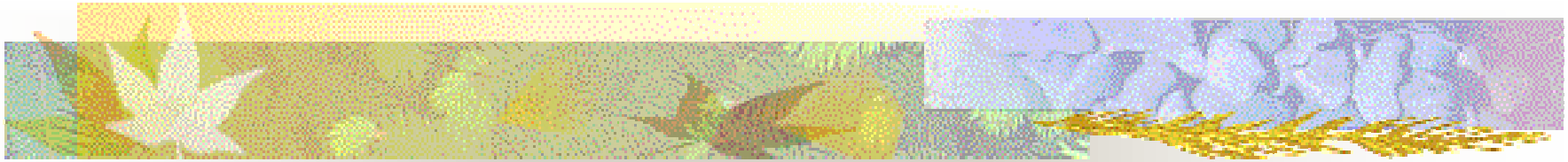
Calibrating and Monitoring MUSMs in Natural Gas Service



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Abstract

Companies today are grappling with implementing multipath ultrasonic flowmeters in an efficient and effective manner. Technology transfer, such as this conference, is essential to successful implementation of this promising technology.

In this light, this paper contains the results of calibration of two 12-inch, 600 ANSI multipath reflective design ultrasonic meters in natural gas service. In addition, the author recommends several techniques to monitor multipath ultrasonic meters in the “real world” environment for troubleshooting and assurance of performance.

The paper contains the fundamentals of MUSM technology, performance levels, installation guidelines, ‘real world’ implications, calibration methods and field monitoring techniques.

National and international standards do not currently exist to ensure proper application at an acceptable level of risk to the user community. The American Gas Association (A.G.A.) has published Technical Report No. 9 to assist the user community in applying MUSM technology.

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MUSM Flowmeters – 1 of 3

Multipath ultrasonic meters for fiscal applications use a single type of ultrasonic technology --- transit time or time of flight (TOF) using invasive acoustic probes.

The TOF multipath ultrasonic meter consists of a short spool piece, usually the same diameter as the pipe, with acoustic signal emitters and receivers mounted through the pipe wall. High accuracy is obtained from multipath ultrasonic meters in which the time of flight of the sonic signal is measured along one or more diagonal paths in both the upstream and downstream directions. In the time-of-flight meter, the time of the acoustic beam to travel between the diagonally positioned transducers is measured by a high frequency electronic clock, the flow of gas causing the time for the pulse traveling in the downstream beam to be shorter than that of the upstream beam.

The multipath ultrasonic meter is more accurate than a single-path meter, but is considerably more expensive. Multipath ultrasonic meters have the ability to monitor individual paths and are gradually being accepted for fiscal measurement in Europe.

MUSM Flowmeters – 2 of 3

CLASSIFICATION OF FLOWMETERS

ENERGY ADDITIVE		ENERGY EXTRACTIVE	
Discrete	**Inferential**	**Discrete**	**Inferential**
PD Pump	Magnetic	Displacement	Turbine
	Ultrasonic		Ultrasonic
	Thermal		Vortex
			Coriolis
			Head Meters
			- Sonic Nozzle
			- Subsonic Nozzle
			- Venturi
			- Orifice
			- Pitot

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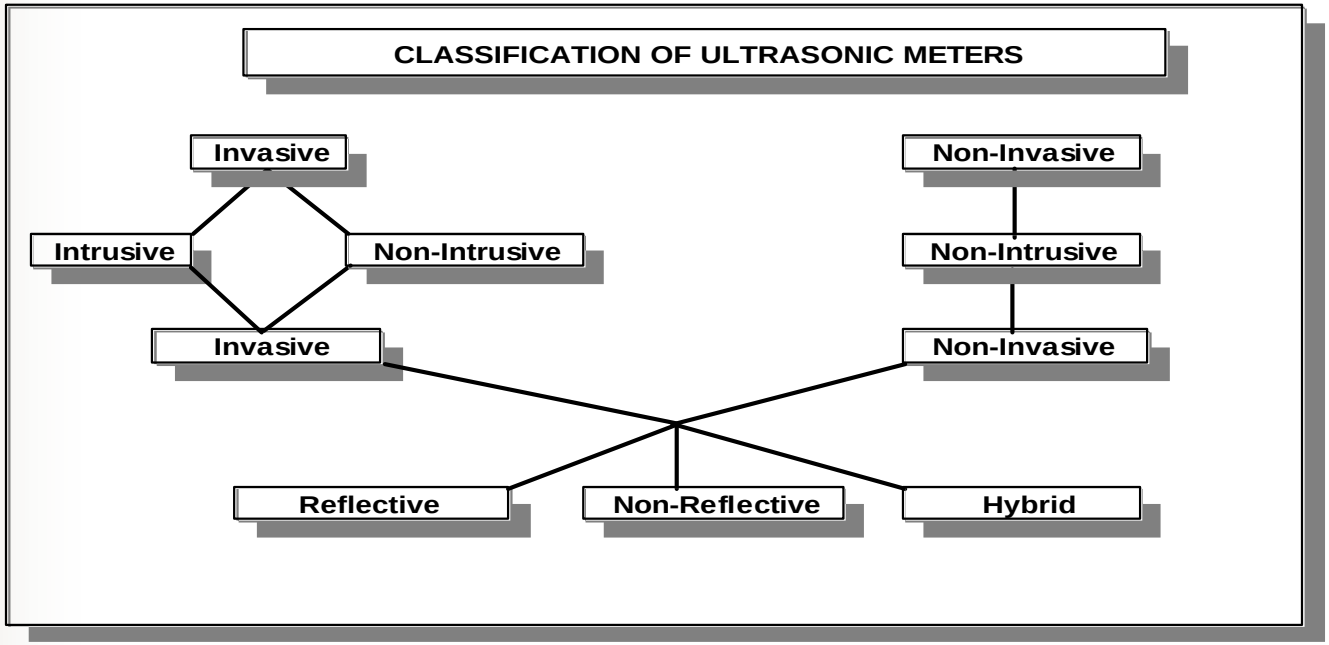
MUSM Flowmeters – 3 of 3



An ***invasive*** design indicates the ultrasonic probe has partially or fully penetrated the outer pipe wall or meter body.

An ***intrusive*** design indicates the probe intrudes beyond the meter body or inside pipe wall and into the flowing fluid.

A ***reflective*** design indicates the ultrasonic beam reflects against the meter body or inside pipe wall.

A ***non-reflective*** design indicates the ultrasonic beam is a straight shot and does not reflect against the against the meter body or inside pipe wall.

Flow Equation – 1 of 2

For multipath ultrasonic meters the mass flowrate (q_m) is obtained from the product of the volume flow quantity and density, both measured at line conditions. The equation for mass flow quantity is as follows:

$$q_m = q_v * \rho_{tp}$$

$$q_v = MF * A_m * \sum_i^n W_i * V_i$$

$$A_m = \pi * (ID^2)/4$$

assuming a constant SOS of the fluid,

$$V_i = \left[\frac{t_u - t_d}{t_u * t_d}\right]\left[\frac{L_i}{2\cos\theta}\right]$$

where,

$$SOS_i = \left[\frac{t_u + t_d}{t_u * t_d}\right](L_i/2)$$

$$t_u = (L_i)/(VOS_i - V_i\cos\theta)$$

$$t_d = (L_i)/(VOS_i + V_i\cos\theta)$$

Flow Equation – 2 of 2

For MUSMs the volume flow quantity at reference conditions (Q_{vr}) is obtained from the time integral of the mass flowrate (q_m) divided by the base density (ρ_r) -

$$Q_{vr} = \{ S^{t} q_m \} / \rho_r$$

The energy quantity Q_H is calculated from the formula:

$$Q_H = (Q_{Vr})(H)$$

The term H is the energy content of the gas mixture at reference conditions (BTU/MCF).

‘Real World’ Application – 1 of 5

Multipath ultrasonic meters are best suited for use at medium and high pressures, since the signal to noise ratio deteriorates at low pressures. They are available in sizes from 4-inch (100 mm) diameter and larger. They have the advantage of minimal pressure loss, and high turndown ratio. The uncertainty of a combined isolating flow condtioner (GFC®) and multipath ultrasonic flowmeter is estimated to be approximately 0.25% of flowrate, not span.

Multipath ultrasonic meters have been generally accepted for fiscal measurement. Additional work is underway to validate the proper performance in the field using ‘smart’ technology.

Based on current research, multipath ultrasonic meters require the installation of isolating flow conditioners, such as the GFC®. No current national or international standards exist for meter run lengths, but a total upstream length of ten (10) pipe diameters, with an isolating flow conditioner is recommended for accurate performance. A length of the downstream meter run of five (5) pipe diameters is considered adequate.

‘Real World’ Application – 2 of 5

The user community has identified four areas of interest to address in the ‘real world’ environment –

- Industrial piping configurations
- Control valve noise
- Coating effects and mechanical tolerances
- Re-calibration

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‘Real World’ Application – 3 of 5

Industrial Piping Configurations

In the industrial environment, multiple piping configurations are assembled in series generating complex problems for standard writing organizations and flow metering engineers. The challenge is to minimize the difference between the actual or "real" flow conditions and the "fully developed" flow conditions in a pipe to maintain a minimum error associated with the selected metering device's performance. One of the standard error minimization methods is to install a flow conditioner in combination with straight lengths of pipe to "isolate" the meter from upstream piping disturbances.

The following table contains a list of ***additional bias uncertainties*** both with and without isolating flow conditioners, such as the GFC®.

	FWME with 10D Spool and GFC@3D						Real World Flow		
Disturbance	**Single Elbow**		**Elbows-In**		**Elbows-Out**		**Elbows-Out**		
Meter Rotation	**0**	**90**	**0**	**90**	**0**	**90**	**Max**	**Min**	**Avg**
Daniel (4-path)	0.04	0.00	0.36	0.41	0.23	0.30	0.30	0.23	0.27
Instromet (5-path)	0.20	0.12	0.28	0.26	0.10	0.05	0.10	0.05	0.08
Kongsberg (6-path)	0.24	0.15	0.06	0.08	(0.13)	(0.11)	(0.11)	(0.13)	(0.12)

Shifts greater than 0.30%

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‘Real World’ Application – 4 of 5

Control Valve Noise

Current research indicates that control valves should be placed downstream of the meter runs to ensure that the acoustic noise generated by the valve does not “scramble” the acoustic signal of the ultrasonic meter.

Some MUSM manufacturers claim to be unaffected by ultrasonic noise generated by control valves and other devices due to their signal processing software. Other MUSM manufacturers offer different transducers for these applications.

Research and development into the design of acoustic filters is ongoing with promising results. The Destroyer™ and SAFE™ has shown positive results in several field trials on different MUSM designs. Additional field trials are underway and will be published as the results become available.

At the time of this writing, the user community anticipates solving the control valve noise generation issue within the next twelve months.

‘Real World’ Application – 5 of 5

Coatings, Mechanical Tolerances and Re-calibration

The accumulation of pipeline rouge and other coatings on the flowmeter piping, ultrasonic transducers and meter body have a significant effect on the bias error of the flowmeter. Recent empirical research has shown the errors to be approximately 1.5% or more due to oil, rouge and small piping offsets.

It is unknown if dynamic calibration of MUSMs will be required at regular intervals to guard against drift due to electronic aging or possible mechanical damage to the probes.

It is also unknown if routine visual inspection will be required to guard against pipe wall roughness or coating of the pipe wall (rouge and other coatings).

The next revision of A.G.A. Report No. 9 will address tightening of the mechanical tolerances as well as inspection and re-calibration intervals of MUSMs.

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Calibration of MUSMs

All flowmeters require individual calibration to achieve a standard of accuracy that is acceptable for fiscal purposes. The only exception is the orifice meter which relies on the Law of Similarity and requires control of the geometric variables involved in the design of the non-proprietary device.

Multipath ultrasonic meters require individual calibration of each meter in two distinct steps:

- Static Calibration (or Zero Flow Calibration)
- Dynamic Calibration

It is unknown if dynamic calibration of MUSMs will be required at regular intervals while in service to guard against drift due to electronic aging or possible mechanical damage to the probes.

It is also unknown if routine visual inspection will be required to guard against pipe wall roughness, coating of the pipe wall.

A salient point for the user is to view MUSMs as electromechanical flowmeters.

Static Calibration – 1 of 2

A ***static calibration*** is required to ensure that all calibration parameters are entered properly and meter components are functioning properly.

Under static or non-flowing conditions, the pressure is varied at a constant temperature to monitor the performance of the electromechanical device.

Typically, the static calibration is performed with pure nitrogen as a fluid. SonicWare is used to predict the SOS of the pure nitrogen. The mechanical paths are adjusted until the SOS_i for each path agrees with the SonicWare prediction. This ensures that the acoustic path utilized by the software.

The ***individual chordal paths*** are monitored for the -

- **Performance rating (or ratio of accepted pulses to the total pulses transmitted)**
- **Raw chordal velocity (under zero flow)**
- **Speed of Sound**

The ***overall MUSM performance*** are monitored for -

- **Stability (the presence of swirl or non-symmetry)**
- **Weighted Corrected Velocity**
- **Weighted SOS**

Static Calibration – 2 of 2

The acoustic paths are calculated using SonicWare for pure nitrogen, pressure and temperature. The mechanical paths are adjusted until the SOS_i for each path agrees with the SonicWare prediction. This ensures that the acoustic path utilized by the software.

Typical static calibrations ***ensures*** control of the following variables:

- **Gross clock stability**
- **Proper programming associated with the calibration parameters**
- **Proper electronic boards performance**
- **Proper acoustic probes**
- **Proper acoustic path lengths**

The static calibration ***does <u>not</u> ensure*** that the following variables are in control:

- **Precise clock stability**
- **Range between parallel raw chordal velocities under flowing conditions**
- **Mechanical angle for chordal paths**
- **delta time delays for each acoustic probe**
- **Signature recognition software**
- **Integration accuracy**

Dynamic Calibration – 1 of 2

A dynamic calibration is, again, required to ensure that all calibration parameters are entered properly, the meter components are functioning properly and the linearity of the mete. A dynamic calibration is conducted at a world-class calibration facility (SwRI, K-Lab, CEESI, Trans Canada, Nmi, etc.).

The dynamic calibration is performed with the upstream meter run and isolating flow conditioner to further ensure transfer of the calibration to the “field” environment.

The dynamic calibration is performed with natural gas as the fluid.

SonicWare is used to predict the Speed of Sound (SOS) of the natural gas mixture. The accuracy of SonicWare for natural gas mixtures is thought to be better than +/- 0.10% when using an online gas chromatograph to determine “real time” composition.

A.G.A Report No. 8 is used to predict the fluid’s density (ρ_{tp}, ρ_b) using the full compositional technique in combination with a gas chromatograph.

Under flowing conditions, the pressure and temperature are held constant to monitor the performance of the MUSM in natural gas. The calibration conditions are typically conducted at the field operating pressure (required) and temperature (if practical).

Dynamic Calibration – 2 of 2

The ***individual chordal paths*** are monitored at each flowrate for -

- **Performance rating (or ratio of accepted pulses to the total pulses transmitted)**
- **V_i range between parallel chords**
- **SOS_i range between chords**

The ***overall MUSM performance*** are monitored at each flowrate for -

- **Stability(the presence of swirl or non-symmetry)**
- **Weighted corrected velocity**
- **Weighted Speed of Sound**
- **Meter Factor versus Velocity**
- **Meter Factor versus average pipe velocity**

Unlike the static calibration, the dynamic calibration performs a thorough validation of -

- **Timing clock stability**
- **Range between parallel raw chordal velocities under flowing conditions**
- **Mechanical angle for chordal paths**
- **Delta time delays for each acoustic probe**
- **Signature recognition software**
- **Integration accuracy**

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Field Monitoring of MUSMs

Well, now that you have completed a successful static and dynamic calibration of the MUSM, what do you do with it?

Well there are several ways to monitor the health of the MUSM:

For Individual Chords

- **Performance rating**
- **V_i range between parallel chords**
- **SOS_i range between chords**

For Overall MUSM

- **Stability**
- **Weighted corrected velocity**
- **Weighted Speed of Sound**

Savant Measurement Corporation has applied for several patents on the application of 'real time' health monitoring or 'smart' technology for MUSMs.

Digital archiving of the MUSM during the dynamic laboratory calibration and field operation is a powerful tool for analysis. However, technically proficient personnel are needed to review this information to prevent the GIGO effect.

Conclusion – 1 of 2

Instrumentation is selected based on its technical and commercial specifications. Usually the selection process considers only the instrument's capital cost and not the full cost of ownership over its lifetime. The full cost of ownership consists of the initial capital, commissioning, training, spare parts, maintenance and calibration costs for the lifetime of the equipment. The full cost is several times the initial capital investment and should be the deciding factor in equipment selection.

The technical selection - accuracy, repeatability, drift, ease of calibration and reliability indirectly affects the cost of ownership.

Proper installation and application of flowmeters are two of the most significant parameters in the measurement chain. These parameters influence the factors mentioned above and are neglected in most assessments. The misapplication of any device brings the wrath of field personnel on the operating company's engineering staff - as it should! More effort is required by the user community to match their expectations with reality.

Standards shall always follow adoption of emerging technology. Standards are written with the understanding of the limitations of technology – successes *and* failures. As a result, technology must have its history, which requires time, and open and honest results among the research and user communities.

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Conclusion – 2 of 2

Digital archiving of the MUSM during the dynamic laboratory calibration and in the field operation is a powerful tool for analysis. However, technically proficient personnel are needed to review this information to prevent the GIGO effect.

Significant changes to the operators' Measurement Manual (operations and maintenance procedures and policies) are necessary to ensure accurate measurement.

The challenge for emerging technology remains the same from the user community --- a lower capital, operating and maintenance cost while maintaining or improving current loss performance levels. The risks of adopting emerging technology must be offset by the improved performance and lower total cost of measurement.

Technological advances will be fast and fierce. The industry should be positioned to take advantage of these opportunities through strategy, structure, systems and people. The elements to success in the next ten years will be flexibility, proper corporate cultures, innovation and creativity, maximization of current capital investments, and prudent investments.

Let's move forward with our eyes open!

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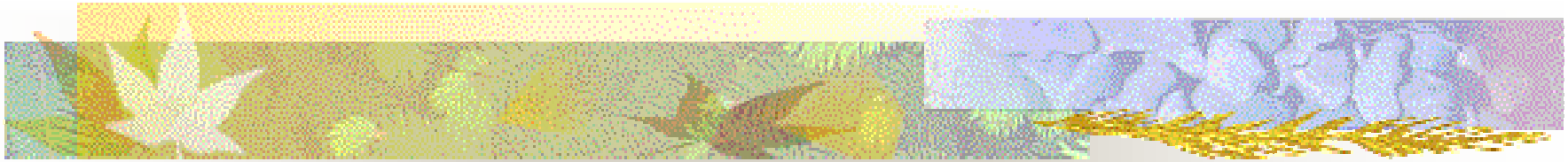
"To Accomplish Great Things, We Must Not Only Act But Also Dream, Not Only Plan But Also Believe." - Anatole France



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