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North Sea FLOW Measurement Workshop

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Paper 2.3

Operating Gas Ultrasonic Meters After The Project Team Goes Home

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OPERATING GAS ULTRASONIC METERS AFTER THE PROJECT TEAM GOES HOME

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1 INTRODUCTION

This paper shares operational experiences and presents data from a variety of installations and operators throughout the world where multi path ultrasonic meters have been deployed. It compares operational data and results from these meters, shares some of the observations and discusses the use of control charts in an attempt to establish the bench mark values for the operational uses of these meters.

All data presented has been retrieved from operational meters and shall be presented blind for the purpose of confidentiality.

The paper contains two main sections; the first section is a discussion on the uses of the Speed of Sound data to provide a confidence level of the meter performance. It describes a simplified method of establishing a meter "Footprint". From the data base of information provided it sets out to demonstrate how the SOS has proven to be a key quantitative measurement of the meters continued performance. It also shows how this approach has identified a number of meters that, unknown to the operator, required corrective maintenance.

Section two looks at meter profiles and evaluates meter performance after installation. It shows a comparison of field data against bench mark data from wet calibrations the impact of the "Installation Effects" once the meters are in operation. Also this section discusses the potential impacts on the future design of the system installations identified by the study.

2 SPEED OF SOUND EVALUATION

Software packages from two of the leading manufacturers of gas ultrasonic meters provide a performance summary report for speed of sound (SOS). These reports contain information obtained directly from the meters by use of the vendor specific software packages.

Whilst the vendor specific software contains a multitude of valuable information the operational requirement is for a ***simple*** and ***easily interpreted*** method of analyzing the meters condition. This is necessary because specialist skill sets are often not readily available in the operational environment and specialist vendor support is high cost and often remote to the installation. Additionally there is the operational requirement for an "***Immediate***" diagnosis which is often not available and may be dependant on the vendor's response time to a request for assistance. Other considerations such as cost of such expert support etc. are not addressed in this paper.

Therefore the questions posed from an operational perspective are: -

Does the vendor report provide the operator with the desired confidence that the meters continue to provide him with good measurement?

Does it provide a **Go-No-Go; Pass-Fail**; type of analysis giving the operator an **imediate qualitative indicator**?

Are the skill sets required to provide this operational support for this technology readily achievable by multi tasked personnel such as offshore support staff?

If not is there an alternative method to achieve the operational requirement.

With these criteria in mind the raw data from the meters were evaluated with a view to providing the required solution. All the data used and presented in this paper was retrieved from the individual meters by the specific vendor software

Simplifying the interpretation of this data soon became a major goal as it was considered that the present vendor reports, while detailed and containing a multitude of good information, require expert analysis and interpretation of results and are therefore without specialist knowledge considered to be of little value to an operator.

2.1 Meter Speed Of Sound, Establishing The Footprint

Log files from a number of meters whilst at their wet calibrations where initially used to establish the base line values. A number of methods where tested against the previously defined criteria. As a result of this evaluation the chosen method of analysis is to plot the SOS along the Y axis by taking the measured speed of sound for the individual chords against the average SOS for all the chords. The advantage of this approach is in making the resultant values independent of the absolute value of the SOS.

It was found that by using this simple evaluation method the operator was provided with a meter SOS "Footprint" and a "control chart" method that is simple to create, simple to interpret and that can be used to evaluate the meter in operation. These methods were also considered of benefit because historically control charts have played a major role in custody transfer measurement and are therefore familiar tools to the industry.

From the evaluation of the log file data a number of characteristics for the SOS were noted that have not previously been presented and that could possibly be of value in developing the use of the SOS measurement for future. Extended use of the SOS for such purposes as density measurement considered by some as the Holy Grail of the USM.

The following section sets out to demonstrate both how the bench mark "footprint" was established and how the footprint of operational meters can be evaluated against this benchmark. The first operational meter contains over 18 month's of history. In all 19 data sets can be seen to display good repeatability and reproducibility whilst the actual range of the SOS was from 383 to 397 m/s. This data set was also used to establish the control limits for the "SOS control chart" The recommended value is a ± 0.1% tolerance level.

The initial data was taken from a four path meter constructed to the British gas design.

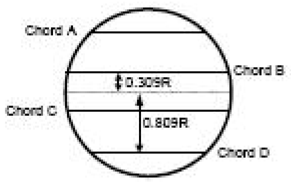

Fig. 1 – 4 Path Chordal Meter

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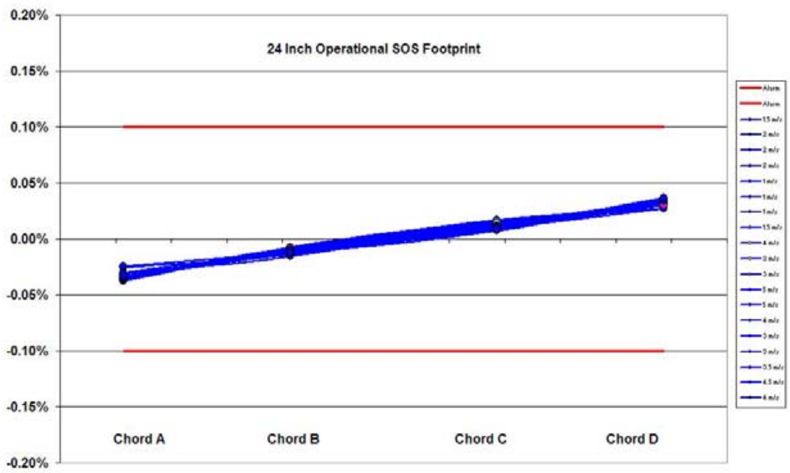

Fig. 2 – SOS Benchmark

The positive incline in SOS footprint is to be noted. This was a characteristic found to be common to a majority of the data sets, it is however beyond the scope of this paper to discuss this phenomenon but it is presently assumed to be due to gravitational effects on a horizontal meter stream. The D chord, being the lower of the chords, is shown to report the faster SOS associated with a "heavier" gas.

2.2 Evaluating the Bench Mark

The meter in Fig 2 was one of a pair of meters. The meters have been installed in, what for Asia Pacific, has become the classical "Z" configuration. This configuration is being chosen to allow the two meters to be placed in series and allowing comparisons of meter volumes to be made in what is known as a "Serial Check".

When the footprint of the twin was plotted in the same manner as the benchmark meters we note some interesting detail.

Over the same history period as the benchmark meter this meter exhibits three distinct footprints.

It has been possible to identify the reasons for each of the changes in the meter SOS footprint by investigating the meter history.

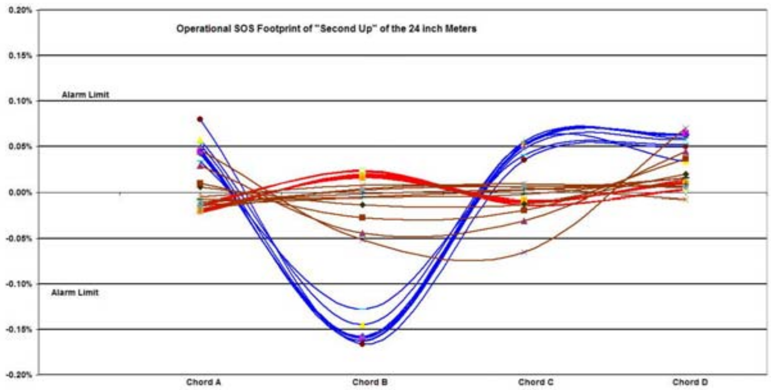

Fig. 3 – Operational Meter Twin

- At Calibration
- After Installation
- After Repair

The data from this 24 inch meter provides us with a good evaluation of the SOS control chart. The first footprint is from the actual wet calibration and the characteristic bending of the footprint as velocity increases will be discussed later in the paper. The "after repair" footprint is shown to be in line with the expectations from the bench mark data.

Whilst the after installation data indicates a deviation for the B chord outside of the tolerance limit.

The root cause of this error was identified as a polarity change in a single B chord transducer's wiring. This occurred at some time between the wet calibration and the site installation. The change of polarity results in a phase reversal at one of the transducers.

The impact of this phase reversal was to take the SOS control chart outside of the 0.1% control limits. The following is an analysis of this observation.

The speed of sound calculation being the well published equation: -

(1) $$t_1 = \frac{L}{C_i + V\,{}^{x}\!/_{L}} \quad and\; t_2 = \frac{L}{C_i - V\,{}^{x}\!/_{L}} \quad giving\; C_i = \frac{L}{2}\frac{(t_2 + t_1)}{t_2 t_1}$$

C = speed of sound
L = distance between transducers
X = axial distance in the flow
t_1 t_2 = transit times

By assuming that the change noted in the B chord does not reflect a true measurement of the speed of sound and that the physical length of the transducers cannot change then something had resulted in an increase in the transit time measurement. In this instance the magnitude of change to the path length would evaluate to a 0.2% change in Chord length or a virtual increase of 0.00167 meters.

By inference a length change would impact the measured velocity of this chord and therefore the overall measured velocity of the meter.

By substituting the new length the impact in this case was that the "B" chords under measures the velocity by 0.4%

0.4% being the magnitude of error if such a fault was present in a single path meter.

For the four path the chords are weighted so evaluating the error, in this instance the observed error would equate to an under reading of 0.14% in average velocity.

The difference in the third "SOS Footprint" from the calibration data is explained by the following.

During initial investigations the B transducer pair was assumed to be faulty and replaced. This action did not fix the fault however it did alter the meter footprint away from its original. Whilst the repair can be seen to bring the meter back into the bounds of the control limits it is clearly seen to have changed the footprint from the original at time of calibration. Therefore changing a transducer pair can be seen to change the meter footprint and the magnitude of the change can be quantified.

2.3 Observations on "The Velocity Effect"

A phenomenon was noted that is considered worthy of a future detailed study.

The SOS footprint can be seen to change in direct relationship to the velocity through the meter this section of the paper discusses the findings and assesses the impact. Apart from the direct impact on the actual measured value of the SOS and meter velocity it raise questions around the use of such meters at extended ranges above the "wet" calibrated range of the meter. The data from the four chordal path meters has been most helpful in highlighting this velocity effect. However this effect is common to all ultrasonic flow meters the use of multiple centreline chords would not visualise this phenomenon. The effect whilst present would be similar on all chords and therefore would be masked.

It is hypothesised that the result of the velocity effect is to introduce a "Virtual Path Length" increase L' into the meter. From the evaluation of the available data this effect is seen to become dominant above a velocity of 8 m/s. below this velocity "local effects" such as local port effects are seen to be dominant.

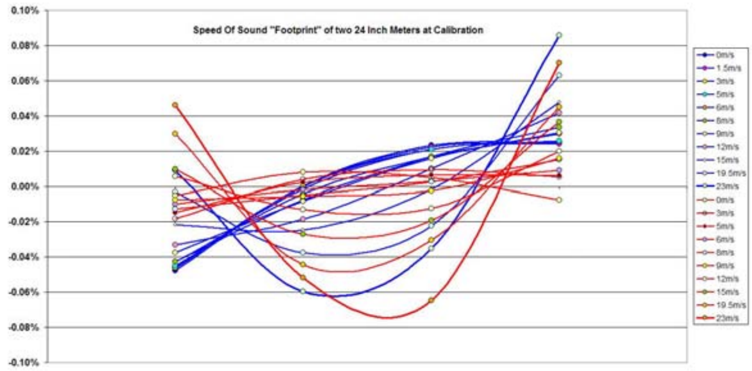

Fig. 4 – Velocity Effect Demonstrated

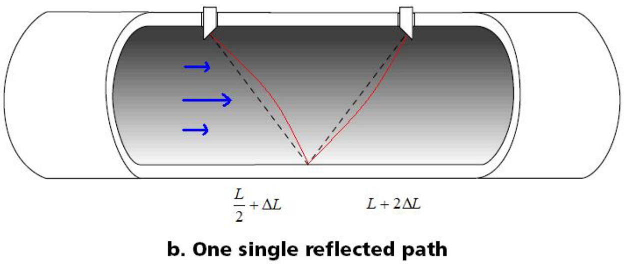

Fig. 5 – Velocity Effect "Virtual Path Length L' "

The following series of graphs demonstrate the characteristics of the velocity effect.

The first graph is a direct plot of the raw SOS against velocity. A stable region covering a velocity range of approximately 5 to 12 m/s before the velocity effect becomes dominant has been previously observed by CEESI during their calibrations and this region was christened as the "Sweet Spot" in a recent presentation.

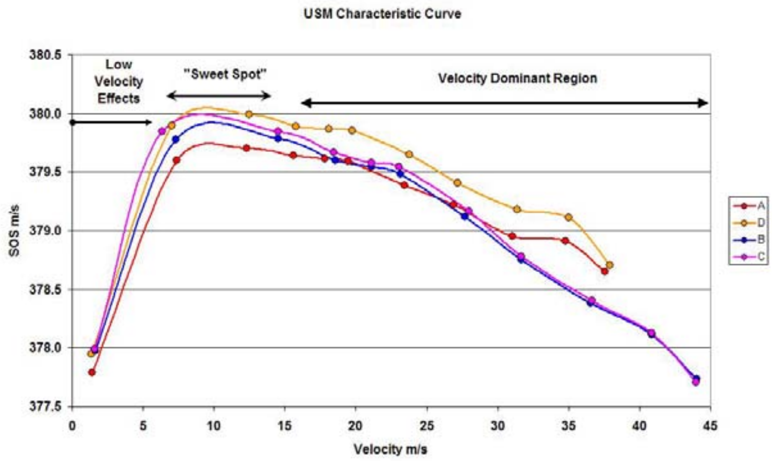

Fig. 6 – 16 inch 60 Deg Meter (Raw SOS)

The measured SOS is seen to decrease as the velocity increases, whilst the positive slope of the SOS in the vertical plane of the pipe remains evident by the higher measurements recorded by the D chord.

By evaluation of the data a clear relationships became evident between the virtual increase in path length and the certified path length. This can be plotted as a change in path angle in relationship to velocity and demonstrated to have a direct relationship to the path length and to be independent of path angle. The data from two 24 inch 45°, one 20 inch 60° and two 16 inch 60° meters is presented bellow.

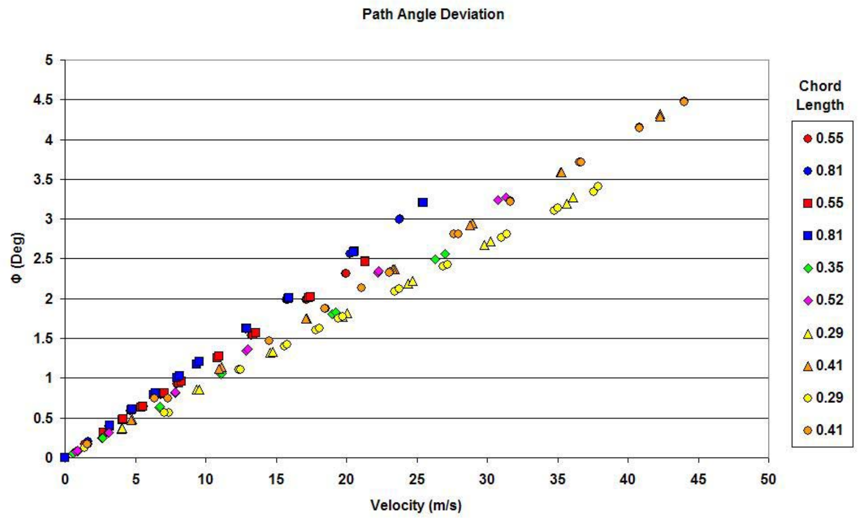

Fig. 7 – Path Angle and Velocity

From this data a Cos(Φ) relationship provides a correction factor that may be applied to the measured SOS

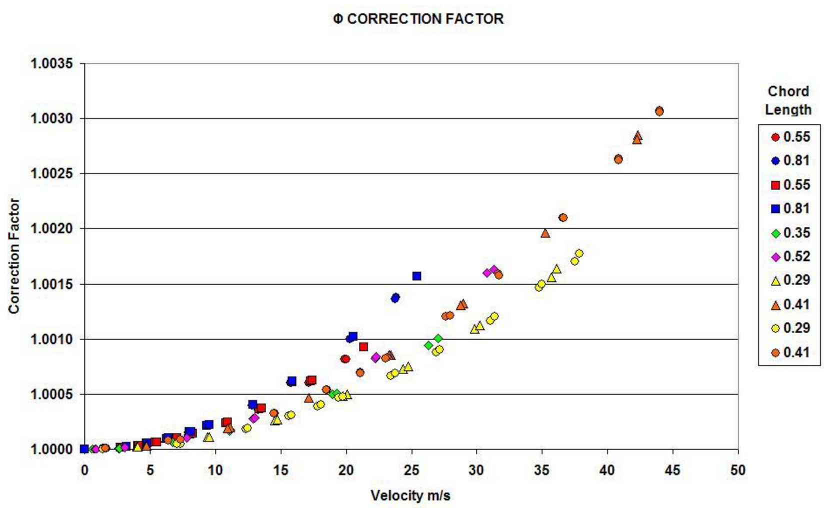

Fig. 8 – cos(Φ) Correction Factor to path length

The following graph shows a comparison between the raw SOS measured by the meter, the corrected SOS from the manufacturers PAF equation and the result of applying the virtual path length correction. Cos(Φ).

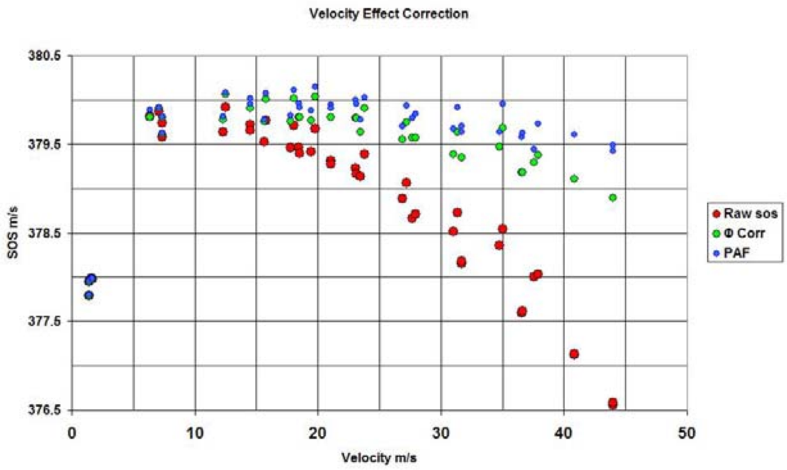

Fig. 9 – Correction for Velocity Effect

The velocity correction factor that this meter manufacturer now applies in the Mkiii electronics under the name of a "Port Angle Factor" is given as: -

$$PortAngleFactor = \left(1 + \left[0.5 \times \left(\frac{V_{chord}{}^{2}}{C_{chordClasic}{}^{2}}\right) \times \left(\frac{X_{chord}{}^{2}}{L_{chord}{}^{2}}\right) \times \tan^{2}\left(60^{o}\right)\right]\right)$$

Fig. 10 – Port Angle Factor

The Cos(Φ) relationship is based on the relationship of : -

$$t_1 = \frac{t_{us} \cdot t_{ds}}{t_{us} + t_{ds}} \cdot 2 \qquad \text{And} \qquad t_{mid} := \frac{t_{us} + t_{ds}}{2} \qquad \text{Giving} \qquad \theta = \operatorname{acos}\left(\frac{t_1}{t_{mid}}\right)$$

i.e. That the effect of the velocity on the Down to Up transmission is not equal and opposite to the Up stream to Downstream transmission

Using this relationship the corrected path length may then be calculated and used to calculate a corrected SOS and a corrected value for the X parameter and therefore a corrected velocity and a corrected Volume.

NOTE: - The difference between the PAF calculation and the Cos(Φ) results are that the PAF calculation assumes that the path angle is exactly 60° whilst the Cos(Φ) method calculates the true angle. In addition the PAF is only applied to the SOS and the velocity effect on the meters measured velocity is then corrected by the meter factor. Therefore consideration should be given to the application of this correction factor to the meter in completeness.

2.4 SOS Foot Printing Of Other Configurations

The Double Cross Meter

The method was then reviewed for other meter configurations, the first alternative configuration was the "Double Cross" meter.

From the experience gained on the four path chordal meter the paths of the double cross meter were analysed as pairs, the upper and the lower pairs being plotted separately.

This evaluation also demonstrates the gradient in the SOS previously observed in the four path chordal meter. The lower pair of transducers, plotted with a dotted line generally showing a higher SOS value.

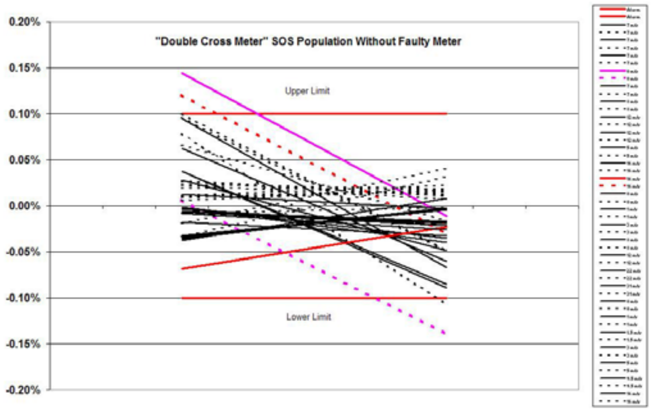

Fig. 11 – Double Cross SOS Population 2

The plot of the remaining meters identified a further meter that required investigation.
The slopes associated with the pairs of transducers are considered to be representative of the uncertainties associated with measurement of path length. Worthy of note is a statement from the manufacturer of these meters that "No adjustment to the path length is made if disagreement is found records of CMM measurements are checked to find any error in determining path length (no "acoustic tuning" used)" It is the authors opinion that this may possibly be an area for review as our knowledge of these meters increases.

The Three Path Meter

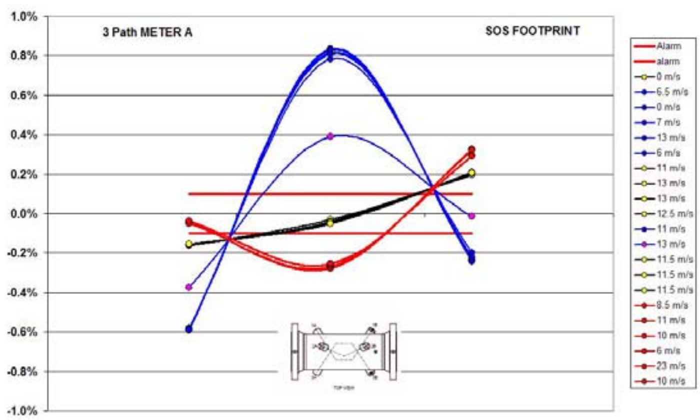

Fig. 12 – Three Path SOS Footprint

The Data provided for these meters is presented without detailed explanation however the effectiveness and ability of the SOS Footprint control chart to identify meter problems in this type of meter is clearly demonstrated.

For example the step change in the second meters footprint [Fig 11] can be identified as to have occurred between the meter leaving the re-calibration centre and it being re-installation at site.

The Five Path Meter

The five path meter has a complex path structure made up of three centreline measurement paths and two double bounce swirl paths. The three measurement paths all pass through the meter centreline with a single bounce and therefore all three chords will be equally affected by the velocity effect. Any variation in the measured SOS between these three paths will be a direct representation of the uncertainty in measurement of the true path length. The swirl paths pass between the pipe wall and 0.5r three times.

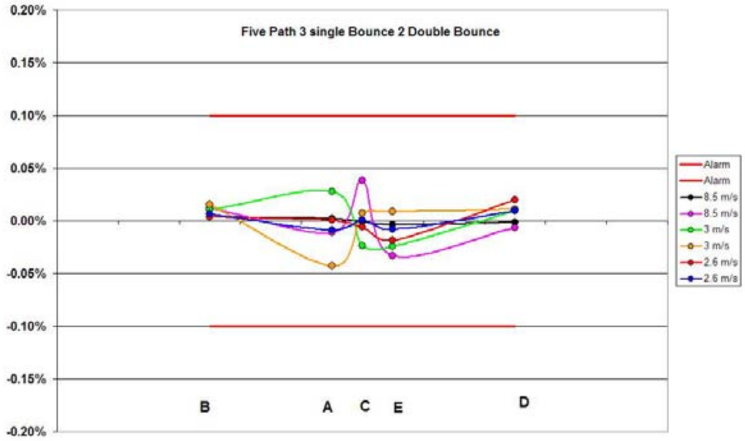

Fig. 13 – Five Path SOS Footprint

Two Path Single Bounce Meter

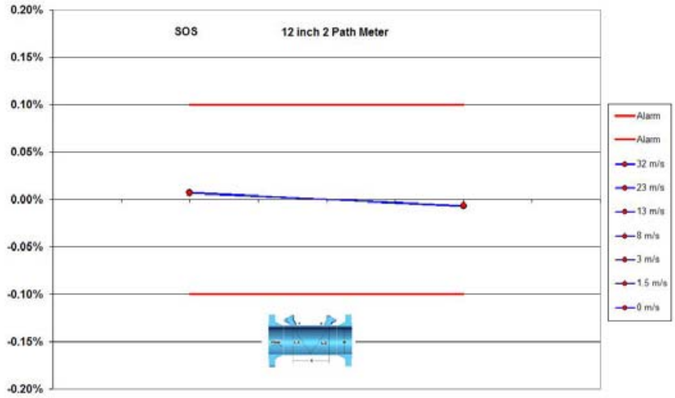

Fig. 14 – Two Path Single Bounce SOS Footprint

3 PROFILE EVALUATION

The software packages from the two leading manufacturers of gas ultrasonic meters provide a performance summary report containing information directly obtained from the meters.

Flow profile data is limited from the 3 “single bounce centreline” meter as theoretically in a good profile all chords should demonstrate the same velocity therefore a profile factor only is provided.

Evaluation of flow profile is a complicated topic and outside the scope or intention of this paper. However it was thought necessary for an operator to have some method of evaluation for the meter profile. Thus providing a degree of confidence in the meter installation and it's continued satisfactory operation.

It was found that due to the different methodologies used in the meters the methods required to provide an analysis are quite different for diferent types of meter. The first meter dealt with is the four chordal path meter and again log files taken at a time of calibration were found useful in establishing the baselines.

3.1 Flow Profile

Based on the data gathered the required profile is best represented by what is known as the *1/7th Power Law.* This estimates the meter velocity in fully developed turbulent flow.

There is no theory, just experimental results. To a good approximation the velocity distribution in the pipe is given by:
u = average velocity at a point a distance *y from the wall*
$u1$ = centre line velocity
a = pipe radius
y = a - r

$$\frac{u}{u1} = \left(\frac{y}{a}\right)^{1/7}$$

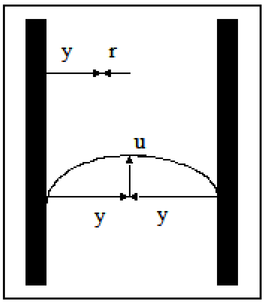

Fig. 15 – 1/7th Power Law

Because of the shear force near the pipe wall, a boundary layer forms on the inside surface and occupies a large portion of the flow area as the distance downstream from the pipe entrance increase. At some value of this distance the boundary layer fills the flow area. The velocity profile becomes independent of the axis in the direction of flow, and the flow is said to be **fully developed**

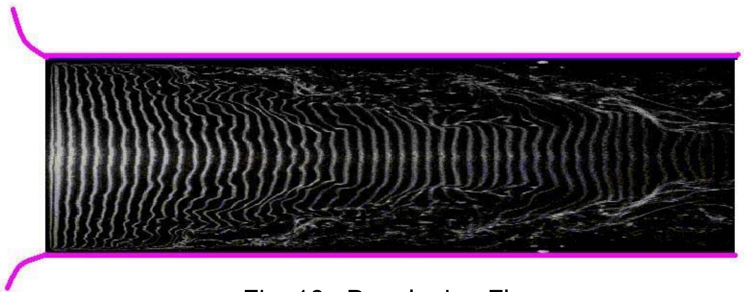

Fig. 16– Developing Flow

Ref [2].

Using this approximation and taking the position of the chords in the meter the calculated velocities at each chord with relation to the average pipe velocity calculates out to be 9.16% for Chords B&C and –9.16% for Chords A&D. How is this in comparison to practical results? The first set of results plotted are from a wet calibration were the assumption is made that the flow profile presented to the meter would be considered good.

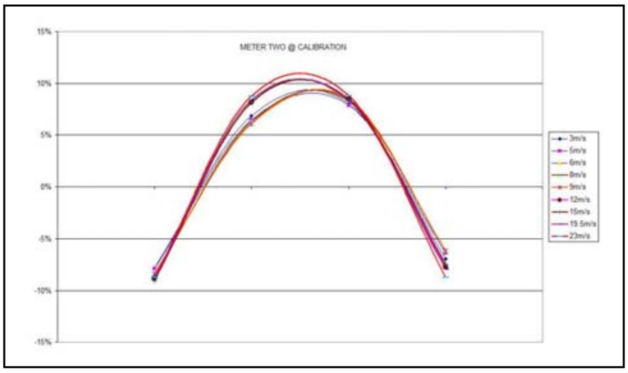

Fig. 17 – Flow Profile of two meters @ Cal

From the plot of the raw meter data a good fit between the theoretical and practical results for a meter operating in fully developed turbulent flow would appear to have been achieved.

Having established a base line we are now in a position to evaluate our control chart against some operational meters.

3.2 "Z" Configuration with Up and Over Cross Connector

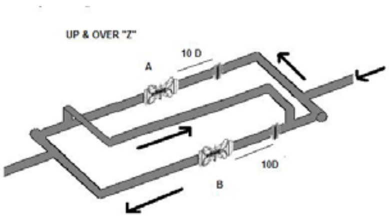

Fig. 18 – "Z" Configuration

The operator of these meters has the meters continuously in the series mode and the flow profile of the first-up meter is shown below to demonstrate a classical profile.

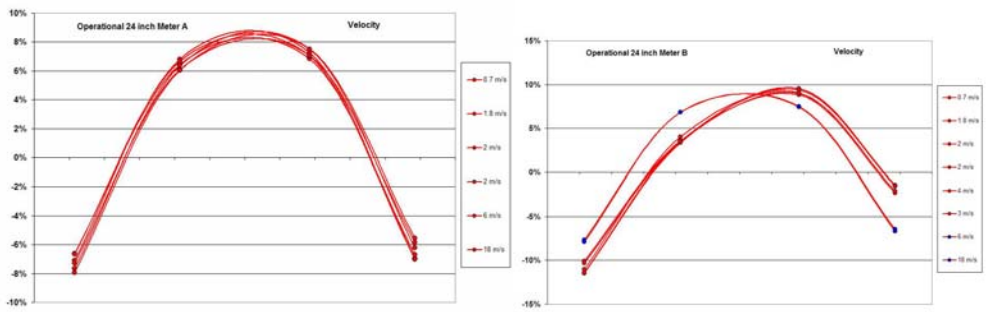

Fig. 19 – Meter A & B Profile

However the second-up meter provided some unexpected characteristics.

These meters were also analyzed by the methods described in : - Ref [2]. Supporting the presence of asymmetrical flow in the second-up meter whilst suggesting swirl is not present presumably having been removed by the profilers. The two distinct profiles are from the two possible modes for this meter, stand alone and in series where the crossover pipe work comes into play..

The question now raised is what impact this could be having on the meter accuracy or performance. To help provide an answer to this question we can look to the series check data for these meters.

There are two schools of thought for series checking, continuous and occasional. It is not in the scope of this paper to discus the merits or draw backs of each of these options but data is presented from operators utilizing both methods.

In this instance the continuous method has been chosen by the operator to provide him with continuous feedback of his systems performance.

From the data it is suggested that the control limits for serial testing of gross volume should be set at 0.15% for the warning level and 0.25% as the action level.

With continuous monitoring the added benefit of the control chart, shown below, is that it can be seen to identify a number of mis-measurement instances allowing corrections to be made without undue delay to the reported quantities.

From this data the performance of the meters appears not to be impacted greatly by the asymmetrical flow profile this would support the meters ability to perform well even in certain none ideal flow patterns.

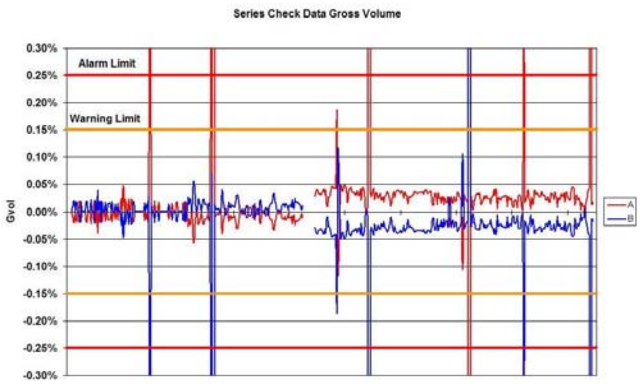

Fig. 20 – Series Check Results

3.3 "Z" Confi

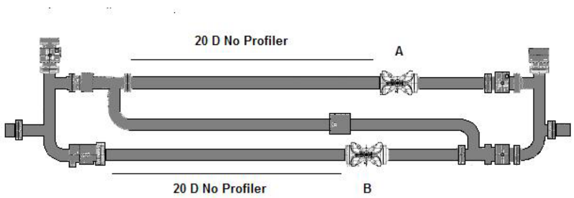

Fig. 21 – "Z" Configuration -1

This 24inch metering skid was designed with the option to add a third metering stream at a later date. The result was that the approach to the first-up meter B was via a "T" and a bend and to meter A via two "T"s All pipe work being of the same schedule i.e no increase in diameter at the inlet or outlet header.

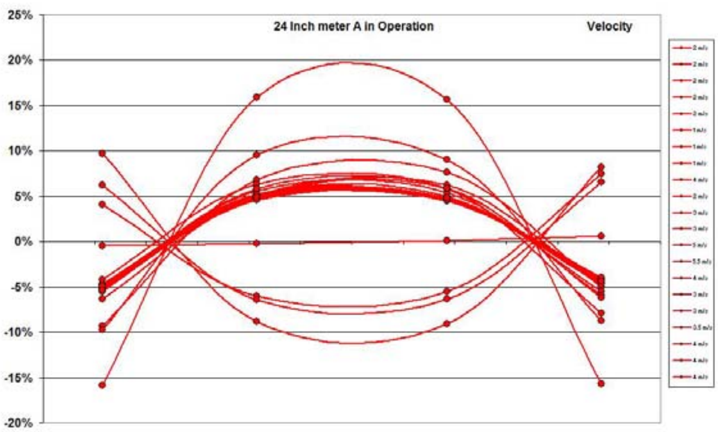

Fig. 22 – Flow Profile 24 inch Meter A

The charting of this system in operation shows an unstable profile that is far different from the profile at the time of calibration. The problematic component is presently understood to be that of swirl which is being introduced by the upstream process.

From the calibration data it is demonstrated that the profile presented by the calibration facility to both the meters was consistent with the theoretical profile. i.e. in line with the expected profile calculated from the 1/7th Power Law

The operator of this system has chosen to carry out occasional series checks and as such only limited data is available. However from this data set, the value of continuously monitoring the series test results can be demonstrated. Again the method chosen for tracking the series check data is that of a control chart.

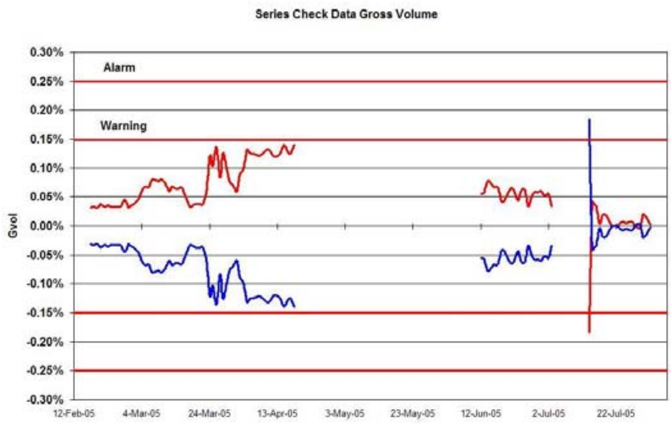

Fig. 23 – Series Check Control Chart

3.4 "Z" Configuration With in Plane Cross Connector (Variation 2)

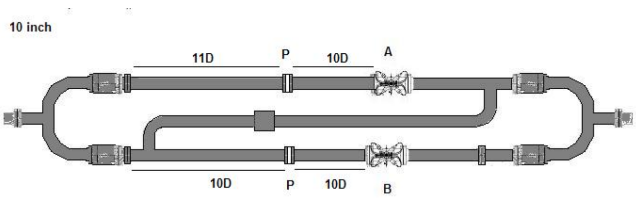

Fig. 24 – "Z" Configuration -2

This configuration would on first impressions fit the present "recommended design" criteria. The approach pipe work however is of a curved construction and is of the same diameter as the main pipe work. It is therefore considered that this cannot qualify as being termed a metering header. Something that should be given consideration in future designs. The following profile data is considered to provided support of this opinion.

Whilst the flow profile plates appear to be effectively removing the swirl component an asymmetrical flow profile is clearly observed.

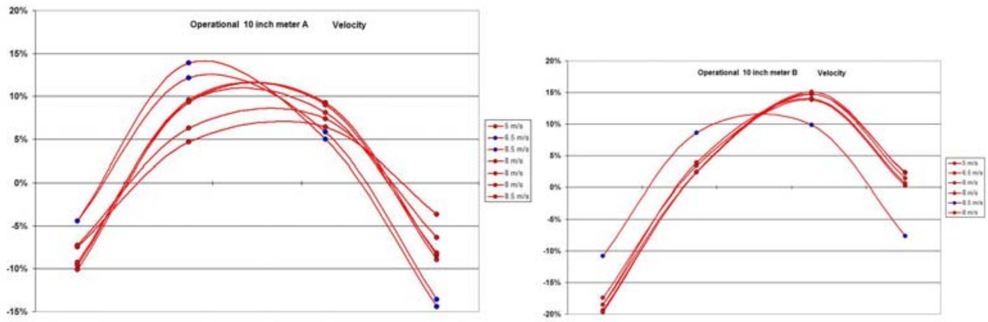

Fig. 25 – Meter A & B Profile "Showing Asymmetry"

3.5 "Z" Configuration With in Plane Cross Connector (Variation 3)

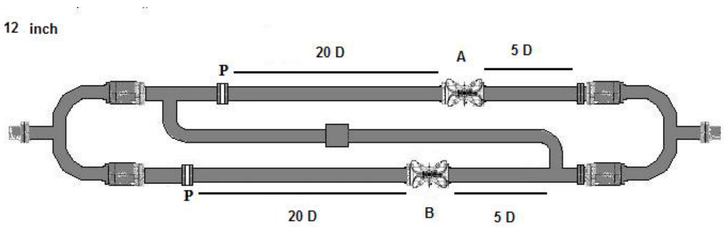

Fig. 26 – "Z" Configuration -3

As with the previous example this configuration would on first impressions fit the present "recommended design" criteria. However the same concerns are expressed over the approach pipe work as the data provides some evidence of asymmetrical flow even with the profiler 20D upstream. It should be noted that the data set for this meter pair is somewhat limited to date.

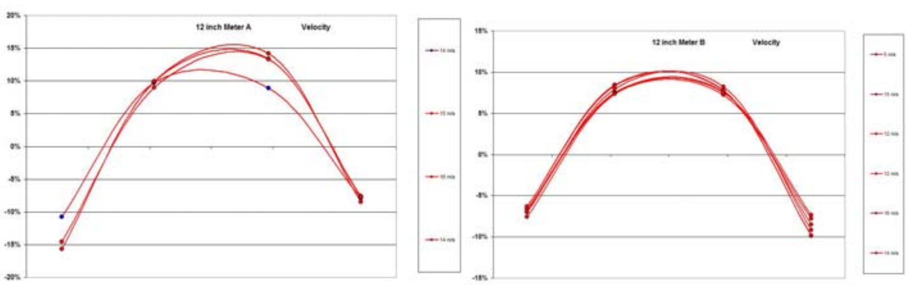

Fig. 27 – Meter A & B Profile

3.6 “Z” Configuration With in Plane Cross Connector (Variation 4)

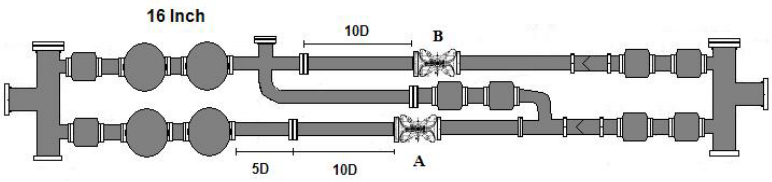

Fig. 28 – “Z” Configuration -4

This configuration is based on a “typical” turbine meter installation and consists of two basket filters upstream of each meter. There are no profilers installed in this configuration.

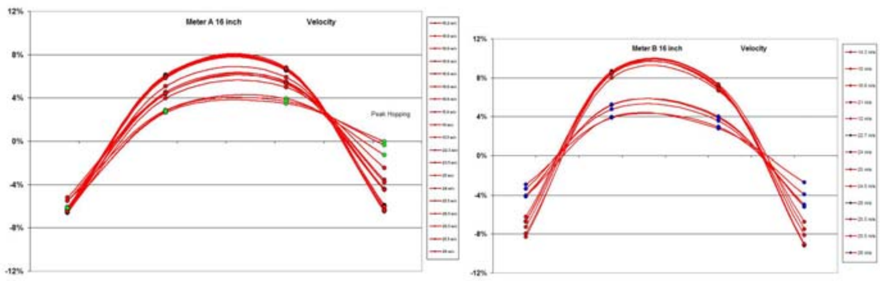

Fig. 29 – Meter A & B Profile

The plot of the A meter profile is seen to demonstrate the impact of peak hopping.

The meter B profile shows two distinct profiles and is consistent with other data sets and demonstrates the different profiles presented to the meter when run in parallel and in series. When operated in series the impact of the crossover pipe work is to “flatten” the profile.

3.7 In Line Series Configuration (Variation 1)

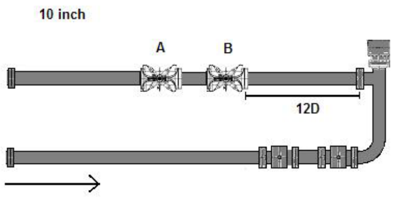

Fig. 30 – In line Pair

This configuration is a permanent “pay-check” configuration on an offshore installation where the allowable footprint for the skid did not allow the installation of a “Z” type configuration.

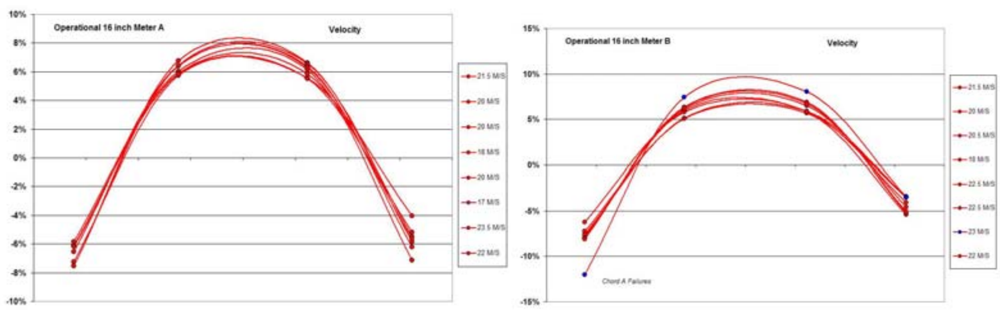

Fig. 31 – Meter A & B Profile

These meters are being operated at the velocity limit of the meter. In the first-up meter, meter B in this instance, at 23 m/s the meter diagnostics was reporting some intermittent chord failures that due to the software configuration in use were causing the meter to report lower than expected velocities when the chord fail was active . The impact can be seen in the profile footprint below.

3.8 In Line Series Configuration (Variation 2)

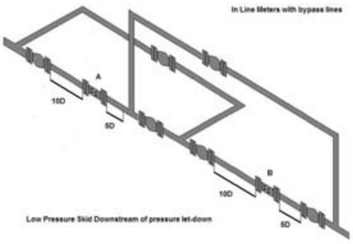

Fig. 32 – In line Pair – with bypass

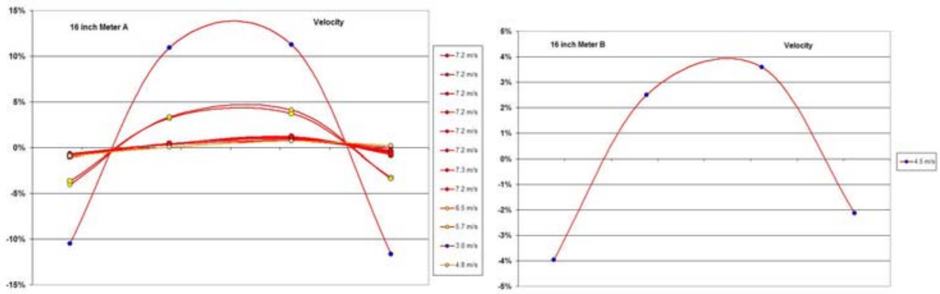

Fig. 33 – 16 inch Meter A & B

The first pair of meters installed in this configuration demonstrates a flow profile that “flattens” as the velocity increases. This is considered to be a direct cause and effect of the upstream control valves. The following are samples from three out of a bank of five similar meter runs, the results are considered to demonstrate a significant installation effect, with unknown impact on measurement. These meters are installed closely coupled to upstream control valves. Presently there is no evidence of valve noise impacting the meters. The meters are presently operating at low flow rates where the DP across the control valve would be at its greatest. However the data set is limited and therefore a full assessment is not possible.

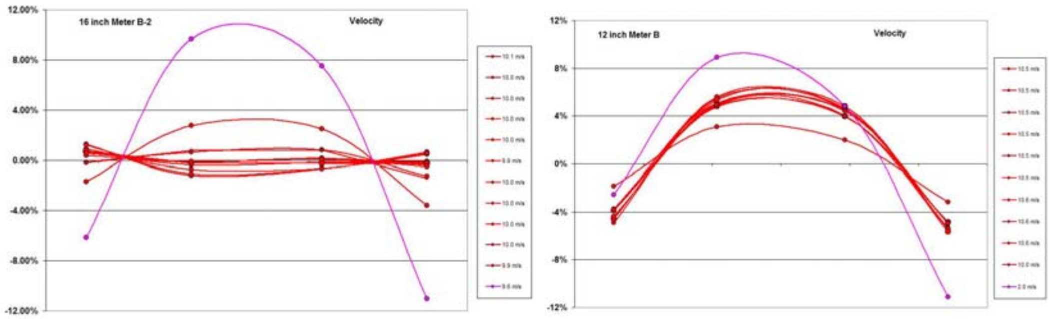

Fig. 34 – 16 inch Meter A & B

3.9 Three Path Meter, Blind Data No Installation Information Provided

This data was used to asses if the method of analysing other meter designs was valid. Whilst as previously demonstrated the SOS analysis method compared very favourably and meets our criteria, the flow profile assessment requires considerably more detailed analysis and more calibration data to establish the bench mark.

However the variations observed in a single meter and the significant differences observed between similar meters would indicate this to be a valuable project to pursue.

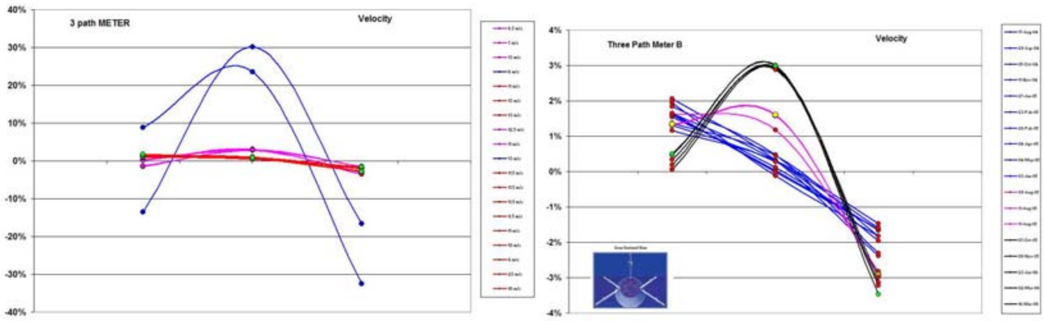

Fig. 35 – Three Path Meter A & B

3.10 Five Path Meter Offshore (Footprint Limited)

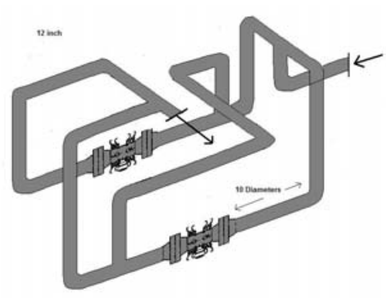

Fig. 36 – Five Path Meter Pair

The present data set is limited and therefore a sound evaluation of the process cannot as yet be made. However from this data the presence of swirl at the point of measurement is clearly demonstrated.

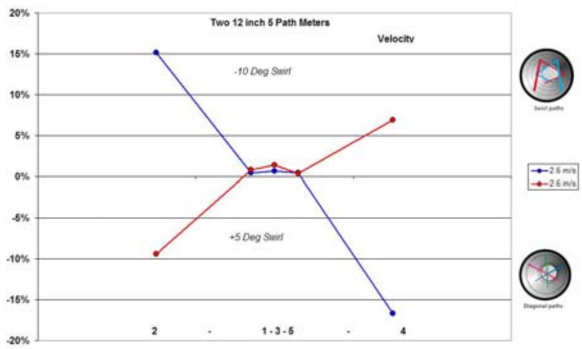

Fig. 37 – Five Path Meter Pair Velocity Profile

3.11 Five Path Meter, Blind Data No Installation Information Provided

Data from another four meters of similar construction as in 3.10 is presented below however this data is presented without information on the system design but is understood to be two "Z" configurations with the up and over cross pipe work similar to that of Fig 18.

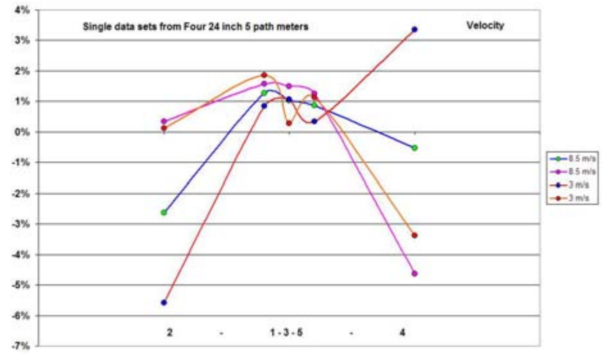

Fig. 38 – Five Path Meter Pair Velocity Profiles - 2

Other profile data is contained in the meter footprint library, in this attachment all the meters in the present meter population have been presented in the currently preferred graphical representation format.

4 VELOCITY TURBULANCE

One of the noticeable differences between data captured at the time of calibration and from the meters when in operation was the turbulence of the measured velocity present in the meters. The concern related to this observation is that the role of signal averaging used in all USMs will therefore play a significant part in the meters "Operational Performance" No available information has been found relating to this issue.

This turbulence can be associated with both process conditions and installation effects. Designers of future systems may wish to give these matters additional consideration to help optimise the measurement process and reduce the risk associated with poor measurement accuracy. The use of metering headers to reduce velocity prior to introduction to the measurement device is recommended for consideration.

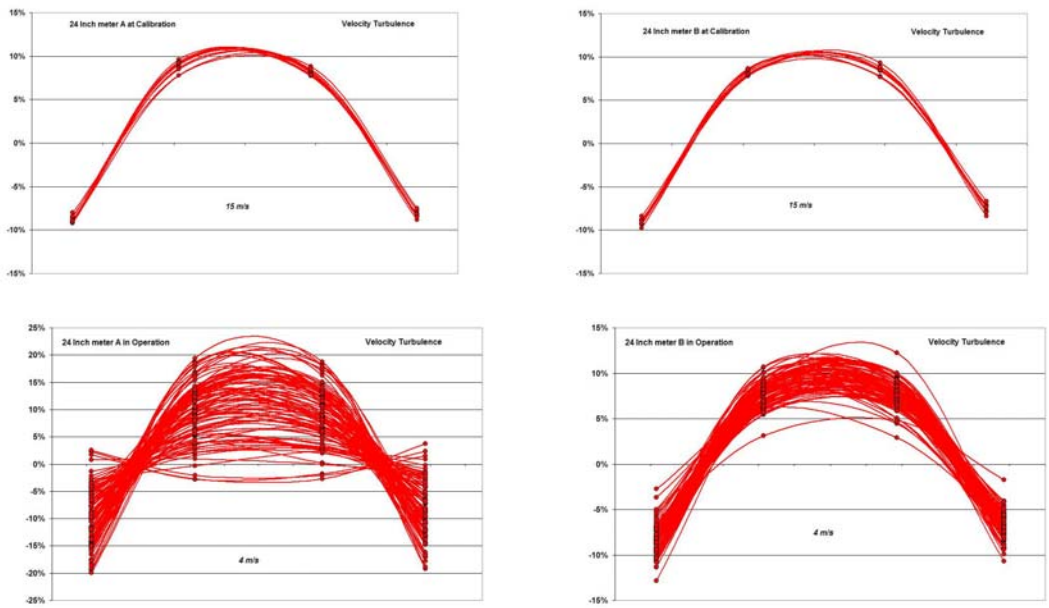

Fig. 39 – Chordal Meter Velocity Turbulence

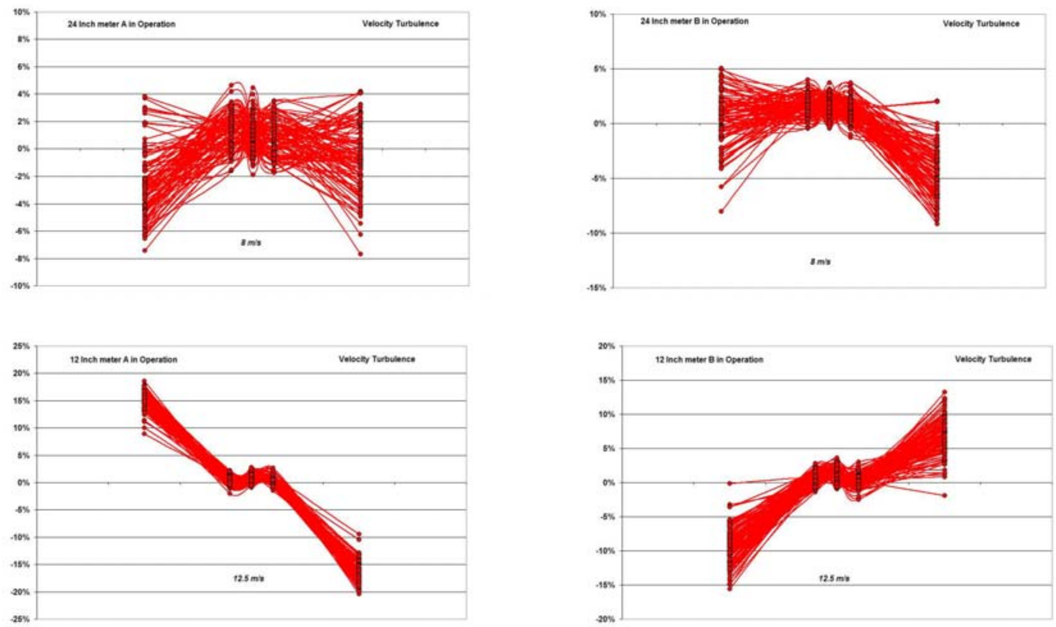

Fig. 40 – Five Path Meter Velocity Turbulence

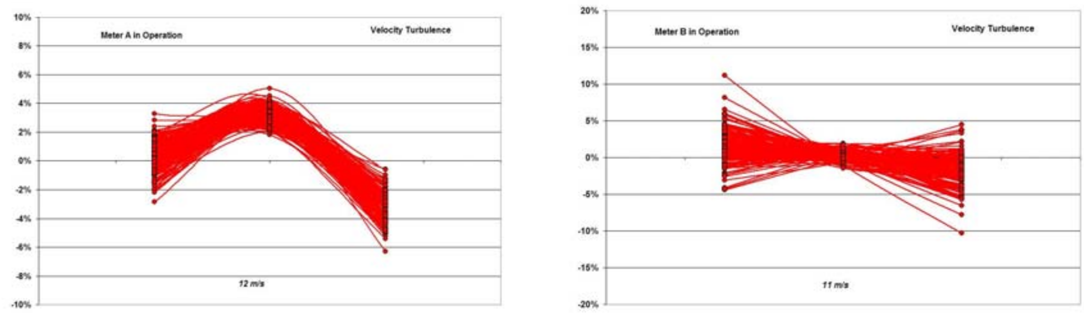

Fig. 41 –Three Path Meters Velocity Turbulence

4.1 Something Interesting When Cleaning Two Meters!

The following is the analysis of a collection of data from two operational meters that are usually run continuously in series mode. These meters were taken out of service, one at a time, for cleaning. The cleaning was instigated as a result of an internal video scope inspection.

The following graph is a presentation of the deltas between the meters for pressure temperature and standard volume. The results would indicate that the significant contributor to the change in standard volume between the two meters before and after cleaning is connected to a temperature effect. After the upstream meter and its associated pipework was cleaned the temperature differential between the two meters diverged. Directly after the second meter was cleaned this again changed but the temperature between the tow meters now had a smaller differential.

As this is a single data set it is difficult to make judgements based on one set of data but it is considered worthy of presenting this to the industry as it may help future understanding of an as yet un-quantified issue. That of meter shift on cleaning.

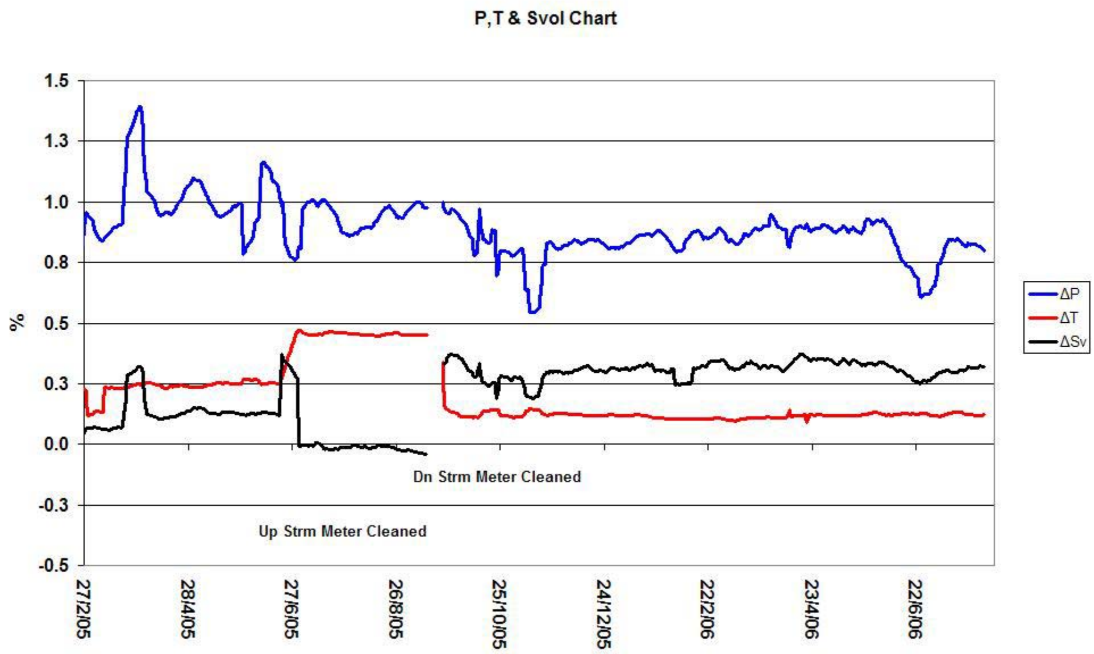

Fig. 42 –Meter Cleaning

5 CONCLUSIONS

A number of metering systems in operation appear to have installation effects that are possibly impacting their operation. It is given for consideration that in some cases these have been introduced by not giving sufficient consideration to some good engineering principles and practices during the time of design and that the present standards do not provide an operator with this guidance.

It is submitted that traditional considerations, well documented in the case of the orifice plate metering systems are presently not being addressed by the present standards.

Such considerations as: -

- Installation and design of metering headers
- Designs for flow balancing
- Straight length requirements
- Conservative meter runs i.e. 50% x 3 not 100% x2

There is a possibility that all these considerations are being compromised in the drive for new “reduced cost” technology. The lack of prescriptive guidance to operators and designers as to the real world requirements from such as AGA and ISO are also considered to be contributory factors.

The operational experiences gained from “living” with these systems after the project team goes home” may have a part to play in reversing this trend.
There is no doubt that the technology is sound and is performing well. In some instances despite being asked to perform under compromised operating conditions. This should not be the case especially in the area of custody transfer measurement were small deviations can have significant commercial impact.

The following is an example of a risk estimate. The calculation is based on a perceived measurement discrepancy (systematic bias) between two measurement stations of similar design.

Note: - The values of associated risk are with the meter flowing @ low velocities generally <10m/s. The risk would therefore be expected to increase as throughput increases.

If the risk is then taken as an accumulation over a period then the risk evaluates to:

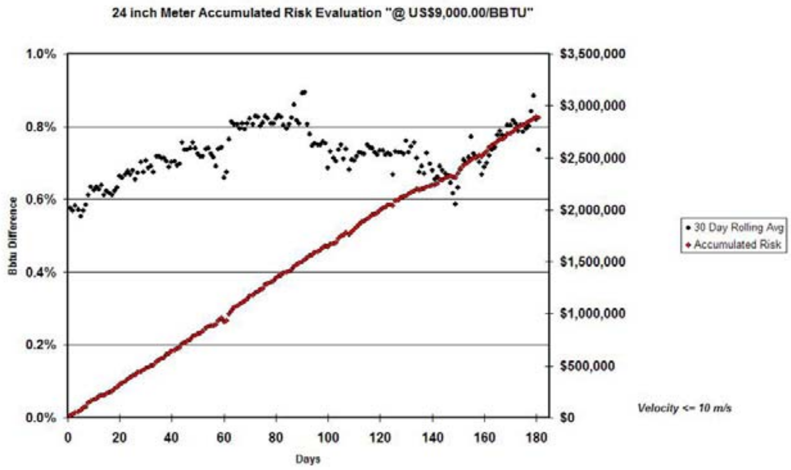

Fig. 62 – Accumulated Risk

It is also considered that the drive towards a policy of short meter runs with a mandatory flow profile plate is open for challenge and should be considered a compromise for not applying some sound engineering principles such as previously stated especially that of larger volume metering headers.

Whilst it is accepted that under certain restricted installation requirements the short run system and integral flow profiler may be necessary. It should however only be accepted as a necessary compromise and not become accepted as a standard especially for high value custody transfer measurement.

From the data presented were 10D and profilers have been used whilst eliminating swirl the profile plates are seen to have introduced asymmetry, clearly not an ideal situation. Flow profile plates are shown not to be a panacea for all ultrasonic meter installations. Ref [3.4].

Diagnostic data from the wet calibration of meters is being wasted or not fully utilized. This data if properly recorded can be used to set the control limits for the control charts of operational meters. It can also aid in identifying installation effects, set bench marks for the meters and provide continuous confidence in meter performance.

There is a general misconception that a serial check is a statement of meter accuracy.
If installation effects or other factors compromise the meter performance then both meters, in a series pair, may respond in the same manner but both may have deviated from the accuracy set at calibration. There is also the added complexity that when two meters diverge identifying which meter has deviated can be problematic.

However by a combination of “Foot printing” the meters at time of calibration, frequent video scope inspections of the internal condition of the meter and demonstrating continued agreement to the footprint control charts in conjunction with frequent serial checks the operator has the highest possible confidence in the continued conformance of his measurement system.

As the operating envelope of these meters continues to increase beyond the capability of present wet calibration facilities the USM uncertainty envelope may require a review.
In that an added uncertainty component may be required to extend the use of the meters but to apply a limit to this extension.

6 AKNOWLEDGMENTS

To all the anonymous contributors without whom this real word data could not have been presented.

7 REFERENCES

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[2] University of IOWA

[3] Diagnostic Ability Of The Daniel Four-Path Ultrasonic Flow Meter
Klaus J. Zanker, Daniel Industries, USA

[4] Evaluation of Flow Conditioners – Ultrasonic Meters Combinations; Gaz De France