

NON-INTRUSIVE ULTRASONIC FLOWMETERS IN LIQUID AND GAS APPLICATIONS—TECHNOLOGY AND INSTALLATION TECHNIQUES

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INTRODUCTION

Gas and Oil are different in their physical, chemical, and ultrasonic properties. Nevertheless, each fluid state can use Widebeam technology that uses the pipe wall as a Sonic Waveguide, permitting accurate, repeatable and reliable non-intrusive flow metering. This paper explains non intrusive gas ultrasonic metering, providing field and laboratory test data demonstrating the ability of Clamp-On Ultrasonic meters to provide accurate Measurement. It also explains the importance of correct installation.

INSERT AND WETTED TRANSDUCER METERS

All transit-time ultrasonic meters rely on the simple principle that sound moves at a lower velocity when traveling against the direction of a fluid and at a higher velocity when traveling with the fluid. By precisely measuring the times of the sound transmission in each direction (upstream and downstream), the line integrated fluid flow velocity can be computed. For an insert or "wetted" ultrasonic meter, where the transducers are inserted through a port into the spool, the equation for flow could be written as shown in equation (1) with reference to Fig 1.

$$(1) \quad V_F = \frac{L^2}{2x \cdot T_{UP} \cdot T_{DN}} \Delta t$$

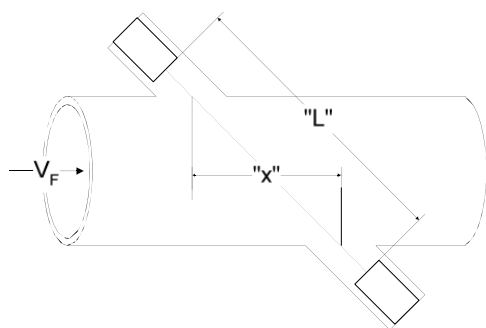


Figure 1. Model for Transit Time Equation

Although this simple relationship has been known for more than a century, it was not until the micro processors introduction for field instruments that accurate, stable measurement could be achieved, along with the use of Piezoelectric ultrasonic transducers, that this theory could be practically applied to accurate liquid and gas flow measurement. Piezoelectric transducers are the most common type of transducer used for transit-time ultrasonic flow meters. The piezoelectric ceramic is used to convert

electronic signals into sound energy and inversely, convert sound energy back into an electronic signal. It is important the crystals are stable to ensure minimal "mismatch" exists between the two elements used in the transducer pair. Any mismatch would be perceived by the flow meter as a small flow offset.

The wetted transducer configuration is able to inject an ultrasonic beam across various chords along the meter body's cross-section. Depending on the number of acoustic beams, this configuration can improve flow profile averaging. If the transducer ports become blocked by contaminants it can impede the acoustic beam and interrupt operation.

NON-INTRUSIVE "CLAMP-ON" FLOW METERING

For flow survey, segmentation check metering or installations where cutting into an existing line is not practical, clamp-on flow meters have become the meter of choice. Recent advances in transducer design and signal processing technology, clamp-on meters using WideBeam™ technology are now demonstrating accuracy and repeat-

ability that rivals intrusive transducer meters. The term

WideBeam is used because of the use of the pipe as a Sonic Waveguide. Its natural ultrasonic mode offers advantages allowing precise measurement of flow rates for liquids and gases over a wide range of fluid sound velocities. (VOS) When a WideBeam transducers are placed on the pipe, they generate a wave that travels axially (diametric) down the pipe wall. The transducer is designed with a phase velocity that matches the Lamb Wave[1] characteristics (or Group velocity) of the pipe wall. The group velocity of pipe wall is dependent on the pipe material. Since the pipes used in the Liquid and Gas industry are various grades of steel all relatively similar, it is easy to handle the variations with WideBeam transducers.

A separate requirement for Lamb Wave transmission is that the frequency of the transducer matches the natural frequency of the pipe's sonic waveguide properties. This is a function of the pipe's material and wall thickness. WideBeam transducers are variable frequency or broadband (low signal Q) this allows better transducer / pipe matching. Most Clamp-On applications in the Liquid and Gas can be satisfied with just four transducer choices, and frequencies ranging from 150 to 450 kHz. The actual frequency selected is determined by an automatic test routine run by the electronics during initial installation. These frequency ranges will allow WideBeam operation on pipe walls ranging from 0.2 to 1.25 inches (5 to 31 mm).

Equation (2), below, can be used to approximate the required WideBeam frequency for any metallic pipe that is capable of supporting shear mode propagation. As the pipe wall thickness “wt” increases the transducer frequency must decrease to maintain the frequency requirement

$$(2) \quad \text{Xdcr freq (Hz)} = \frac{V_p L}{2 Wt}$$

As the WideBeam sonic wave is introduced to the pipe wall it travels down the pipe wall axially between the Transmit and Receive transducers maintaining a coherent signal wave shape as illustrated in Figure 2.

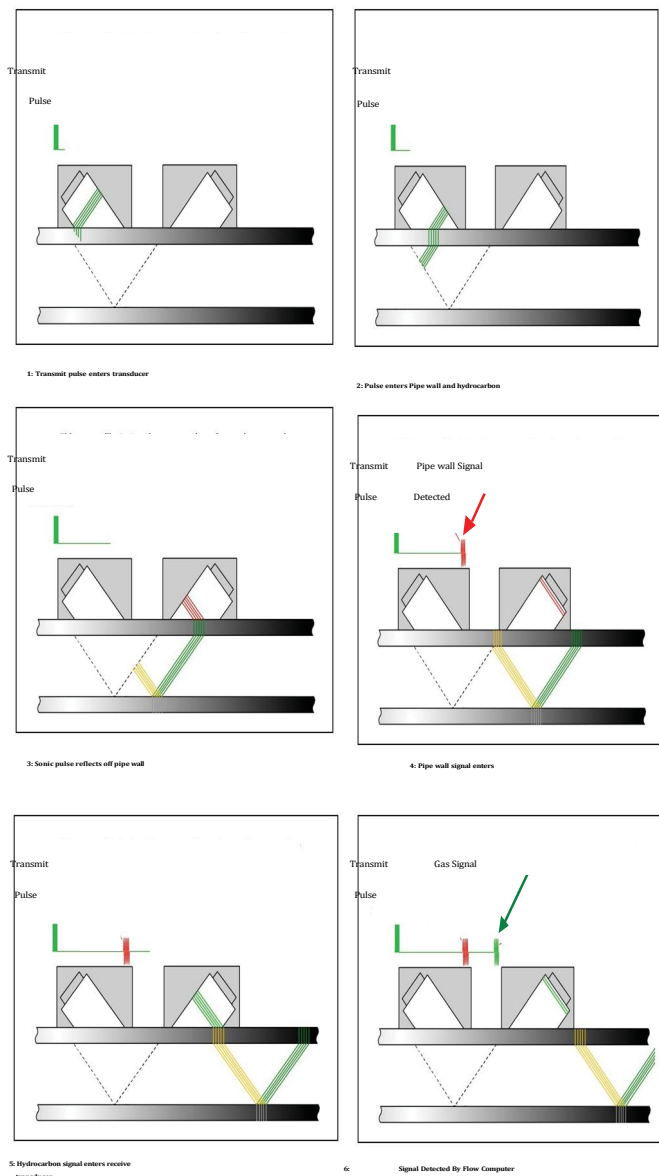


Figure 2. WideBeam Signal maintains Coherence

Shear mode clamp-on transducers do not match the waveguide properties of the pipe, and will quickly lose signal coherence after traveling only a short distance

for WideBeam transmission.

along the pipe wall, as shown in Figure 3. This signal does not provide the coherence required for operation over a wide range of fluid properties, or for high velocity gas applications.

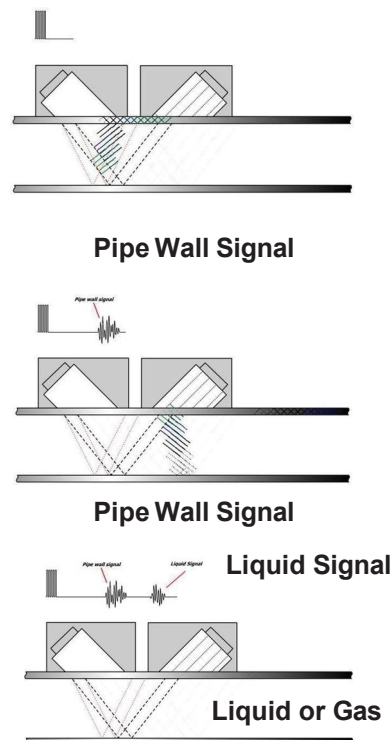


Figure 3. Shear Mode Signal Loses Coherence

WideBeam Clamp-On Technology Properties improve Accuracy

WideBeam clamp-on operation is less affected by Beam Blowing conditions found in liquid and gas applications due to transducer size and use of pipe as a waveguide.

In Clamp-On ultrasonic technology, Snell's law of refraction determines the place where the beam actually emerges from the pipe wall as it travels through the fluid, and is independent of the actual spacing of the Transducers. The angle of emergence is dependent on the sonic propagation velocity of the fluid relative to the propagation velocity of the beam in the pipe wall, as described in equations (3) and (4) and Figure 4.

$$(2) \quad \sin(\Sigma) = \frac{V_s}{V_d}$$

$$(3) \quad V = \frac{V_{BX}}{\sin(\angle)}$$

High flow velocities can cause significant displacement (or blowing) of the sonic beam as it travels from the Transmit to Receive transducer. This is primarily a concern for gas metering applications where the gas flow velocity represents a relatively high percentage of the gas sound speed (VOS) 1350ft/sec. In Insert (pencil beam)

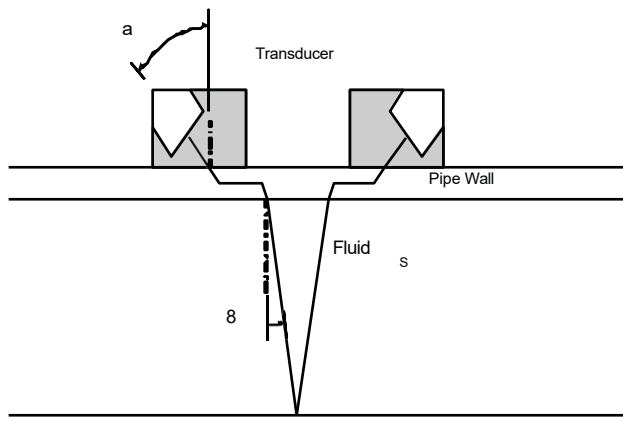
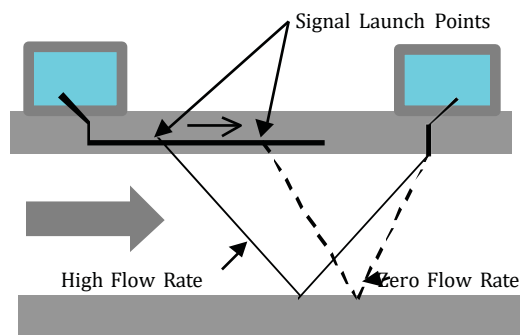


Figure 4. Refraction of clamp-on beam

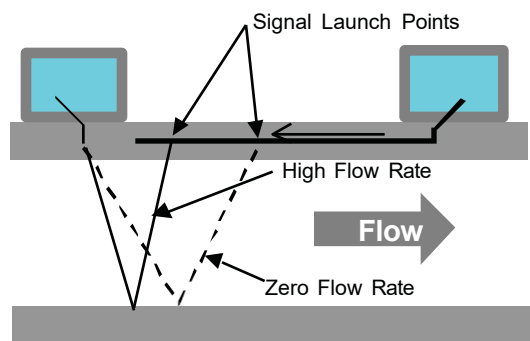
transducer ultrasonic meters, the beam can actually be blown away from the Receive transducer.

In WideBeam ultrasonic flow meter, it simply changes the place on the pipe wall from which the beam emerges permitting operation at high flow rates.

This beam displacement, where the upstream and downstream receive signals originate from different locations along the pipe wall, is illustrated in Figure 5.



Downstream Transmit



Upstream Transmit

Figure 5. The Effect of High Velocity Flow on Upstream and Downstream Sonic Beam Position

In Shear Mode Clamp-On Ultrasonic meters, as the flow increases, the upstream and downstream receive signals emanate from different positions on the pipe wall relative to the transmitting transducer. This makes the sonic signals so dissimilar that they lose any correlation features. Without proper signal correlation, it is impossible to accurately measure the transit-time and provide stable operation or accurate flow measurement.

WideBeam signal transmission method makes the sonic signal independent from where on the pipe wall it has emerged, and assures the phase coherency of the receive signal. This permits both stable operation and accurate measurement at low and high flow velocities and the ability to operate in varying pressure applications.

The Clamp-On Transit-Time Flow Equation

Clamp-On transit-time systems differ from Insert systems in the way sonic energy enters the fluid medium. Insert transducers inject their acoustic signal perpendicular to their emitting surfaces, whereas clamp-on systems must inject their acoustic signals at an angle to the emitting surfaces to allow for sonic beam refraction. The pipe wall injects the acoustic signals directly into the fluid which travels in a vector parallel to the pipe wall.

The clamp-on acoustic beam must traverse the pipe across its diameter as the beam must be at right angles to the pipe.

The vector analysis for the Clamp-On geometry results in the simple equation as shown below which uses the transducer phase velocity V_X shown earlier in equation 4.

$$(4) \quad \text{Where: } V_F = \frac{V_X}{2} \frac{\Delta t}{T_{\text{Fluid}}}$$

$$(5) \quad T_{\text{Fluid}} = \frac{2 \text{ id}}{V_S \cos(\Sigma)}$$

The transit-time flow meter measures Δt , by subtracting T_{UP} and T_{DN} . It must also derive the required time-in-the-

fluid " T_{Fluid} " (T_F) and sound velocity " V_S ". Sufficient information is available to compute (Theta), the system calibration angle, and the time of the sonic beam traveling down the pipe wall to accomplish this in real time. This can be achieved by solving the acoustic timing equation (7) below, or by generating an appropriate lookup table. Finally the line integrated flow velocity is then compensated for flow profile effects, which requires only inputting the installation pipe configuration (i.e., elbow, reducer etc., and the number of diameters downstream from such a configuration). The Profile averaged flow velocity is converted to volumetric flow rate using the correct pipe inside diameter.

$$\frac{T_{\text{UP}} + T_{\text{DN}}}{2} = 2 \cdot T_F + \frac{2 \cdot \text{wt}}{V_{\text{PL}}} + \frac{2 \cdot \text{id}}{V_S \cos(\theta)} + \frac{L_t = 2 \cdot \text{id} \cdot \tan(\theta)}{V_{\text{ap}}}$$

Using The Pipe Wall Signal For Zero Drift Correction [3]

The WideBeam transit-time meter is capable of measuring a “live” or active zero flow reference. All transit-time meters are affected to some degree by zero drift or zero flow offset. The use of this feature eliminates both the need to actually “set” a zero flow adjustment in the field, or suffer from zero drift in this type of flow meter. This zero drift can be attributed to subtle changes in the flow meter electronics and/or changes in the temperature of the ultrasonic transducers. This is why we temperature compensate the transducers. Since the difference in transit time is very small, this is a potential problem area in other ultrasonic flow meters.

The most common cause of zero drift is non-common mode temperature that can occur between the transducer pair. Sun loading is one situation that can cause differential heating of the transducer pair. Some users install their ultrasonic flow meters under the protection of a shed to avoid such sun loading.

The pipe wall can also be viewed as an acoustic beam splitter, where one portion of the acoustic energy travels into the fluid and the other straight down the pipe wall into the receive transducer (see Figure 6a, below). A typical receive signal for this configuration is shown below in the Fig. 6b oscilloscope trace meter installation using WideBeam transducers.

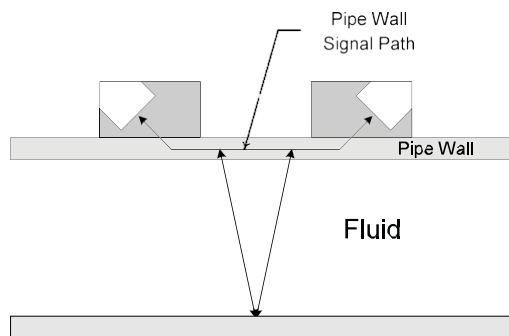


Figure 6a. Acoustic Signal Splitting

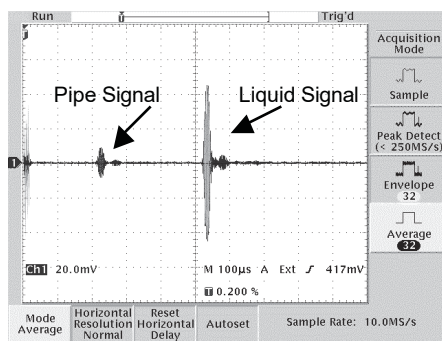


Figure 6b. Typical WideBeam Signal

The beam that travels through the fluid is used to measure flow rate directly, but the beam traveling only along

the pipe wall never “sees” the liquid and is therefore unaffected by flow rate. The WideBeam transmission technique takes advantage of this pipe wall signal, which is digitally processed in the same manner as the fluid signal. By continually measuring the transit-time difference of the pipe wall signal, the meter dynamically corrects the flow measurement for any changes in zero drift. This method is valid whether the drift is due to changes in the electronics, cables or transducers. Not only does this improve accuracy during normal operation, but it also permits accurate low flow operation, and can reduce the need for multiple meters to cover a wide range of flow rate.

This enables automatic correction of the zero flow set point, even if flow cannot be stopped. Non-common mode environmental conditions vary hour by hour. This method is known as ZeroMatic™ and only works if both transducers are installed on the same side of the pipe, in a Reflect mode. ZeroMatic cannot be implemented for either Chordal (insert) or Shear-mode Clamp-On systems. In Chordal systems no Zero pipe wall reference path exists and in the Shear mode system the upstream and downstream pipe wall signals cannot be correlated

Benefits Of Diametric Reflect Clamp-On Transducer Installation

As with most conventional meters, the flow profile imposed on ultrasonic meters is dependent on upstream piping configuration. Depending on the number of ultrasonic beams used an ultrasonic meter is affected to a smaller or larger degree by upstream conditions.

An ultrasonic flow meter installation, in which the transducers are installed on opposite sides of the pipe, (Direct Mode) can be seriously affected by Cross-flow. The susceptibility of this geometry to cross-flow profile (such as produced after a single upstream elbow) can generate flow errors of 3-6% per degree for gas applications. Figure 7 depicts the mechanism for this error and how an installation on the same side of the pipe (reflect) can compensate for cross-flow condition.

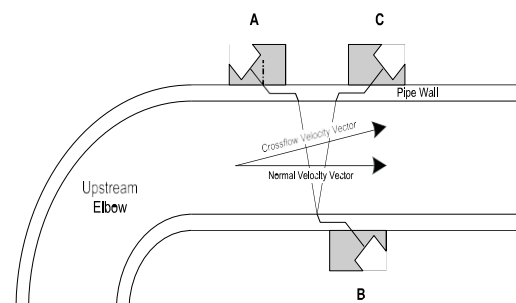


Figure 7. Cross Flow Diagram

With transducers installed on opposite sides of the pipe (acoustic path AB) the beam geometry cannot compensate for the error caused by the cross-flow angle. However, when the transducers are installed on the same side of the pipe (acoustic path AC), the geometry provides compensation (0.007% per degree of Crossflow). In this case, path AB would tend to under-read and path BC would over-read, thereby providing a self-compensating

and correct average flow indication. Insert and Clamp-On installations, with transducers installed in the AB configuration, are more susceptible to cross-flow conditions. (As described by Snell's law). Accordingly, WideBeam systems use normally Diametric Reflect installation.

Other profile aberrations, such as swirl induced by single and double out of plane elbows can also impact meter accuracy. In the case of Insert Transducer flow meters, swirl tends to align directly with the Chordal paths, and can produce errors in the individual chord. Compensation for this error can be accomplished by using multiple chords.

WideBeam flow meters are not as susceptible to swirl because the swirl is at right angles to the Diametric Beam, therefore, does not induce a time difference. Swirl can also impact the accuracy of a WideBeam system since it flattens the shape of the flow profile (shown in Figure 8). Errors up to 5% could be induced from the flow profile flattening effect of Swirl. With better understanding of this phenomenon the proper compensation can be input to correct for the majority of this errors.

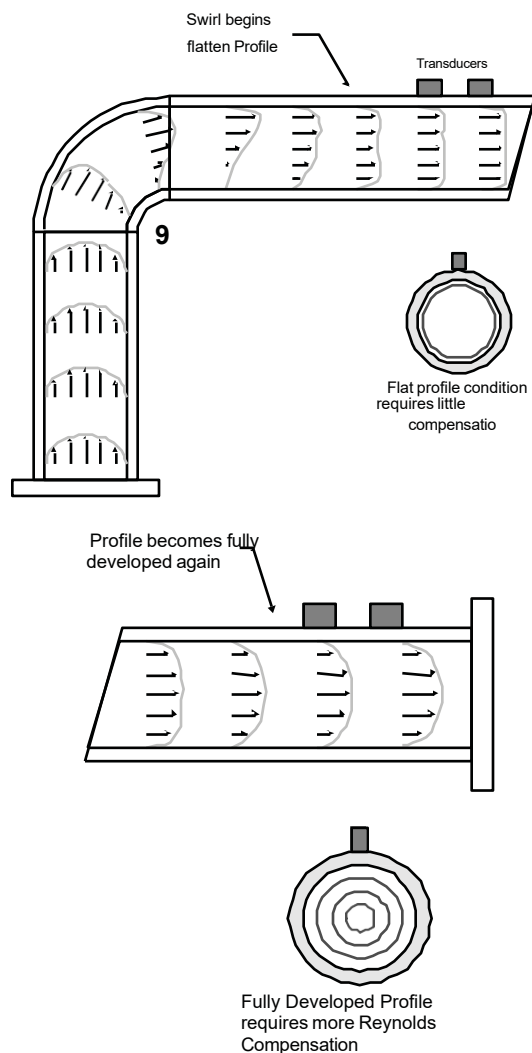


Figure 8. Flow Profile Flattening Due to 90° Elbow

CONSIDERATIONS FOR LIQUID AND GAS METERING

The WideBeam Clamp-On transit-time equations and functions described apply equally to the measurement of any liquid or gas. Gas metering does however present manufacturers with a far greater challenge than most liquid metering applications.

The **Sonic Impedance** of liquid, which determines how much sonic energy in the pipe wall is transferred into the flow stream, is much higher than for gas applications. This is because the sonic impedance is the product of its density and its sonic propagation velocity. Liquid is much higher in both categories, and it is much easier to transfer sonic energy into a liquid than a gas. As the pressure of a gas increases, so does its density; although it becomes more accepting of sonic energy, it never reaches the magnitude of any liquid signal level. Table 1 illustrates the difference in acoustic impedance between water and natural gas at various operating pressures. Also shown is the signal amplitude and beam angle.

Parameter	Clamp-On Water	Clamp-On Gas @ 15 barg	Units
Fluid Sound Velocity	1500	400	m/sec
Fluid Density	1	0.009	g/cc
Relative Acoustic Impedance	1500	3.6	
Typical Signal Amplitude	100	0.24	mV
Beam Angle	30	7	degrees

Table 1 – Relative Acoustic Impedance of Water and Gas

It is important to note that the detection of upstream vs. downstream transit times is independent of the signal amplitude, the effects of low-pressure causes low signal amplitude and reduces the Signal to Noise ratio. This increased data scatter which is integrated out in normal applications. At normal Transmission line pressures of between 400 to 1200 PSI, the signal is strong and in the millivolt range. In Normal application conditions signal to noise ratios of over 100:1 are obtained.

Effect of Residual Pipe Noise on Clamp-On Natural Gas Meters

New, improved signal amplifier can operate on acoustic receive signals smaller than 0.1 millivolts. However, if the signal baseline contains high levels of synchronous noise, the gas signals can become indistinguishable from the baseline. The elimination of synchronous "Pipe Noise" is one of the greatest challenges of Clamp-On gas meters.

The low acoustic impedance of gas means that most of the energy will remain in the pipe wall with only a small fraction will enter the gas medium. This sonic pipe wall energy travels along the axis of the pipe, and can continuing to reflect back to the receive transducer from flanges and welds until it slowly decays. To prevent pipe "noise" from obscuring the gas signal acoustic damping must be used to absorb the pipe wall sonic energy.

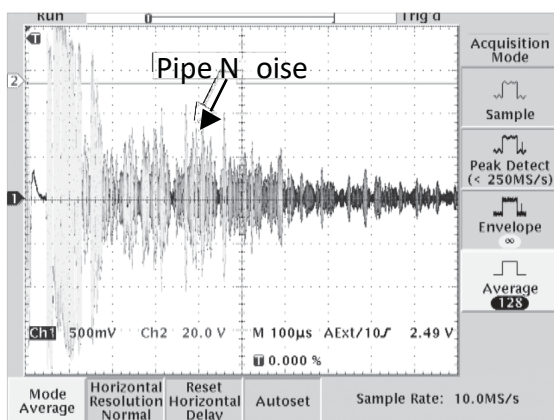


Figure 9a. Synchronous Pipe Noise on 6" Gas Spool Hides Gas Signal

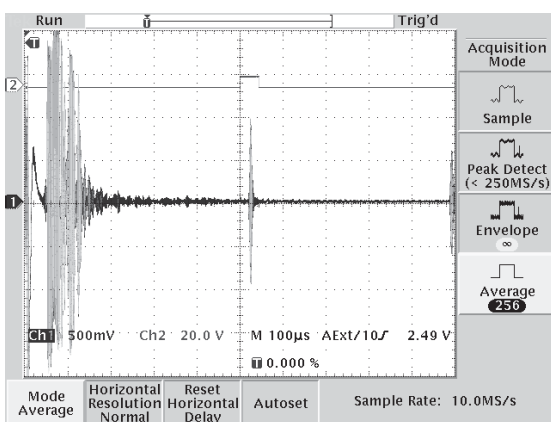


Figure 9b. Pipe Noise Elimination Permits to Gas Signal to be Seen

A Clamp-On system installed on a short pipe section or spool provides a good example of how synchronous pipe noise can interfere with the signal. Fig. 9a, above, shows the receive signal from a 6" class 600 Clamp-On gas spool meter pressurized to 100 psig with transducers installed on the bare pipe surface. The larger saturated signal to the left side of the trace is the main pipe noise signal that continues to decay as time progresses. The actual Gas signal is so small that on this scale it is buried in this noise. Fig. 9b represents the exact same installation except that the outside surface of the spool is coated with a sound absorbing material. Even at low pressures the gas signal now becomes distinct with a high signal to noise ratio. Installation of this sound absorbing material is simple and can be performed on a field installation in less than 15 minutes.

GAS CHECK METERING

Field installable, non-intrusive Gas flow meter provide sufficient accuracy to perform Check metering offer great value to those who buy and sell Natural Gas. The availability of calibrated WideBeam Clamp-On spools for high accuracy check metering is another option. This design and its performance have been confirmed by testing at major laboratories worldwide. These spool meters also offer low maintenance.

Conformance to Ultrasonic Flow Meter Standards

While Clamp-On technology is different from the Insert technology it conforms to the same standards, which have been developed worldwide for the ultrasonic meter. They are able to measure the Sonic Velocity (VOS) to within AGA-10 standards. The spool meters are in conformance with AGA 9 for gas ,API for liquid hydrocarbons and ISO standards Internationally.

Rugged Clamp-On Flow meter Transducer Assemblies

Field installation of Clamp-On transducers can be performed quickly for temporary survey jobs or temporary check metering. However if permanent field installation is required, a more rugged and secure WeldSeal transducer housing is recommended. These housings can be either tack welded to the pipe, or strapped to the pipe as preferred by the user (see Figure 10 below). Transducer spacing is precise and controlled by use of an indexed Spacer Bar, which prevents any movement between transducers. The clamping assembly applies all the force necessary to prevent any movement of the transducers. The entire assembly is enclosed to prevent accidental disturbance.



Figure 10. Four Beam, Weld Seal Transducer Installation

Field and Laboratory Testing of Clamp-On Flow Meters

This section presents test data. Calibrations show performance from 0.2% to 0.45% over a large turndown ratio.

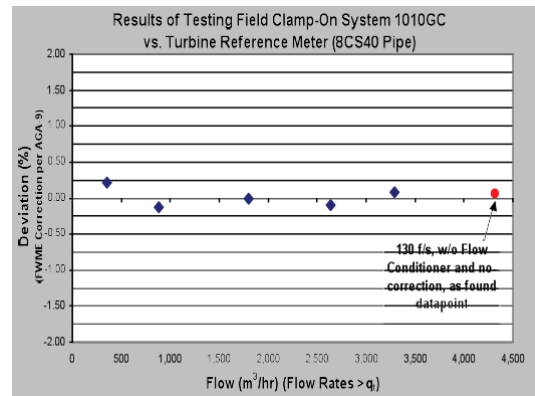
In Check metering applications, tests for field installed Clamp-On flow meters in proximity to calibrated reference meters show conformance from 0.25% to 1.0% for acceptable upstream conditions. In the tests, no attempt was made to correct the Clamp-On meters to account for the influences of the pipe configuration flow profile effects. It was always assumed that the reference meter was perfect in its calibration.

For Clamp-On gas meter testing, the measured VOS played a key role in validating the installation before any flow comparison was made. In some cases pipes were found to be out of round, or the assumed inside diameter or wall thickness was found to be incorrect.



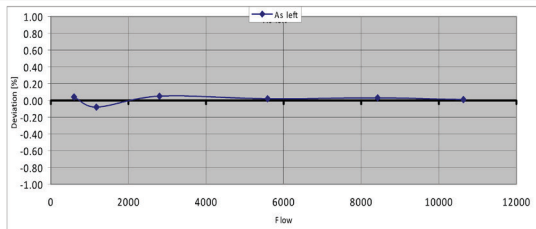
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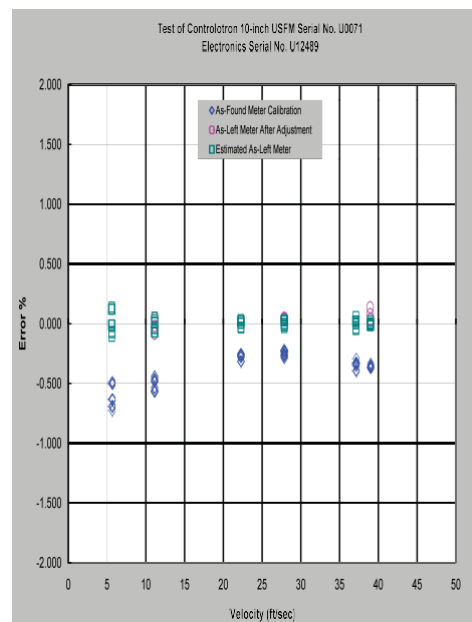


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Test number	1140

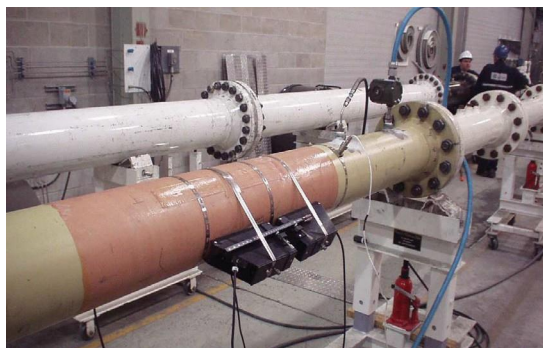
Test date	23-Oct-03								
Kind of meter	Ultrasonic								
Manufacturer	Controlotron								
Serial Number	U12289	Pulses/m3:	1000.00	1000.00					
Type	Sonicgas 1010GCS	Adjust Factor:	1.0000	1.0000					
Id	0.3792 (m)	Test points	6						
Q _{max}	11000 m³/h	Vender	Controlotron						
Q _{min}	550 m³/h	Owner	Controlotron						
Flow Conditioner	None	Direction	Unidirectional						
Customer Piping	N/A	Witness	None						
Pipe Spool S/N	None								
Average error	0.02								
Adjusting	0.00	Tested by	W. Haner						
Error (%) ----->	Before adjusting	After adjusting							
	Flow	Velocity	Deviation	Stdev (2s)	Flow	Deviation	Stdev (2s)	Measured	
	10634	26.15	0.01	0.05	10634	0.01	0.05		
	8423	20.71	0.03	0.04	8423	0.03	0.04		
	5588	13.74	0.02	0.06	5588	0.02	0.06		
	2802	6.89	0.05	0.05	2802	0.05	0.05		
	1177	2.89	-0.08	0.13	1177	-0.08	0.13		
	598	1.47	0.04	0.16	598	0.04	0.16		
PRELIMINARY DATA ONLY NOT AN OFFICIAL CERTIFICATE									
	Medium	Pressure	Temp	Density	Place				
	Natural gas	6258.04 (kPa)	28.56 (°C)	46.38 (Kg/m³)	Winnipeg				



Results and Setup of the Test of 10" Siemens Clamp-on Gas Spool Flow meter



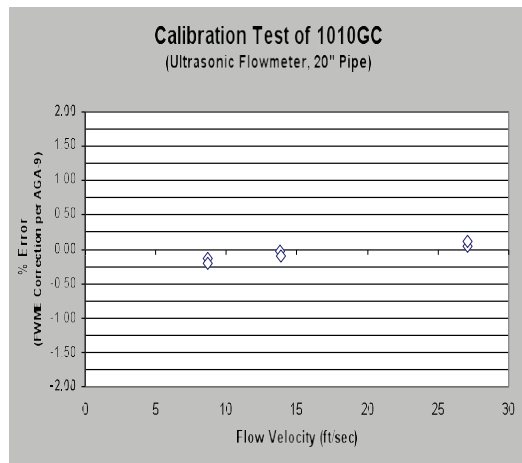
SWRI TEST



Setup and Results of a Test of a 16" Siemens Clamp-on Gas Spool Flow meter at TCC



CEESI TEST



PEMEX TEST

PARAMETRO	VALORES PEMEX	VALORES CONTROLOTRON
VELOCIDAD GAS	21.8 f/s	21.9 f/s
VELOCIDAD ACUSTIC	1410 f/s	1414 f/s
Flow	3.54 MMSCF/Hr	3.5 MMSCF/Hr
TEMP	91.9 °F	91.9 °F
PRESION	812 psi	812 psi



TRANSPORTABLE METER





Non-Intrusive Inline Ultrasonic

SUMMARY / CONCLUSIONS

In summary, the theoretical and practical information presented in this paper suggests that the following conclusions are valid:

- * The Field Installed WideBeam Clamp-On Ultrasonic flow meter can be used for metering with knowledge only of the Pipe Diameter, Material and Wall Thickness.
- Pipe configuration tables permit substantial increase in accuracy for non perfect installations.
- The ZeroMatic™ function permits excellent accuracy for applications with low flow rates. This can help reduce the need for multiple meters to cover wide flow ranges.
- WideBeam principle is resistant to Beam-blowing (because of the large transducers) effects, which can limit the maximum flow rate of Insert and Shear Mode clamp-on meters.

ACKNOWLEDGEMENTS

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