Fundamentals of Multipath Ultrasonic Flow Meters for Gas Measurement

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Introduction

Ultrasonic meters have been used in gas custody transfer measurement worldwide for over 25 years with varying degrees of success. Initial attempts proved unstable and maintenance intensive, this was contrary to the initial expectations which foresaw a device with little or no obstruction, limitless turndown and little to no required maintenance. The advent of higher speed, more robust electronics enabled the use of digital signal processing which eliminated the need for analog threshold levels and the constant problem of peak skipping and lost timing. The improved electronics also enabled the implementation of large internal logs, advanced diagnostics, improved communications and overall stability, all of which increased user confidence in the ultrasonic technology. Today meters have the ability to store years of audit, alarm and operational data, communicate via Ethernet, locally and remotely, continually monitor diagnostic parameters and alarming when values exceed preset limits. This paper will briefly cover GUSM history, look at USM transit time basics, path configurations, meter construction, installation requirements and trends to look for in the future.

History

A brief description of GUSM history will be given here, a more detailed description can be found in a paper titled 'Celebrating Quarter of a Century of Gas Ultrasonic Custody Transfer Metering' written by Klaus Zanker and Tom Mooney and presented at the NSFMW in 2010 [ref 1].

One of the initial methods of ultrasonic measurement was the use of Doppler effect technology, the theory was that a single transducer could be used to emit a signal and receive the energy once it had bounced off of particles in the fluid stream. The accuracy and repeatability of the measurement depended on the distribution of the particles, the fluids sonic conductivity and the flow profile. This configuration had limited success in liquid measurement and poor results in natural gas installations and was quickly abandoned. The use of transit time measurement greatly improved the meters ability to measure repeatably as it was immune to changes in fluid characteristics and did not require any particulates in the gas. The addition of multiple paths further improved uncertainty by reducing the meters susceptibility to changes in flow profiles.

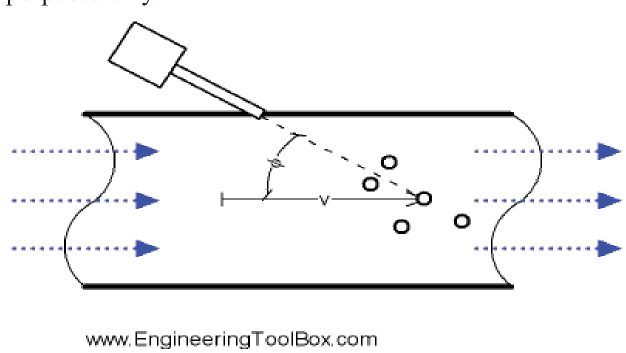
The original development drivers were based on the need to reduce the size and weight of measurement devices used on offshore platforms in the North Sea. The promise of shorten piping requirements, greatly increased metering ranges and the elimination of pressure drop accelerated the development and deployment. All of the aforementioned benefits were also very attractive to pipeline companies that could eliminate the number of meters, the pressure drop and the inherent maintenance required by traditional meters such as orifice and turbines.

Over time the expectations somewhat diminished, with limitations realized in upstream requirements, the use of flow conditioning which introduced pressure drop and self imposed velocity limitations. However the use of GUSMs has greatly reduced the overall size and cost of today's metering installations and improved the overall long term accuracy and repeatability of measurement, while reducing the required maintenance and the associated costs.

Basics

Doppler Effect

As previously discussed Doppler effect devices incorporate a single transducer which acts as a transceiver both sending and receiving ultrasonic signals. Diagram 1 shows a Doppler meter and the placement of the transceiver, this technology is not very prevalent in custody transfer measurement and is included for interest purposes only.



The fluid velocity can be expressed as:

$$v = c\frac{fr - ft}{2}\, ft \cos \emptyset$$

Where:

fr = *received frequency*

ft =*transmission frequency*

v = *Fluid velocity*

$\emptyset$ = *the relative angle between the transmitted ultrasonic beam and the fluid flow*

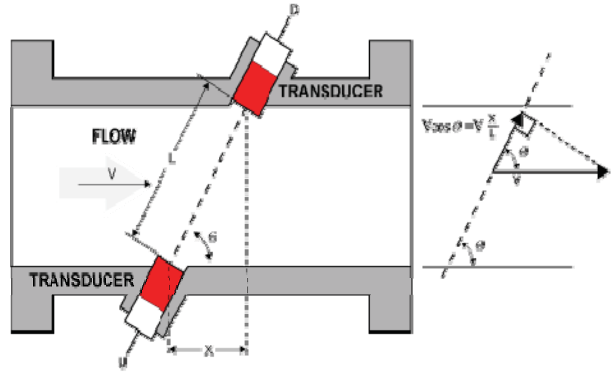
c = *velocity of sound in the fluid*

Transit Time

All meters currently used in gas custody transfer employ transit time measurement; this is also true for the majority of allocation, check and clamp-on meters. The advantage is that only the time difference is used in the velocity calculations, this greatly reduces the effect of changes in fluid properties such as pressure, temperature and composition. As well slight drifts in timing circuitry will be eliminated as the offset that may occur, either positive or negative will be the same for both up and downstream time measurements. This immunity to changes in fluid characteristics coupled with the use of multiple paths has greatly increases meter reliability, repeatability and immunity to changes in flow profiles. It must be understood that GUSMs are designed to be tolerant of flow profile fluctuations, however large shifts caused by pipe wall build up, flow conditioner blockages and changes to the initial installation will cause measurement offsets. The use of the inherent diagnostics available on all multipath meters can alert users to these types of changes long before they affect the meters accuracy. The use of the available diagnostics has revolutionized ultrasonic meter usage; the ability to monitor not just meter health but changes in process diagnostics has greatly increased user confidence by offering data unavailable in any other type of measurement device.

Transit Time Basics

The ultrasonic signals have a time of flight across a known distance passing through the fluid stream, these times are measured in both directions and then subtracted from each other. This difference in time is referred to as the delta time, this is the basis for all the velocity and eventually volumetric calculations. Once the delta time is measured all that remains is simple math. Below is a diagram of a single path meter and the calculations used to derive gas velocity as well as the velocity of sound.



$$t_{UD} = \frac{L}{C + V.\frac{X}{L}} \qquad t_{DU} = \frac{L}{C - V.\frac{X}{L}}$$

Where: t_{UD} = Transit time from upstream to downstream transducer

t_{DU} = Transit time from downstream to upstream transducer

C = Velocity of sound in units per second

V = Fluid Velocity in unit per second

X = Theoretical dimension from the intersections of the ultrasonic beam and the inside meter walls

L = The distance from the face of the upstream transducer nto the face of the downstream transducer

The variable required is the velocity of the gas through the meter in the axial direction, therefore the two initial equations need to be combined and solved for V. One variable that can be removed is the velocity of sound (C), it is assumed that since meters sample the gas stream in fractions of a second that the gas composition, pressure and temperature will remain constant. This is also important as it eliminates any uncertainty caused by changes in pressure, temperature and gas composition. The resulting equations solve for gas velocity (V) and velocity of sound (C).

$$V = \frac{L^2}{2X} \cdot \frac{t_{DU} - t_{UD}}{t_{DU} \,.\, t_{UD}} \qquad C = \frac{L}{2} \cdot \frac{(t_{DU} + t_{UD})}{(t_{DU} \,.\, t_{UD})}$$

Once the transit times are measured accurately, the velocity is calculated and realigned using trigonometry to reflect the fluid movement through the center of the pipe. These calculations are for a single path, depending on the meter design a number of these individual measurements will be done. Once these individual values are calculated an average value needs to be found, the averaging of the individual path velocities will vary depending on path placement, the equation below shows the equation. The weighting (averaging) factors used in this equation are from the table below, note that the different values are based on the number of paths and their placement relative to the meter's center line.

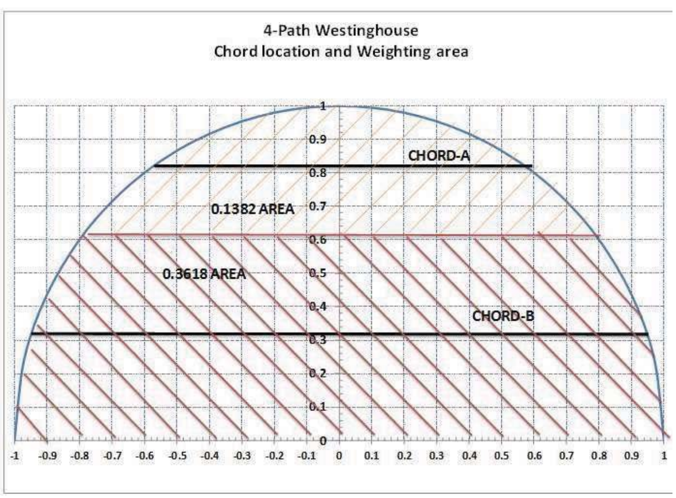
$$\overline{V} = \sum_{i=1}^{n} V_i \cdot W_i$$

Where: n = number of paths

W = weighting factor from the table below

	Radial	Position		Center	Radial	Position		Sum W
z2			0.5000		-0.5000			
W2			0.5000		0.5000			1.0000
z3			0.7071	0.0000	-0.7071			
W3			0.2500	0.5000	0.2500			1.0000
z4		0.8090	0.3090		-0.3090	-0.8090		
W4		0.1382	0.3618		0.3618	0.1382		1.0000
z5		0.8660	0.5000	0.0000	-0.5000	-0.8660		
W5		0.0833	0.2500	0.3333	0.2500	0.0833		1.0000
z6	0.9010	0.6235	0.2225		-0.2225	-0.6235	-0.9010	
W6	0.0538	0.1746	0.2716		0.2716	0.1746	0.0538	1.0000
z7	0.9239	0.7071	0.3827	0.0000	-0.3827	-0.7071	-0.9239	
W7	0.0366	0.1250	0.2134	0.2500	0.2134	0.1250	0.0366	1.0000

Westinghouse table for z and W



The diagram above shows half of a 4 path meter and what the weighting factors represent, the values used for chords A and B are highlighted in the upper table. Chord A is located .809 times the radius from the center line of the meter and has a weighting factor of .1382, this means that Chord A measures 13.82% of the total cross sectional area of the meter. Chord B is .309 times the radius from the centerline and has a weighting factor of .3618. The placement in the meter dictates how much of the overall volume each path measures or is responsible for in the overall average velocity calculation.

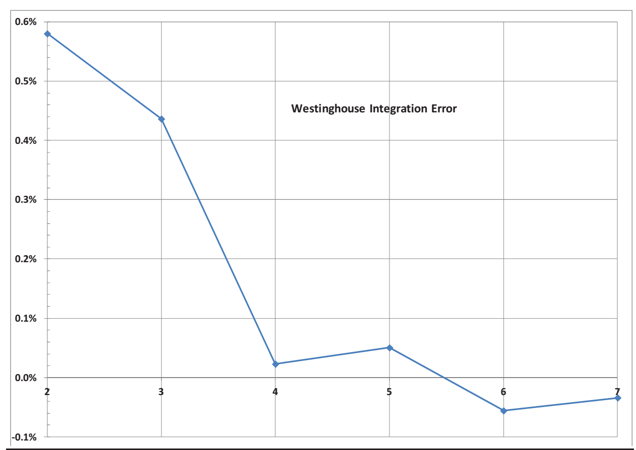
We have now derived an average velocity through the meter, it should be remembered that this example is for a chordal style meter as these are the easiest to model without the need for proprietary, meter specific algorithms. This average velocity is still in non-volumetric units, the final step is to multiply average velocity by the cross sectional area of the meter body.

$$Q = \overline{V} \cdot \frac{\pi \cdot d^2}{4}$$

We now have a value for Q which is the average uncorrected flow rate through the meter, the units will depend on what units were used to calculate the velocity and cross sectional area.

Meter Configurations

We will now look at the different path configurations currently being used, in a recent paper given by Klaus Zanker at the North Sea workshop [ref 2], he discusses how more paths do not necessarily translate into a more accurate meter. The chart below shows this, it should be noted that this is based on meters in fully developed flow. In many cases additional paths are used to increase a meter's immunity to none ideal flow caused by installation affects and process changes.



The Westinghouse integration improvement with number of paths

Based on this information it can be determined that there is a diminishing return above 4 paths and an actual increase in error with jump to 5 paths, this is due to the fact that meters with an odd number of paths normally have a center path which can increase uncertainty. The figure below shows a 4 path Westinghouse distribution.

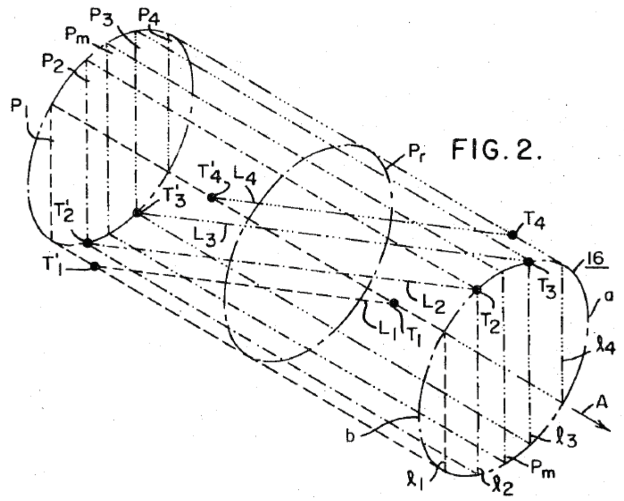
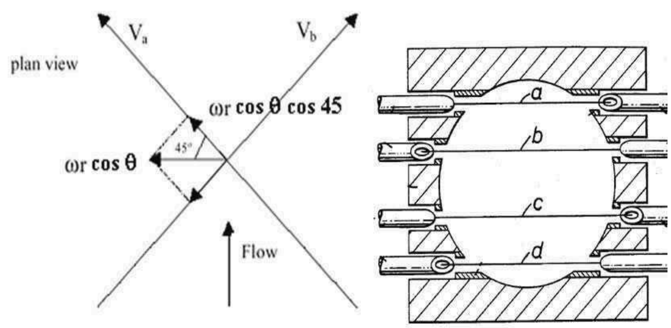


FIG. 2.

An off shot of the Westinghouse design is the British gas configuration developed in the early 80s, it incorporate the Westinghouse vertical distribution but changed the positioning of paths 2 (B) and 4 (D) so they cross paths 1(A) and 3(C) at 90 degrees. This modification was done to enable the meter to measure and correct for flow transients across the horizontal plane, it allowed for 3 dimensional measurements.



British Gas path configuration

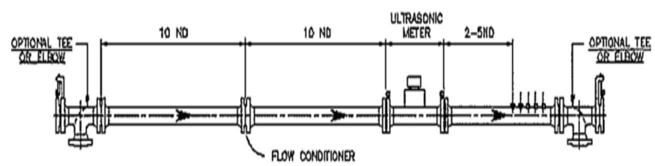
Standards

Multipath gas ultrasonic meters started to gain limited acceptance in the mid 90s, it wasn't until 1999 when the first edition of AGA report #9 was release that acceptance grew exponentially. End users needed some type of guidance to ensure that meters were installed correctly for optimal results, Measurement Canada followed shortly after with PS-G-06 which was a provisional specification for the installation and operation of ultrasonic meters in custody transfer applications. PS-G-06 was one of the first GUSM standards that required type approval of meters and associated components as well as initial and subsequent calibration. These and subsequent standards and reports increased the acceptance of GUSMs as users became more confident that their installations met current metrological requirements.

Meter [illegible]tion Design Considerations

Despite the original thought that USMs would eliminate the need for long upstream piping and flow conditioning some basic installation requirements must be followed to ensure optimum repeatability and uncertainty. The use of upstream piping and high performance isolating flow conditioners are now standard to ensure that installation affects are kept a minimum and that results achieved at calibration facilities can be transferred to the field with little or no change. As well the promise of limitless turn down has also been reined in significantly due to concerns of erosion, increase uncertainty and the high cost of accelerating gas above 80 to100 feet/second. Single large bore meters have not gained the acceptance initially expected, the statistical distribution of uncertainty over several smaller meters has been more widely accepted.

Below is the recommended ideal meter installation assembly from AGA report #9 2007



It should be noted that this exceeds the requirements of most meter and flow conditioner manufacturers and is only a recommended configuration, the end user should consult the manufacturer for their recommendations.

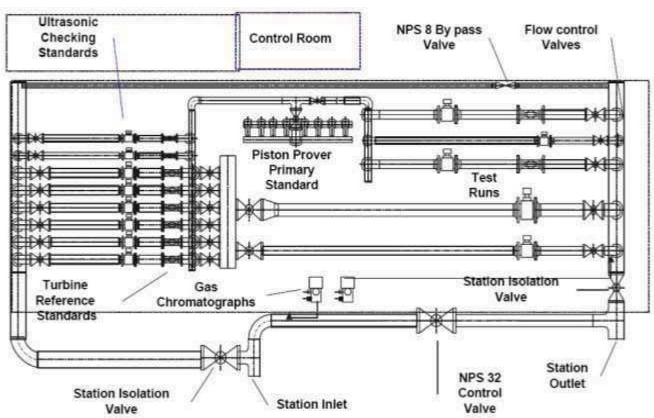
It is important that any recommendations made by manufacturers must be backed up and based on sound test data from independent agencies and/or test facilities.

Once the meter and spools are built it is highly recommended that where possible the entire assembly be sent to a certified calibration facility for testing. After the test and again where possible the entire assembly should remain in one piece, in some cases this is not practical but all attempts should be made to keep the upstream spool and flow conditioner assembled. If the unit must be disassembled all the components must be indexed to ensure proper on site reassembly.

Meter Calibration

All current reports and standards require that GUSMs used for custody transfer must have an initial high pressure calibration at a certified calibration facility. Some metrological bodies also require subsequent recalibrations on a prescriptive basis, however the use of meter diagnostics has lengthened these periods by basing the recalibration on performance data. Most standards and reports have an acceptance criteria for out of the box accuracy, these are to ensure that the manufacturer can repeatably build meters and that flaws in production are not masked by calibration corrections.

When a meter is calibrated it is installed in a test run preferably with the site specific piping and components, gas flows through the labs reference meters and the meter under test and any difference is corrected by use of single or multiple meter factors. In some cases high order polynomials are used but the majority of the corrections are done using multipoint linearization which ensures that the meter is linear throughout its entire calibrated velocity range. Below is a sketch of the piping layout of TransCanada Calibrations, the gas enters the facility form an external high pressure pipeline through the station inlet and is discharged through the outlet once it has travel through the reference meters and the meter under test. The gas used in the facility comes directly from the pipeline so no changes to pressure, temperature or composition can be made.

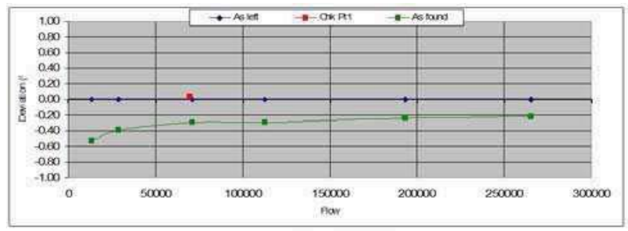


There are a number of test facilities in North America capable of calibrating ultrasonic meters, they include CEESI in Iowa, SWRi in San Antonio, Fortis' triple point facility in Penticton and CEESI in Nunn Co... All of these facilities have the ability to calibrate meters, however some have limited velocity and meter size capacities.

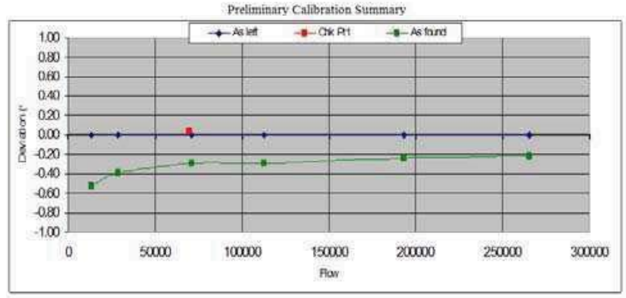
Once the calibration is complete the correction factors are entered into the meter and verification measurements are made to ensure that the points were correctly calculated and entered and that the meter can repeat within a reasonable value, usually less than .05%.

Once the meter has been calibrated it is within less than .1% of the test facility, it should be noted that test facilities around the world all fall within a ±0.25% band and therefore a meter's overall accuracy is a combination of the meter and facility uncertainties, which is around .3%. On the next page is an example of the data from a calibration:

Meter Flow (Acf/hr)	Ref. Flow (Acf/hr)	Velocity (ft/s)	Deviation (%)	Stdev (2s)	Flow (Acf/hr)	Deviation (%)	Adj. Factor	As Left Measured (%)
264827	265417	94.85	-0.22	0.03	265417	0.00	1.0022	
192655	193105	69.01	-0.23	0.03	193105	0.00	1.0023	
112336	112667	40.26	-0.29	0.03	112667	0.00	1.0029	
70789	70993	25.37	-0.29	0.04	70993	0.00	1.0029	
28798	28911	10.33	-0.39	0.08	28911	0.00	1.0039	
13502	13573	4.85	-0.52	0.11	13573	0.00	1.0053	
69907	69881							0.04



Preliminary Calibration Summary



Preliminary Calibration Summary

Meter Installation and Initial start up

Once the meter assembly has been designed, built and calibrated it's time to install the unit. What is done during the initial startup is very important for monitoring future meter operation. Once the meter is in line and all the connections are made the meter can be powered up, the first thing that should be done is to collect the configuration from the meter. Having the original configuration gives you a starting point should there be any type of failure or corruption of the meter's data. Once the configuration is collected any site specific entries should be made, once the meter setup is complete another configuration should be collected and stored. Depending on the meter brand there will be different procedures used during the initial startup and commissioning, refer to the manufacturer's guidelines to ensure everything is correctly initialized and configured. Some meters have the ability to set baseline or initial finger print values in the meter's memory, this should be done once the commissioning personnel are satisfied with the meter setup and operation.

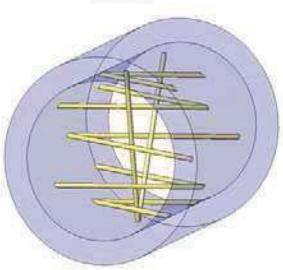
This baseline information will be used throughout the life of the installation, it will be compared with live operational data to ensure diagnostic parameters remain within the set limits. If the meter does not have these capabilities it's important to collect as much data during start up and commissioning as possible as this will allow for future comparisons should the meter's operation come into question. A check list of important data would include, where possible: configurations, operational logs, waveforms and archive data, these should be collected and stored in multiple location to ensure integrity and easy access. Once the meter is up and running and all the available information has been collected and stored, the device should be checked on a regular basis, this can be done locally or remotely using a WAN, Modem or data radio. These scheduled visits allow the user to collect logs and check the meter's operation. It is important to remember that USMs are low maintenance and not NO maintenance, scheduled maintenance is an important to ensure reliable and accurate operation.

Current and Future Developments

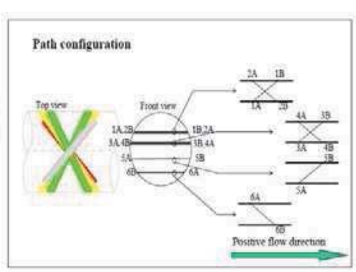
Ultrasonic meters are continually evolving, from the initial installations where a single pulse was used to emulate a turbine meter to today's highly complex installations where meter information is communicated through high speed connections. Users have become more familiar with the devices and the onset of user groups and dedicated USM conferences and meetings has allowed for the open exchange of information, ideas and issues. This growth in user knowledge and experience has and will continue to force manufacturers to continually improve their offerings and incorporate more complex features while making the operation of the meters simpler. This increased acceptance and broadening of applications has spawned an explosion of USM suppliers, where there were originally only a few, there are now over a dozen manufacturers of meters for custody transfer applications. These competitive pressures will result in continual improvements and innovations in meter geometry, electronics and interfaces.

Path Configurations

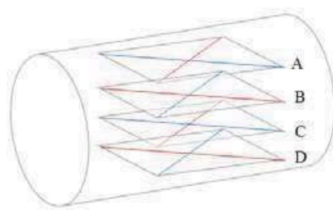
Krohne V12



FMC 6 Path



Daniel 4 + 4



Conclusion

Despite the limitations placed on GUSMs from their original claims of measurement bliss, they remain some of the most accurate and reliable measurement devices currently available. With little or no pressure drop, large turn down, low maintenance and inherent real time diagnostics, ultrasonic meters are ideal for a myriad of applications in both gas and liquid metering. In depth user understanding has increased confidence and driven manufacturers to simplify interfaces and incorporate on board analysis to ensure real time monitoring of all diagnostic parameters. This constant monitoring ensures optimal operation with minimal end user input, however as previously mentioned, meters cannot be installed and forgotten. Alarms and/or faults will be reported and action needs to be taken to ensure that any issues are corrected in a timely manner. It is also important that end users provide training for their technicians and engineers in the basics of ultrasonic metering so that they understand the fundamentals and can make knowledgeable decisions on product selection, design, installation and operation.

The continual improvements in design and user interfaces has accelerated acceptance as meters become more robust and simpler to install and operate.

REFERENCES

[1] KLAUS ZANKER, TOM MOONEY, Celebrating Quarter of a Century of Gas Ultrasonic Custody Transfer Metering, NSFMW, Oct 2010.

[2] KLAUS ZANKER, TOM MOONEY, Limits on Achieving Improved Performance from Gas Ultrasonic Meters and Possible Solutions, NSFMW, Oct 2012.