that, initially, the gain of the topmost chordal path (path 1) in both directions (up and down) is much higher than it is for both directions on path 4, a path of the same length as path 1 on the bottom side of the flow element. That in itself is not a necessarily a problem, but it does indicate something very different with the transducers, the fluid or the flow at chordal location 1 versus chordal location 4. Essentially something is making the automatic gain control drive the receiver harder for path 1. One must conclude that the received signal before amplification is much smaller on path 1 than it is on path 4. A further clue is the sudden change in receiver gains on Figure 6 at about 650 time units, when path 1 gains in both directions fall abruptly to values similar to path 4.

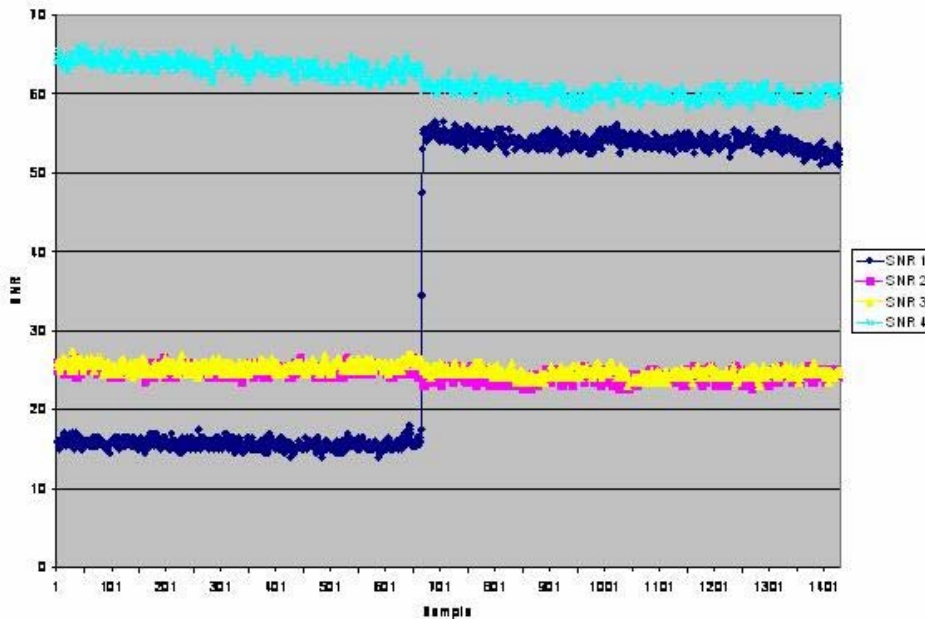
Thus we have unexplained gain shifts, the second of which is apparently correlated with flow rate shift.

Figure 6 Receiver Gains



A further clue as to the cause of the problem comes from reviewing the signal/noise ratio log. As shown in the average signal to noise ratio for the top path (Path 1) is significantly worse initially than the equivalent path (Path 4). Again there is a sudden improvement at 650 time units and the ratio improves to a value close to that of the bottom path.

Figure 7 Signal/Noise Ratio



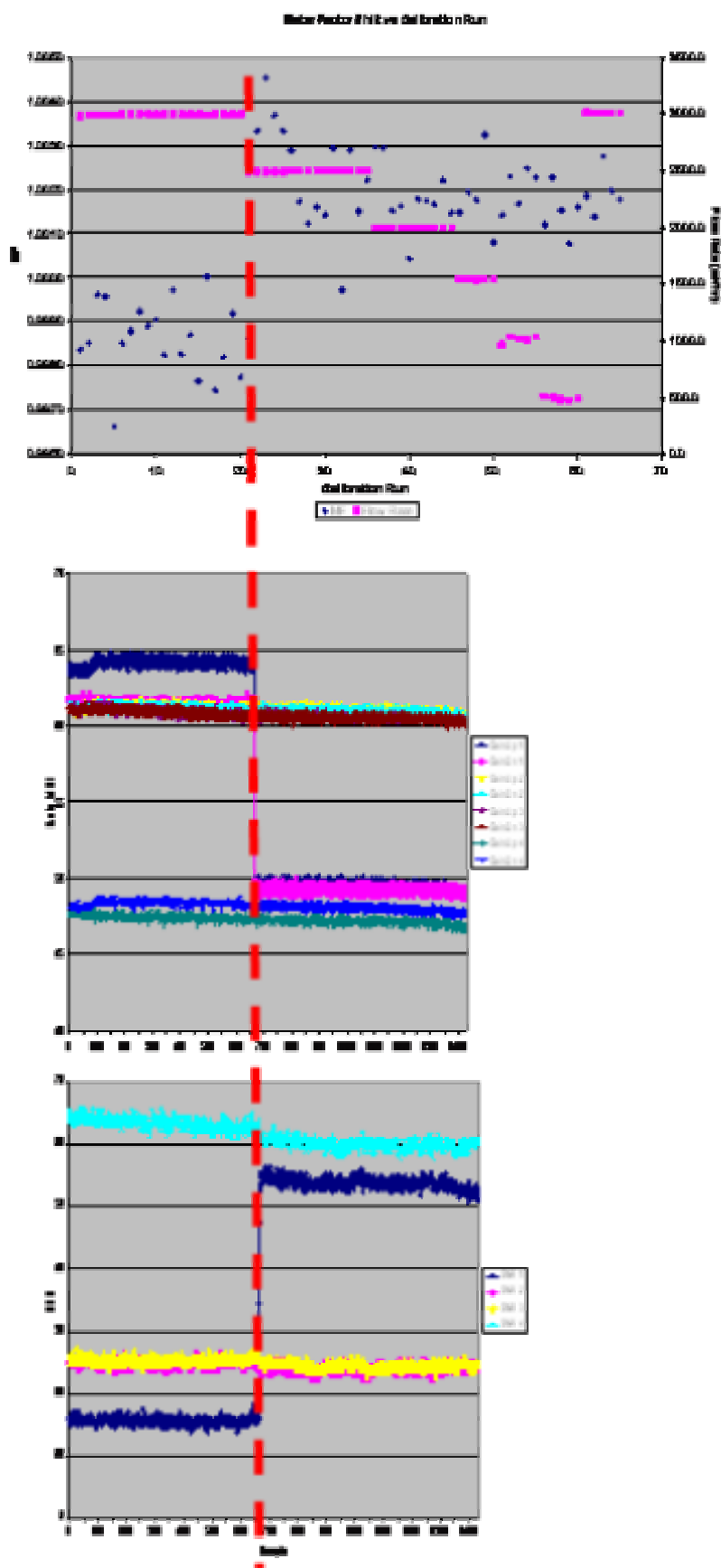
How does all this fit together? All of the diagnostic changes occur at the point of calibration change, and also at a flow rate change. This is shown clearly in Figure 8, with the three previous diagrams scaled to the same base scale. The red dotted line shows the point of all of the changes.

The cause of the problem now becomes clearer; something was causing problems with the upper path at start-up and then cleared itself. It could have been, for example, an intermittent electrical or mechanical connection, but a problem of this nature would almost certainly have reoccurred. Later tests showed no indications of reoccurrence. Furthermore, the meter had in no way been disturbed physically. So the explanation is more likely in the fluid.

Because the problem occurred in the uppermost path and because it occurred at start-up, the most likely explanation that fits all the data is that gas was trapped in one or both of the upper transducer apertures—the “pockets” created by the intersection of the bores for the transducer assemblies and the internal diameter of the flow element. Why did it go away? Simply, the flow rate reduction and the attendant reduction in pressure (Low pressure line) likely caused the bubble to enlarge and thus be swept of the pocket.

The troubleshooting of the problem described above involved the use of the diagnostics provided with a 4 path meter and also the use of a master meter. With an 8 path meter however the capability to carry out such investigations is enhanced, by the presence of a second plane of data. The additional data provided by the second plane provide the opportunity to detect the problem *without* the use of a master meter.

Figure 8 Full Sequence of Diagnostics



5.0 AUDITING OF CUSTODY TRANSFER ULTRASONIC METERS

Auditing is an essential feature of all custody transfer systems. It is normally a combination of a continuous health check of the meter and its associated systems, along with an attempt to determine the continuing stability of its calibration. The health check essentially confirms the functionality of the meter, and is dependent on the meter type. Different methods must therefore be used to determine the state of a meter, depending on what kind of a meter it is. In liquid measurement, the calibration stability is historically checked by using some form of on-line proving, which is only feasible up to a certain size, or meter capacity. Above such limits site calibration becomes increasingly a problem.

Because of the diagnostics described previously, auditing of multi-path UFM's is easier and more conclusive. If proving is unavailable, it is possible to review continuously the important performance parameters, including any significant flow profile changes, to give continuing confidence in the meter.

While continuous auditing is useful to the user, snapshot audits are often essential to satisfy second and third parties. Such audits impose a proper discipline on the user and his UFM and ensure that performance has been correctly validated using appropriate procedures—that there has been no relaxation in the quality of the metering system.

With a chordal UFM, all important aspects of the meter health and performance can be tracked throughout its history.

- At its calibration, whether at the factory or at a calibration facility, a performance template of the meter can be captured.
 - Such factors as signal to noise, receiver gains, data rejects, sample variations etc. give the health of the meter.
 - Also the factors, described previously, that define the flow profile can be recorded, to show the range of validity of the installation.
- When installed and commissioned, a new performance template can be taken and compared to the original. Any major variations, or out of tolerance will be resolved at this early stage.
- Continuous monitoring of the meter can be carried out.
- Regular snapshots, particularly at calibration times can also be taken and compared to the original performance templates.

This allows:

- The production of a definable audit trail for the meter.
- Control charts for important functions (For example those that indicate wax build-up).
- Identification of flow regime changes
 - Individual variations, such as slugs of water or oil composition.
 - Long term variations such as changes to the pipework internally.
 - Changes in the process, such as DRA variations or profile variations due to flow rate changes.
- The implementation of preventative and predictive maintenance regimes.

6.0 CONCLUSIONS

- Experience with very large (16 to 32 inch) 8 path (two plane) chordal UFM's in nuclear feedwater applications give promise to the use of meters of similar design in large-bore petroleum applications. The configuration, calibration practices, and diagnostics of the nuclear meters are such that their accuracy—typically better than 0.2%—can be confirmed on-line without proving. This capability would appear to have application in offshore petroleum installations, where space limitations often lead to complex hydraulic geometries and restrict the use of provers.
- Diagnostics can be used to improve confidence in the installed meter performance
- The extensive use of Diagnostics can help in the auditing process of Custody Transfer Ultrasonic Flow meters
- Caldon has fabricated two 10 inch 8 path meters in an explosion proof configuration suited to petroleum applications. These meters have been extensively tested in three different standard labs. Results will be described in a later paper. Suffice it to say that they show that the nuclear feedwater experience does indeed read across to petroleum flow measurement.

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.