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REAL LIFE ULTRASONIC FLOWMETER VERIFICATION FOR UPSTREAM CUSTODY TRANSFER METERING OF NATURAL GAS

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Abstract – Ultrasonic gas flowmeters (USM) employing multiple paths and transit time technology are becoming established in the upstream oil and gas industry for custody transfer flow measurement. This is mainly due to the advantages of wider flow range capability, and lower pressure loss over that of conventional differential pressure type flow meters such as orifice plates.

It is now more than a decade since ultrasonic meters were first applied to high accuracy gas flow metering, and standards and guidance documents have developed much in this time [1, 2]. However in the area of on-going measurement verification procedures, there is still minimal standardisation. Current standards provide guidance but leave ongoing verification procedures to the parties involved. Industry regulators such as government departments, pipeline operators etc require that flow measurements are verified on an ongoing basis to the required uncertainty levels.

This paper describes a custody transfer USM metering station (measurement uncertainty of ±1%) installed on the Petrojarl Banff an FPSO (Floating Production, Storage and Offload vessel). It describes the specifically developed verification techniques, and reviews verification data collected over 4 years of operation.

The verification procedures applied have been successful in satisfying the pipeline operator of the suitability of the ultrasonic metering station. It is proposed that the procedures described could form the basis for industry standard USM verification.

Keywords: Ultrasonic, Flow Measurement, Verification

1. INTRODUCTION

Gas ultrasonic flowmeters are becoming increasingly popular for high accuracy flow measurement. The main advantages over other meters are the low pressure drop across the meter and the large measureable flow range. This lessens the need for multiple metering streams which is particularly important on offshore installations where space is normally very limited.

However as with any custody transfer measurement interested parties such as industry regulators, pipeline operators and commercial partners require that the measurement system is suitable and verifiable. In this case, the permission of the pipeline operator, BP's Central Area Transmission System (CATs) had to be obtained before installing the ultrasonic meters. This required the operator to verify that the meters are operating to within the pipeline entry measurement uncertainty requirement of ± 1%.

However unlike orifice plates which have been the traditional measurement for natural gas custody transfer, USMs cannot be verified by a type test. The challenge to verify USMs is currently being met by a variety of techniques. These normally include one or two of the following; initial flow calibration, subsequent re-calibration, monitoring of meter diagnostic data and in-line verification with another installed meter [3, 4]. The metering station on the Petrojarl Banff is unusual in that it employs all these techniques. This paper describes the metering station and how the verification procedures ensure suitable measurement accuracy is maintained

2. METERING STATION DESIGN

The metering station incorporates two metering streams, each stream employs a 4"nb Instromet Q-Sonic 3S ultrasonic flowmeter [5], a temperature probe and pressure transmitter. A gas chromatograph common to the station is also installed. Observed volume, standard volume and mass flow rates are calculated using dedicated stream flow computers.

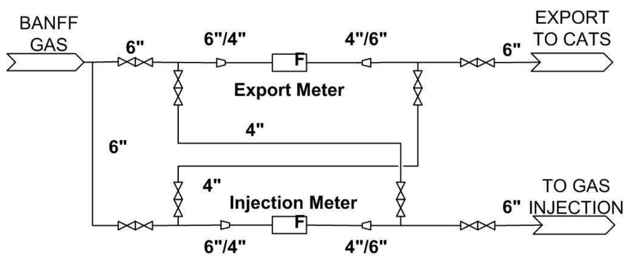

Fig. 1. Metering Station Schematic.

The meters are installed in a 'Z-arrangement' which has been utilised previously [3, 4]. The system allows for flexible operation, as the gas can be directed to either of two locations. It can be routed to the re-injection manifold where the gas is used to pressurise the field to improve field production, or it can be exported via a subsea pipeline and sold. It also offers the possibility of placing the two meters 'in-series' to allow in situ comparison.

A complete spare meter stream is also provided to allow either the export stream or the re-injection stream to be removed and sent for onshore re-calibration.

The flow meters are installed in the field with 21.8D of straight upstream pipework and 5.8D downstream, in keeping with the recommendations of BS 7965:2000 [1].

Fig. 2. Metering Station.

3. FLOWMETER VERIFICATION

The verification procedures are based on onshore laboratory calibration at agreed intervals, and in-service monitoring which includes series line checks and monitoring of the meters diagnostic data. The following describes these in detail.

3.1 Flow Laboratory Calibration

The primary means of verification is flow calibration at a traceable, accredited flow calibration laboratory. Prior to start-up and at regular intervals during their operation the export and injection meters have been flow calibrated at the National Standard of Germany for High Pressure Natural Gas, PIGSAR.

Fig. 3. Meter at Calibration Facility.

Re-calibration is important as experience has shown that meters can drift after a period in operation [6]. This is often attributed to build up of dirt on the pipe walls reducing the effective cross-section of the meter, dirt on the walls also affects the surface roughness which in turn can affect the flow profile 'seen' by the meter. Hence re-calibration is required to account for this drift.

Three meters were purchased to allow onshore calibrations whilst still maintaining full operational capability. Initially the pipeline operator required re-calibrations on a 3 monthly basis, however following the presentation of satisfactory meter verification data; this was extended to 6 months in September 2007.

The meters are calibrated with their upstream and downstream spools permanently attached to avoid any potential effect of misalignment between meter and pipe spool. The effect of misalignment was considered to be greater than normal due to the relatively small nominal bore of the meters (4"nb).

Calibrations are performed using natural gas at a nominal pressure of about 50 barg. The meters are calibrated at 6 nominal flow rates over a 30:1 turndown ratio. Each flow point comprised of the average of at least three test runs.

Meter diagnostics are recorded during the calibration; these are used to confirm the health of the meter and as a reference with which to check the meter once in-service.

Figures 4, 5 and 6 show the full calibration history of each meter.

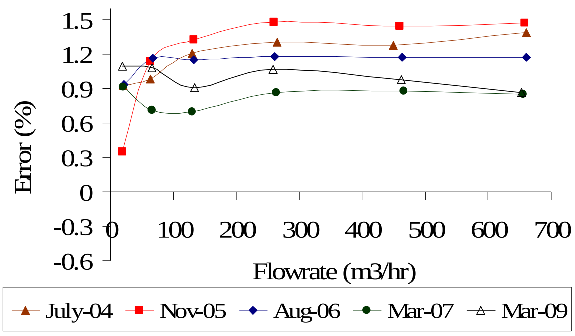

Fig. 4. Calibrations of Meter 2901.

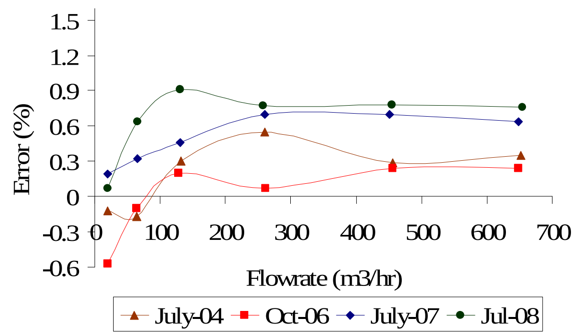

Fig. 5. Calibrations of Meter 2902.

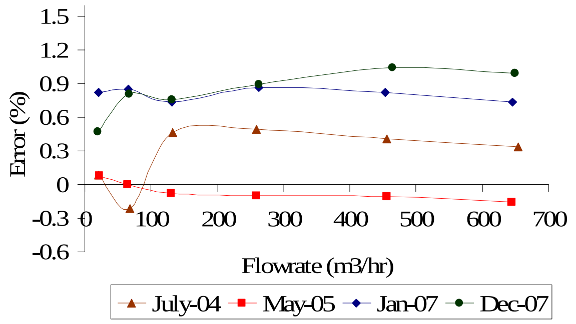

Fig. 6. Calibrations of Meter 2903.

The calibration results show meter errors of up to 1.5%. Uncorrected errors of this magnitude would be unacceptable in a system with an overall uncertainty budget of ±1%. Hence the errors are corrected by applying a linear interpolation correction function when the meters are in service.

The results also show shifts in meter performance over time. Figure 7 shows the flow weighted mean (FWM) error [1] for each calibration. Some shifts in meter performance can be explained by specific events in the meters life such as the replacement of damaged transducers which occurred twice on meter 2901 between its 2nd and 3rd calibrations and its 3rd and 4th calibrations, or the misalignment of the upstream spool observed in the 3rd calibration of meter 2903. Calibrations of identical meters which reflect the effect of in-service effects on the meter only are shown with solid connecting lines in figure 7.

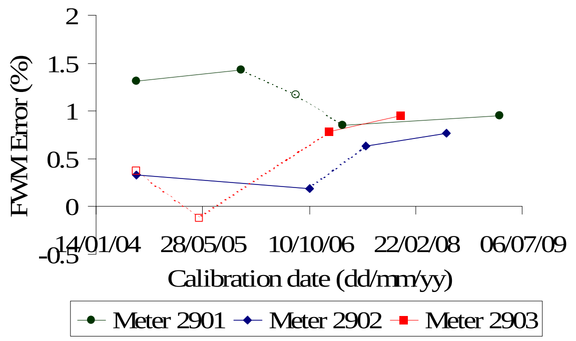

Fig. 7. Calibration FWM Errors.

Table 1 details the drifts observed, the maximum drift was 0.17% over periods of between 6 and 20 months in-service. Overall the calibrations show the meters to have a linear stable response. The meters are stable enough for the operational 6 month calibration interval. Further calibrations may allow the interval to be extended in the future.

The criteria for acceptance of ultrasonic meters are contained within the standards BS7965 [1] and AGA9 [2]. In particular with reference to these meters the criteria state that

> Small meter (< 12” NB) maximum error limit ±1% for flow rates of 10% of max and above.
>
> Maximum peak to peak error (difference between maximum error and minimum error) 0.7% for flow rates of 10% of max and above.

Strict adherence to these criteria would have resulted in rejection of all but one of meter 2901’s calibrations as the results were above the 1% maximum limit. Also the initial calibrations of meters 2902 and 2903 just exceeded the maximum peak to peak error of 0.7% for flow rates of 10% of max and above. However these meter calibrations were accepted for the following reasons.

Table 1 Meter Drift due to Operation In-Service

Meter (Period)	Installed (Months)	Use	Shift (%)
2901 (04-05)	12	Continuous	+0.12
2901 (07-09)	20	Infrequent 4m*, Continuous 16m	+0.10
2902 (04-06)	18	Infrequent	-0.15
2902 (07-08)	7	Infrequent	+0.13
2903 (06-07)	6	Continuous	+0.17

* split use

Although meter 2901 is out with the ±1% criterion, the linearity of the meter is excellent and the application of the linear interpolation correction provides a suitably accurate meter. For 2902 and 2903 the peak to peak failures were at the lower half of the flow range (i.e. out with the FPSO’s normal operating range) and in the experience of the authors, peak to peak errors exceeding 0.7% by small amounts are not uncommon in small bore ultrasonic flowmeters. It is interesting to note that the meters have met the 0.7% limit on all subsequent calibrations. Following the experience gained with these meters, it is the authors’ opinion that strict application of the criteria in AGA 9 and BS 7965 may be too onerous for small bore meters (4” nb for example) and a slight relaxation may be appropriate to avoid rejection of otherwise satisfactory and effective meters.

3.2 Series Line Checks

The metering station is designed to allow the injection and export meters to be lined up in-series. This enables the relative performance of the meters to be assessed during operation. The station is fully flexible; gas can be routed to the export pipeline or the injection system while operating in Series check mode.

Series line checks are performed on a weekly basis. Each test lasting one reporting hour. The accumulated mass totals for that hour are recorded and the discrepancy is calculated as in (1).

$$E = \frac{Total_{inj} - Total_{exp}}{Total_{inj}} .100 \quad (1)$$

Where

E Discrepancy (%)

$Total_{inj}$ Injection Stream, 1 hour mass total (tonnes)

$Total_{exp}$ Export Stream, 1 hour mass total (tonnes)

Comparison of the meters mass totals means that the stream pressure and temperature measurements, and the flow computer calculations are included in the check. The gas chromatographs are not verified in this check as they are common to both streams. The results are trended and limits which trigger further investigation have been set. The limits are any discrepancy greater than ±1% or any change in discrepancy greater than 0.3% which is not related to a change-out of a meter.

Due to operational requirements gas has almost exclusively been directed to the injection system. Hence the injection meter has been in operation almost continuously and the export meter has only been used infrequently during series line checks. This minimal use of the export meters has had the positive benefit of reducing the risk of common mode errors masking a shift in meter performance. Common mode refers to the phenomenon when making comparisons with equipment using similar technologies, that errors are mirrored and thus not observed in the comparison.

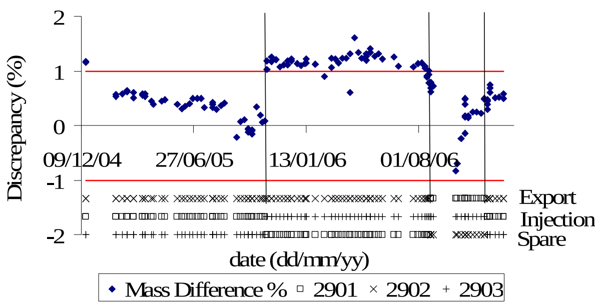

Fig. 8. Series line check results (Dec 04 – Dec 06).

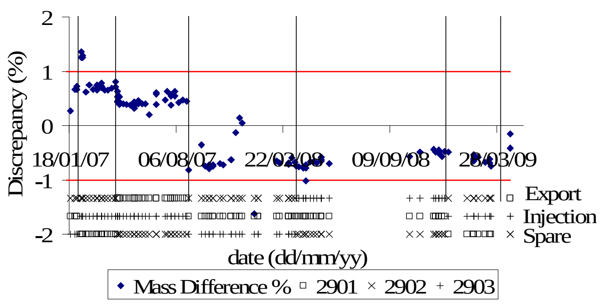

Fig. 9. Series line check results (Jan 07 – April 09).

Figures 8 and 9 show the history of series line checks. Overall the results are generally stable between meter change-outs, with distinct shifts at meter change-outs. It shows the majority of results to be within the ±1% action limits. Results out with the limits are nearly all in the period between Nov 2005 and Aug 2006. This corresponds to when meter 2903 was first installed. At the time the failures initiated a series of checks, including review of meter diagnostics, additional re-calibrations of pressure and temperature transmitters, and additional valve integrity checks, none of which identified a problem. The results returned to within limits at the following meter change-out. There is still debate as to the cause of these out of limit results; however this is beyond the scope of this paper.

The results also show a tendency for increased scatter and/or temporary excursions from the stable result following meter change-outs or shutdowns. The reasons for this are unclear, it may be due to initial liquid drop-out, the results stabilising once the liquid has dried out, however there is no evidence of this from the meter diagnostics.

3.3 Meter Diagnostic Data

Ultrasonic meters can report various diagnostic parameters which can assist in the early detection of meter faults. However these are currently not at the level where the actual measurement error can be quantified [7], this data is used in conjunction with the series line checks to provide enhanced in-service monitoring.

The meter diagnostics are normally logged on a weekly basis during the series line checks using the meter manufacturers utility / diagnostic software application UNIFORM. The logged data is averaged, trended and limits applied as defined by the meter manufacturer [8]. Any deviation out with these limits triggers further investigation. Table 2 details the monitored diagnostics and the action limits set.

Table 2 – Action Limits for Meter Diagnostics

Diagnostic	Action Limits [8]
Velocity of Sound (AGA-10 comparison)	±0.25 %
Velocity of Sound (VOS) Footprint	> 0.1% shift
VOS Footprint – (shift from Cal.)	> ±0.1%
Path Velocity Ratio (PVR)	<0.99 or > 1.07
Performance Level (all paths)	< 60% *1
Automatic Gain Control (AGC) ratio	< 1
Swirl Angle	> ± 20 deg

*1 for high flow rate operation

The overall velocity of sound as measured by the meter is compared to the value calculated from the live gas chromatograph composition using the equation of state described in AGA10 [9].

The velocity of sound (VOS) ratios are monitored, the ratio of one path's VOS to another, and one path to the average VOS are trended. A full set of ratios is known as the meter's VOS footprint. The footprints are monitored for relative change over time and against change from the footprint recorded during calibration. As the VOS footprint does vary slightly with flow rate, the calibration footprint used in this check is taken from the test point closest to the expected operational flow rate.

The path velocity ratio is the name given to the ratio of the gas velocities measured on the diameter path (2) to the average of the swirl paths (1 and 3). It can detect changes in the flow profile at the meter.

The performance level is the percentage of ultrasonic signals which are accepted by the meter's electronics in any one calculation cycle. This indicates if the meter is having difficulty in detecting the ultrasonic signal. Under normal circumstances the performance level should be greater than 90% however 60% is acceptable at higher flow rates.

Automatic gain control (AGC) is used by the meter to amplify the detected signal to a suitable level without over amplifying the background noise. The AGC ratio is related to the signal to noise ratio (SNR). The minimum limit is set to 1, this relates to a SNR much greater than 1.

Finally the swirl angle diagnostic monitors the difference in the gas velocities measured on the swirl paths (1 and 3), and converts this to an angle measurement. As the name suggests a larger swirl angle indicates a greater amount of swirl in the flow profile. Instromet advised that a swirl angle of less than 10 degrees would have no impact on the measurement, and that up to 20 degrees of swirl can be tolerated.

4. REAL LIFE METER FAULT

This section describes how a real metering fault was detected in-service using the series line check and meter diagnostics.

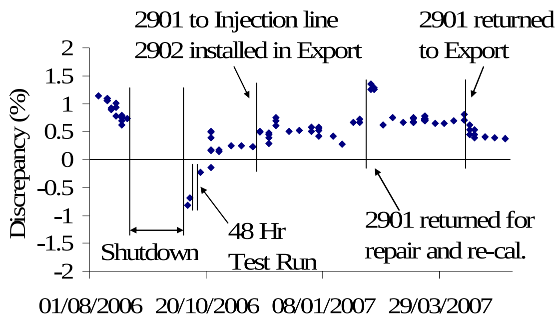

Fig. 10. Series line Check results.

Following a six week maintenance shutdown the injection metering stream was brought back online without any apparent incident. Immediately preceding the shut down the series checks had been returning discrepancies of about +0.7%, however following the shutdown the checks returned a -0.8% result. This 1.5% shift indicated that there may be a problem with one or both of the meters. A negative shift in series check results indicated that either the injection meter was under reading or export meter was over reading. Meter 2901 was in the export line and 2903 in the injection line. Figure 10 shows the series line check results over this period.

The large change in discrepancy prompted a review of both meters' diagnostics. Figures 11 and 12 show the velocity of sound foot prints for both meters with the series line check results overlaid. These show a significant change in the export meters velocity of sound (VOS) footprint (2901) following the shutdown. Whereas the injection meters footprint remained fairly constant. The alarm limit for changes in footprint recommended by [8] is 0.1%. The change in footprint registered by meter 2901 ranged from 0.04% for the path 3 to 2 ratio to 0.42% for the path 3 to 1 ratio. It was this variation in the footprint that pointed to the fault. The only ratio which had not shifted out with the 0.1% limit was the 3 to 2 path ratio. This indicated that the relative velocity of sound measured on paths 2 and 3 had not changed from prior to the shutdown, but that VOS measured on path 1 had changed with respect to paths 2 and 3. This suggested that the fault may lie on path 1 of the export meter (2901). None of the other monitored diagnostics for meter 2901 i.e. path velocity ratio, signal to noise ratio, or path performance were outside limits.

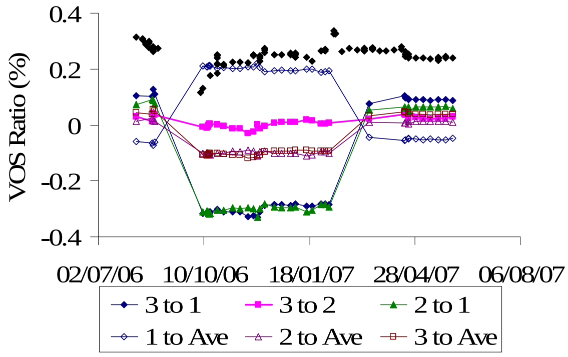

Fig. 11. Meter 2901 VOS Footprint.

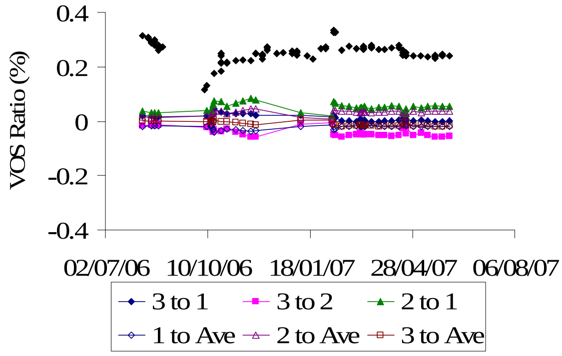

Fig. 12. Meter 2903 VOS Footprint.

At this stage it was thought that the meter may have been affected by contamination. The export meter had been lying depressurised for some time during the shut down and as the station had not exported after the start-up it had only been run for a few hours during the series line checks. It seemed credible that there might be some liquid or debris in the line, which might be affecting path 1. This seemed particularly plausible as path 1 has a transducer port located in the bottom half of the pipe. Hence it was decided to run the export meter for a prolonged period (48hrs) to see if this would clear the contamination and the fault. However although some improvement in the series checks was noticed; the shift in series checks reduced to about 0.5%, the change was still significant and export meter (2901) VOS footprint remained stable in its new state.

At this point meter 2901 was removed from the export stream as it was decided that it could not be relied upon to operate as a custody transfer meter. It was transferred to the injection line and the recently calibrated meter 2902 was installed in the export line. The VOS footprint on meter 2901 remained in its new state following the relocation of the meter.

The in-service monitoring concluded that the shift in series line checks was caused by a fault on path 1 of the original export meter 2901. Based on this conclusion meter

2901 was removed from service and returned to the manufacturer for investigation.

This investigation found that path 1 was indeed faulty, an initial check in a stable atmosphere found that the VOS on path 1 read 1m/s higher than of paths 2 or 3.

Figure 13 shows both path 1 transducers, on the left is the damaged transducer, its face has been dislodged slightly from the holder. The movement was very small, no more than about 1mm; however this shortening of the path length, increased the measured flow velocity on path 1. The series check results suggest that this fault resulted in a meter shift of +0.5%. The manufacturer indicated that this sort of damage may have been caused by rapid depressurisation of the metering run.

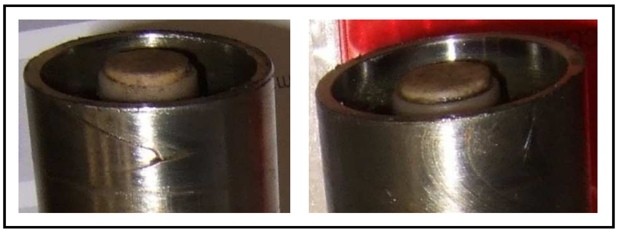

Fig. 13. Meter 2901 Path 1 Transducers, damaged transducer on the left.

Both path 1 transducers were replaced and the meter re-verified. Following re-calibration the meter re-entered service shortly afterwards.

This incident demonstrates how regular series line checks and diagnostics monitoring can quickly identify faulty meters, allowing remedial action to be taken to minimise any potential mismeasurement.

5. CONCLUSIONS

To summarise the following conclusions can be drawn:

Laboratory calibrations have demonstrated the meters capability for custody transfer measurement. The meters have shown good linearity across the flow range. Successive calibrations have shown that the meters response does drift slightly over time, though the shifts have not been excessive. Shifts have not exceeded 0.17% over periods of between 6 and 16 months in continuous operation. Recalibration has enabled this drift to be monitored allowing compensation to be applied. The magnitude of drift indicates that recalibration intervals of greater than the current 6 months may be acceptable. However this will require further extension to the meters recalibration history.

The experience of operating these meters has shown that the performance limits of current standards [1, 2] can be too restrictive for 4"nb meters, and if applied strictly might result in suitable meters being rejected.

Regular series line checks have shown the meters to agree within the acceptable flow rate limits of ±1% for most of period considered. Where this has not been the case meter diagnostics have been used to identify the meter at fault. Meter diagnostics are a powerful tool in ensuring acceptable meter performance between calibrations. This is a significant advantage over traditional orifice plate metering, where no such in-service monitoring exists.

The in-service monitoring of these meters during a fault condition indicates that a slight dislodging of one ultrasonic transducer resulted in a shift in meter performance, of +0.5%.

The verification system uses laboratory calibration to monitor and compensate for long term shifts in meter performance, and in-line series checks and meter diagnostics to monitor meter performance whilst in-service. The combination of these verification techniques has generated confidence in the operation of these meters which has satisfied the regulatory body, in this case the pipeline operator. It is proposed that these procedures could form the basis for industry standard USM verification.

ACKNOWLEDGMENTS

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