

TITLE: THE DESIGN AND APPLICATION OF CLAMP-ON ULTRASONIC FLOWMETERS FOR CUSTODY TRANSFER AND CHECK METERING GAS APPLICATIONS.

Author / Affiliation: Douglas Baumel
Controlotron Corporation
Fluid Type: Gas
Topic: E: Issues dedicated to Specific Metering

Recent advances in externally mounted sensor design and related electronics have enabled gas meters using clamp-on, non-intrusive, ultrasonic transducers to provide performance equal to or better than meters using conventional insert transducer technology. It is acknowledged that this claim will be met with skepticism; however, the following pages provide evidence of this performance capability. This paper also presents the technical challenges to this design, and how they were overcome. We will review the applicability, benefits, and limitations of the various configurations of this technology.

The two basic challenges of adapting a refractive sensor design, of the type previously utilized in liquid ultrasonic metering that met the recently approved API proving standard, to gas measurement were:

- 1) Signal strengths are much lower due to the much-reduced efficiency of sonic transmission into gas.
- 2) Varying Gas properties and the combination of high flow velocity and low sonic velocity cause large variations in the beam angle in the gas.

Controlotron, with over 30 years of ultrasonic flow measurement experience, has produced a flow meter for gas (Figure 1), using externally mounted transducers (aka 'Clamp-on') capable of meeting AGA-9 standards for custody transfer performance while providing significant benefits over conventional insert transducer designs. Both field-clamp-on models for check metering applications and pre-calibrated, cavity-free flanged models are available. Each can provide repeatability to within 0.1% over the full range of flow rates generally required for pipe sizes 2" (50mm) to 40" (1,000mm) in diameter.



**Figure 1 – Controlotron 'SonicGas' Cavity Free Gas Flowmeter
(Shown with Rugged Protective Shroud for the Externally Mounted Transducers)**

Although Controlotron's method of WideBeam™ clamp-on technology is virtually identical for both liquids and gas, this presentation will focus primarily on the new advances in gas applications. The presentation will compare the WideBeam method of Externally Mounted Transducer technology for gas measurement to conventional Insert Transducer technology. It should be noted that Controlotron manufactures both insert and external types of meters and, as such, can offer an objective viewpoint on these issues.

Field-Clamp-on vs. Manufactured Spool Meters - Both with External Transducers

Creating a factory built spool with a flanged body and externally mounted transducers provides the manufacturer the opportunity to carefully control the pipe dimensions and ensure that the signals are optimized. Robust mounting structures, quality control and dimensional stability, combined with an adherence to assembly, welding and finish specifications, allow these meters to meet custody transfer performance criteria. In the case of a field clamp-on meter, pipe dimensions are user programmed based on nominal pipe dimensions, often with some verification with proper tools (wall thickness gage, tape measure, calipers). Admittedly, pipe dimension and condition uncertainty may contribute to errors and, in some cases, operational difficulties. In addition, mounting structures for field-clamp-on systems tend to be designed primarily for ease of use in field conditions; those systems are installed either semi-permanently or permanently with strapping kits where welding is not an option. (Note: Field installed clamp-on systems offer tack-weld-able protective covers.)

Other than certifiable accuracy and initial quality control regarding signal waveshape and transducer mounting, the basic technology for field-clamp-on and pre-calibrated spool based meters with external WideBeam transducers is identical. Therefore, it is possible that a field clamp-on system can perform as well as a pre-calibrated spool of the same design in both overall accuracy and repeatability - especially on high quality pipes of known and accurate dimensions. (See Figure 2)



Dual Beam Reflect Mount Installation at Ysclosky LA, USA
 (Line Pressure: 58 barg)

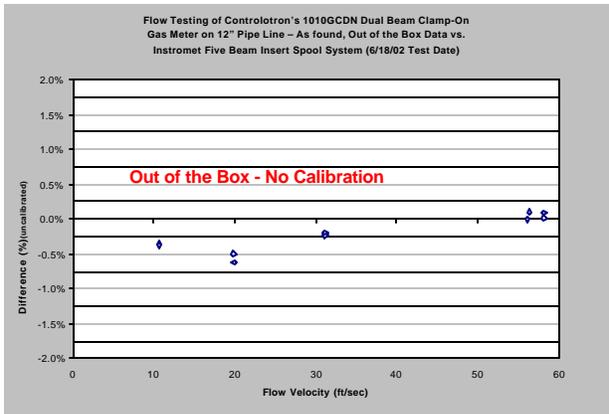
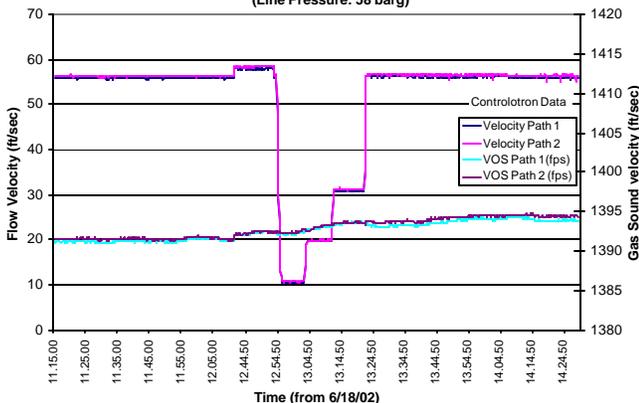


Figure 2

Example of typical test results, conducted on 6/18/02 show "out of the box" performance meeting AGA-9 (as compared to "a reference" insert ultrasonic 5-Path meter) for a Dual Path, Field-Clamp-on, WideBeam™ gas flowmeter installation at an El Paso pipeline facility. (Test results show good correlation of both Flow and Speed of Sound measurements for Path 1 and Path 2 Data.)

Externally Mounted Transducers

In order to better distinguish the technology advancement that this paper is addressing, reference will be made to Externally Mounted Transducers or Refractive Signal Injection, rather than 'Clamp-on', for factory built, spool based meters. The term 'Clamp-on' will refer only to field installed, clamp-on devices. The specific technique, which Controlotron uses for its Refractive Signal Injection, is called WideBeam and is at the heart of this technological advancement and which differentiates the technique. WideBeam signal injection succeeds in overcoming the two basic challenges previously mentioned for gas applications – i.e., injection signal inefficiency and injection angle variability.

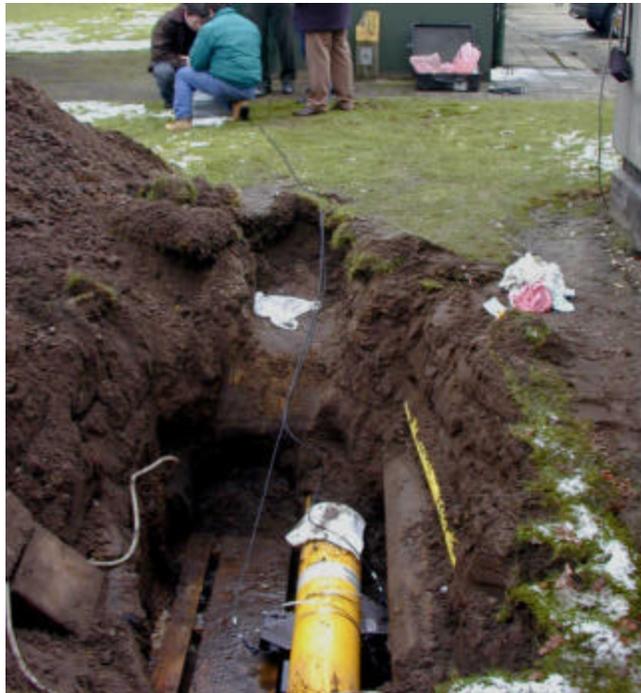
External mounting requires that the transducers transmit across the diameter of the pipe only, thus allowing for a cavity free design. A chordal configuration is neither possible, nor required with this design. Also, as will be shown, the insert-chordal configuration is not the only ultrasonic technique capable of high performance metering.

External Transducer Mounting Advantages

1. External Mounting is cavity-free, with no chance of wax or oil build up, condensation, pooling, and corrosion – all of which can block the sonic beam and impact linearity and accuracy.
2. External mounting requires no special extraction tool for transducer replacement or inspection. Transducer installation, inspection, and service can be done easily and at full pipeline pressure.
3. External Mounting provides no additional potential leak paths.
4. External mounting results in a simple meter body geometry, which is temperature stable, and has no complex transducer alignment issues. This should translate to lower price and lower maintenance costs.
5. External mounting enables field-clamp-on products to provide simple field installation without cutting pipe or stopping flow.
6. External mounting, in Reflect Mode offers better zero stability by employing a continuously active Zeromatic Path. (See later discussion.)
7. Externally mounted transducers operate at significantly higher frequencies than insert transducers. This makes them highly immune to environmental noise that has been a source of problems for insert sensors.
8. External Mounting requires fewer paths than chordal techniques as cross-flow is cancelled out in each path (in reflect or same-side mounting), and the diametric configuration is highly tolerant of swirl conditions. In addition, using a reflect-mode configuration, the path-length is typically more than twice as long as a typical chordal path and, due to WideBeam transmission, represents a much wider sample of flow.

Challenges for External Transducer Mounting

External transducer mounting does provide a challenge regarding signal strength. Signal transmission is much easier for insert transducers since these systems transmit through cavities (holes) made in the measurement section rather than through the pipe wall. A refractive technique is less efficient at getting sonic energy into the fluid or gas stream. Therefore, manufacturers of these systems must take great care in their mechanical and electrical design to maximize the signal-to-noise (S/N) ratio of their systems. It is for this reason that meters using externally mounted transducers generally require higher low-end pressures than insert based systems for operation. WideBeam refractive systems are generally specified for operation with a minimum of 7 - 15 bar for steel pipe, depending on application conditions. Plastic pipe provides a much more efficient transmission and can provide operation at atmospheric pressures. Some insert meters can provide operation at or below atmospheric pressure (See Figure 3).



Test at CoGas of 10" Plastic Pipe at 0.100 bar pressure

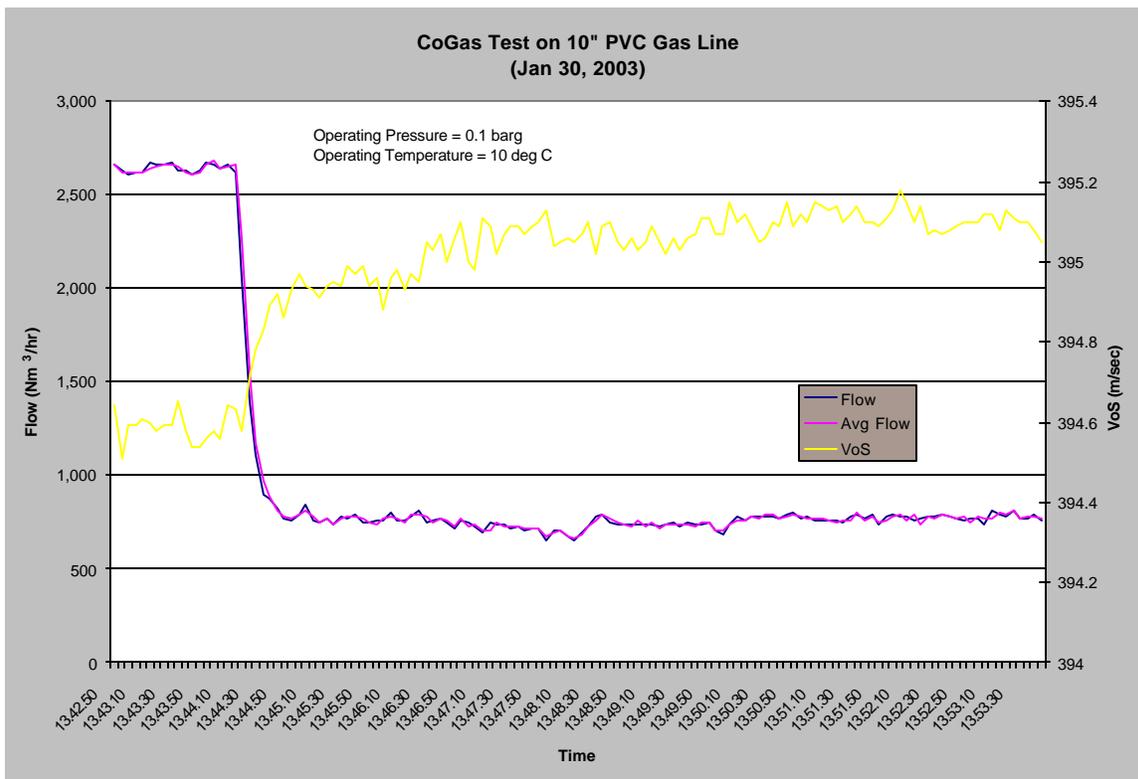


Figure 3b
Showing flow rate and speed of sound measurement for natural gas distribution in underground plastic pipe

Refractive Signal Injection

We will take time to review the fundamental difference between the two technologies. First, let us review Insert systems that are, in a sense, simpler systems. The transducer faces are parallel to each other and the signals are sent directly back and forth to each other through the fluid or gas. Some manufacturers provide reflection paths off the inside walls of the meter body in order to increase the path length and to provide better flow profile averaging. These systems are simpler because refraction does not need to be considered in their operation. Changes in fluid properties or changes in temperature do not impact the beam angle, as they do in refractive systems, since the transducers face each other directly. Refractive systems have the additional challenge of accommodating a potentially variable beam injection angle, which is not an easy problem to solve and is the primary differentiating factor among manufacturers of refractive (Clamp-on) systems. This paper not only describes one method of dealing with beam refraction, but it shows that, once dealt with effectively, refraction techniques offer significant benefits in performance over non-refractive (or Insert) systems.

WideBeam Transmission Technique

The technology breakthrough of the WideBeam technique requires the selection of matched pairs of transducers whose injection angle and frequency are specifically chosen to match the sonic properties of the pipe wall in order to generate a characteristic WideBeam resonant wave shape.

The pipe is used as a sonic waveguide in which signals travel without distortion. (See Figure 4) Since the pipe is actually the element that transmits the signal into the fluid, the wave shape of the signal in the fluid must match the wave shape of the signal in the pipe wall. In effect, the transducers simply excite a resonance in the pipe wall. The pipe wall actually becomes an integral part of the transducer system - not an impediment to overcome. And, since the pipe wall acts as a sounding board during transmit, the effective length of the sonic emitting surface is much longer than the physical dimensions of the actual transducer – hence, the WideBeam distinction. The typical beam width is between 3 to 5 times as long as the active area on the transducer surface or from 3” to 15” depending on transducer size. The beam in the gas is highly collimated, due in part to the large transmission aperture and low gas sound speed, so there is very little beam spreading.

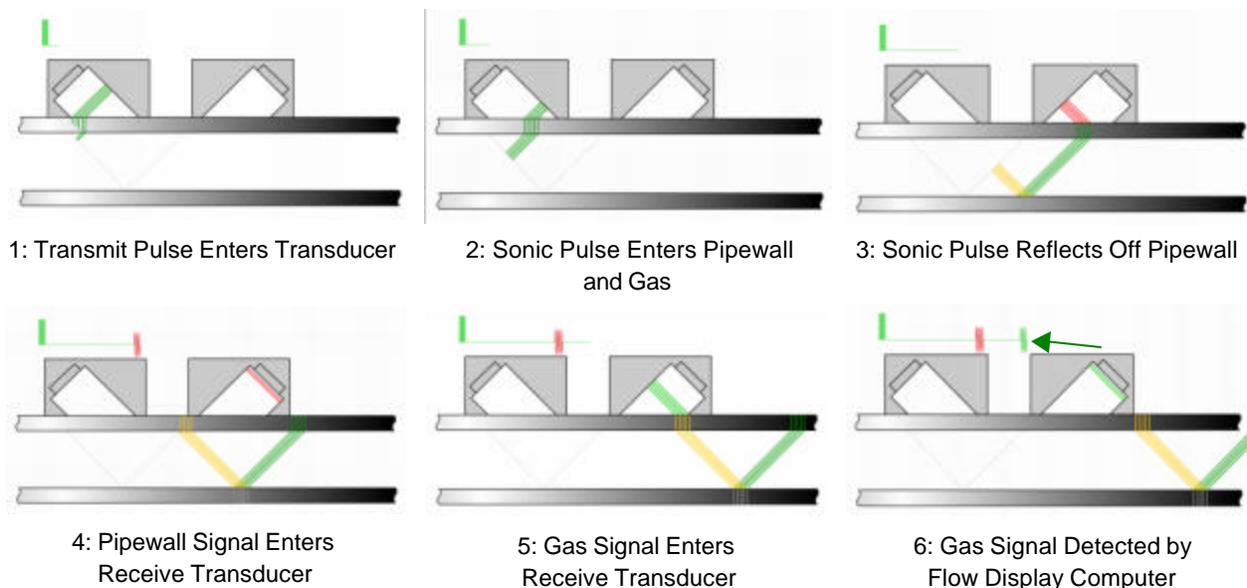


Figure 4
Wide Beam Signal Injection
(Showing Coherent signal that transforms the pipe into the "Flow Sensor")

In order to properly match the pipe's sonic properties, the WideBeam technique requires the use of frequencies much higher than a typical insert transducer. The range of frequencies that the WideBeam technique employs for gas measurement is typically between 200 kHz and 2.0 MHz. This provides immunity to the lower frequency noise from valves, etc. that have plagued the wetted sensor ultrasonic meters that normally use frequencies from 100 kHz to 200 kHz.

Pipe Noise - Friend or Foe?: Zeromatic Path

Refractive signal injection requires putting sonic energy into the pipe wall. When the flow transducers are mounted in Reflect Mode (same side mounting), a transmit signal actually takes two different paths as it travels to the receiving transducers. Some of the signal refracts into the fluid, is reflected off the opposite pipe wall, lands on the inside surface of the pipe wall, and is received by the transducer. However, the signal that is not refracted into the fluid stays in the pipe wall and travels to the receiving transducer through the pipe wall. Since the sonic velocity of the metal pipe is much higher than the fluid, and since the path length is much shorter, the signal arrives much sooner than the main 'measurement' signal. Since the signal traveling in the wall is not affected by flow rate, this signal can serve as a zero point reference that is constantly active by assuring that the travel times between the sensors are always equal. (See Figure 5)

Using Zeromatic Path eliminates all zero drift – enabling a true, usable 'live' zero that can be used to detect small leaks and valves that may not be fully closed on supposedly blocked lines. In addition, flow does not have to be shut and blocked in order to zero the unit. This should not be confused with zero-clear and deadband features offered by other manufacturers. These techniques simply approximate and hide zero offsets. Zeromatic Path eliminates zero offsets actively and continuously.

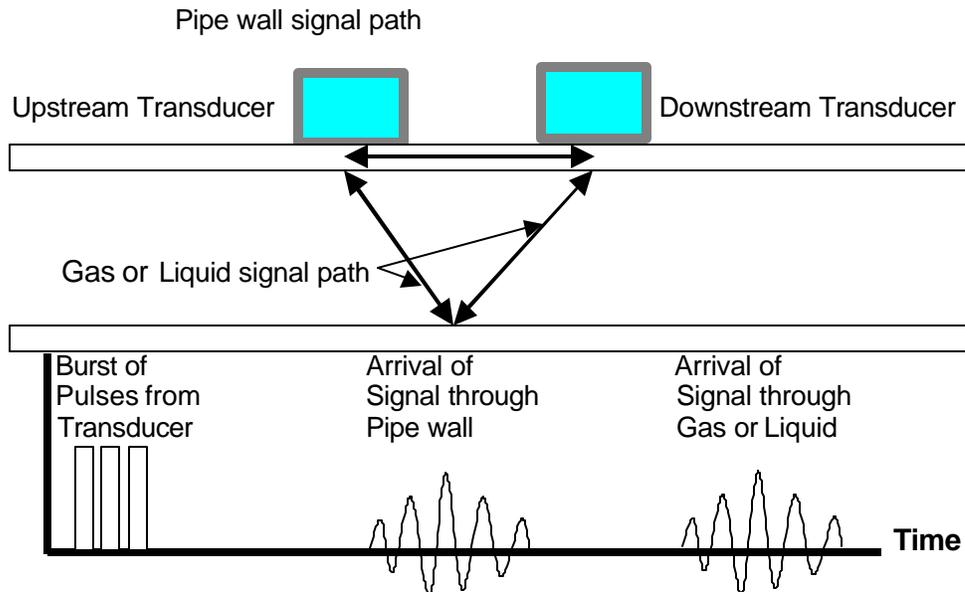


Figure 5 -Zeromatic Path Technique

(Allows flowmeter to actively set live zero without stopping flow.
Continuous operation of Zeromatic Path feature eliminates zero drift.)

Key requirements for Zeromatic Path operation are that the signal must travel within the pipe wall without being distorted by cancellations, and, the signal wave shape must be identical to the wave shape of the measurement receive signal. Both of these characteristics are provided by WideBeam technology as shown in Figure 4.

Beam Movement Problem

For non-wide beam, clamp-on systems (known as shear mode or narrow beam), application conditions for gas impose difficulties that limit performance and flow range. As the gas composition, pressure, or temperature change, the signal that is refracted into the fluid takes different path angles. Thus, the receive signal 'walks' on the inside surface of the pipe. In addition, at high velocities, the beam is blown – either compressing or elongating the path angle in upstream or downstream modes. (See Figure 6a)

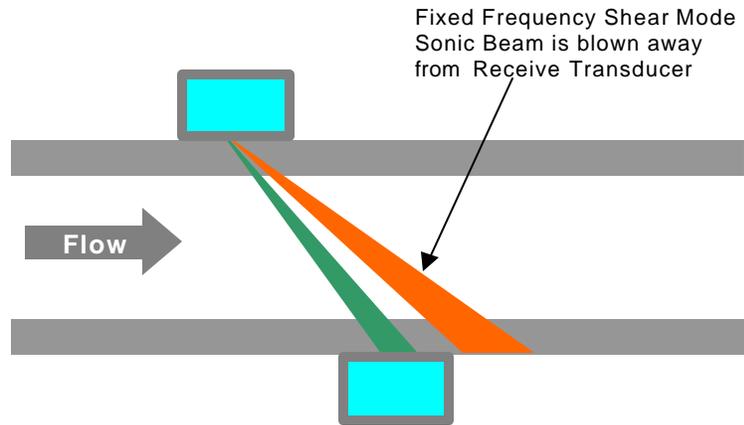


Figure 6a - Conventional clamp-on, shear mode technique showing susceptibility to beam blowing and exhibiting instability when application conditions change.

It should be said that Beam Blowing also impacts insert systems. At high flow rates the beams get blown away from the receive transducers. In addition, since the sonic beam spreads somewhat, even before the signal gets interrupted from beam blowing, the up/down signals can vary in waveshape producing drift and non-linearity.

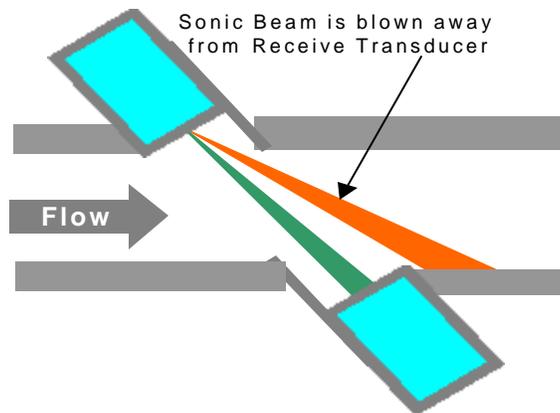


Figure 6b – Wetted sensor design showing effect of high flow velocity

Solution

For a refractive system to work reliably, the system must be able to detect signals that fall over a large range of lineal area on the inside surface of the pipe. Moreover, these signals must be free of distortion related to the degree of pipe travel that is required to get the signals to the sensor. The WideBeam transmission technique provides one way to overcome the effects of refraction angle changes due to gas composition, temperature, or pressure changes - not to mention beam blowing. The WideBeam approach is specifically designed to accomplish this. By acoustically matching the transducers to the individual pipe characteristics, the signals are transmitted between transducers without distortion, even under varying conditions of fluid and pipe travel.

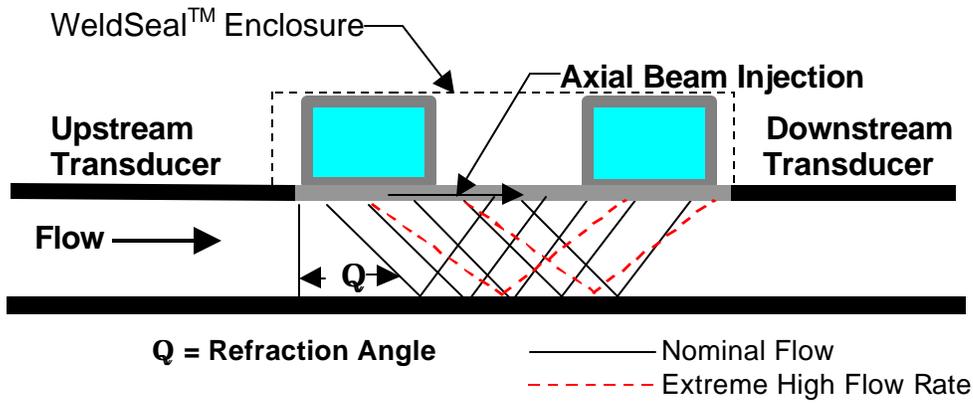


Figure 6c

Wide beam transmission utilizes the pipe as a waveguide sounding board, which produces a very large ultrasonic footprint and provides high tolerance to beam-blowing effects.

With WideBeam technology, very high velocity flow measurement is possible, and the flow range will normally exceed the capacity of the insert, chordal system. As shown in the test results from TransCanada Calibrations (Figure 7), the WideBeam system continued to perform very well at up to 130 ft/sec velocity while the insert, 5-path, chordal system failed at about 95 ft/sec. Keep in mind that this was in reflect mount configuration and if the application required higher velocity measurement, mounting in a direct configuration would double the range to at least 260 ft/sec, while sacrificing the benefit of Zeromatic Path, which only operates in Reflect Mode. Figure 6d shows a simplified illustration of how WideBeam overcomes the beam-blowing effects of high flow velocities encountered in gas applications.

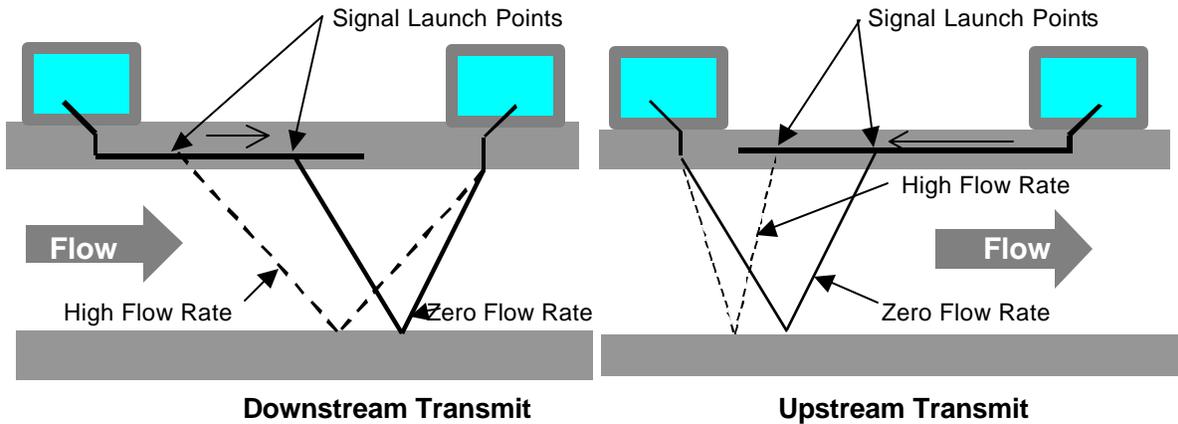


Figure 6d

(Note different degrees of Pipe Travel of Upstream vs. Downstream Transmit Pulses)

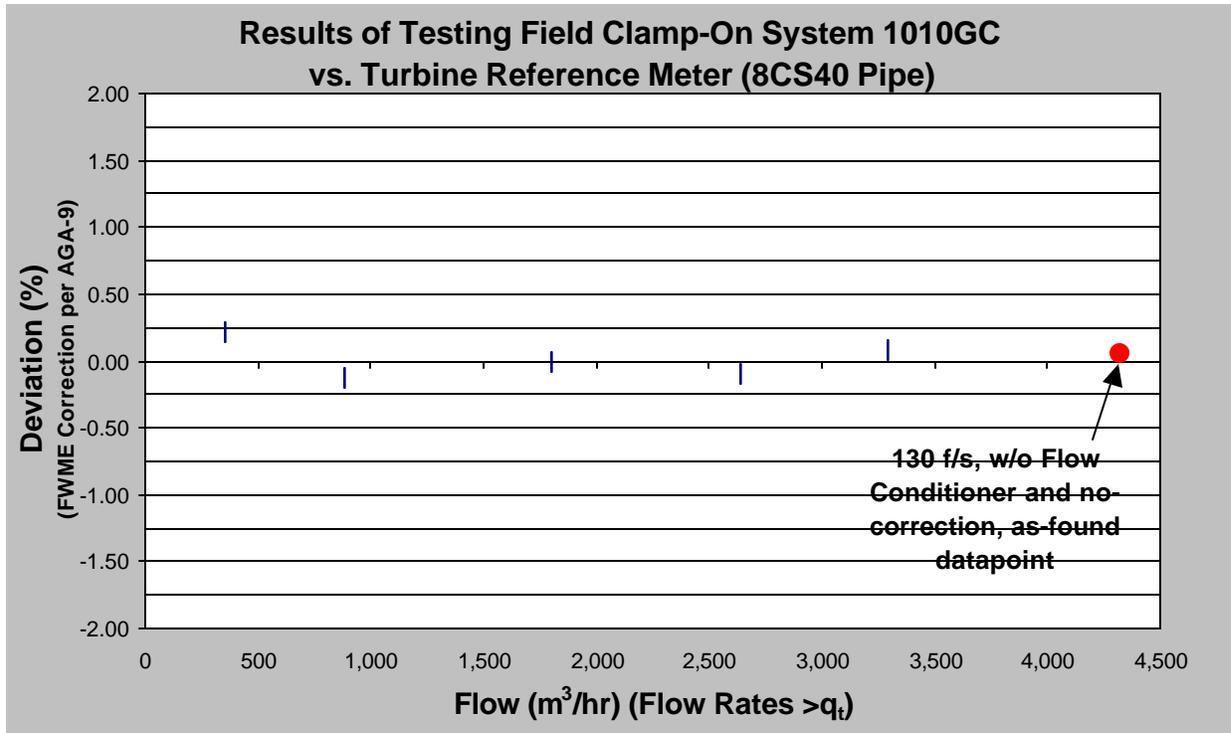


Figure 7 - Results of Testing of System 1010GC at TCC with flow rate conditioner (◆) and adjustments except for the data point at 130 ft/sec (●), which was “out-of-the-box” performance with flow conditioner removed.

Injection Angle

Snell's Law dictates the injection angle for Refractive systems. An Insert System can be designed at any injection angle. Typically a 45-degree angle is chosen to maximize time difference as a function of flow velocity. Smaller angles are chosen by some manufacturers to provide a shorter flange-to-flange length. Refractive systems use injection angles of between 5 and 10 degrees, depending on the technique used for signal injection. This at first may seem like a challenge, as the steeper injection angle will yield a smaller time difference for a given flow velocity. However, manufacturers of these systems generally come from the liquid side and have developed signal-processing techniques that can resolve very small time differences. In liquid transit-time flow measurement, the sonic velocity of the liquids is much faster than gas and the flow rates for liquids are much lower than is typical of gas pipelines. The result is that even with the steeper injection angle, the time differences evidenced in gas applications are equal to or larger than for the liquid case. Resolution, therefore, is the easy part. A side benefit of a refractive system is the potential for smaller flange-to-flange lengths due to the steeper injection angle.

WideBeam signal injection generally produces shallower angles as compared to typical 'shear mode' transducers used by other manufacturers of refractive ultrasonic meters. This shallower angle provides some degree of improved time difference resolution.

Comparing 'Paths'

The characteristics of the sonic beams produced by WideBeam refractive signal injection with external transducers mounted in reflect-mode (same-side mounting) are very different from those produced by insert or chordal transducers.

Externally mounted transducers are limited to injecting sound only through the diameter of the pipe. Utilizing a single reflection off the far wall enables reflect mode mounting and provides the convenience and alignment precision of same side mounting. However, even more important is the advantage that diametric reflect mode mounting has in overcoming the effects of cross flow (See Figure 8) and providing high immunity to the effects of swirl. A comparison of the geometries shows that insert chordal techniques must use opposing pairs of transducer in 2 planes in order to achieve the same cross-flow cancellation and swirl tolerance. Therefore, a single pair of diametric, reflect mounted transducers (external or insert) provide the crossflow and swirl benefits that would require 4 pairs of chordal transducers!

For most applications, between 2 and 4 paths, maximum, are recommended. This can be evidenced from liquid tests run for API testing which showed that a simple 2 path (reflect-mode), wide beam, externally mounted sensor system showed equal or better performance as compared to insert sensor systems with up to five paths.

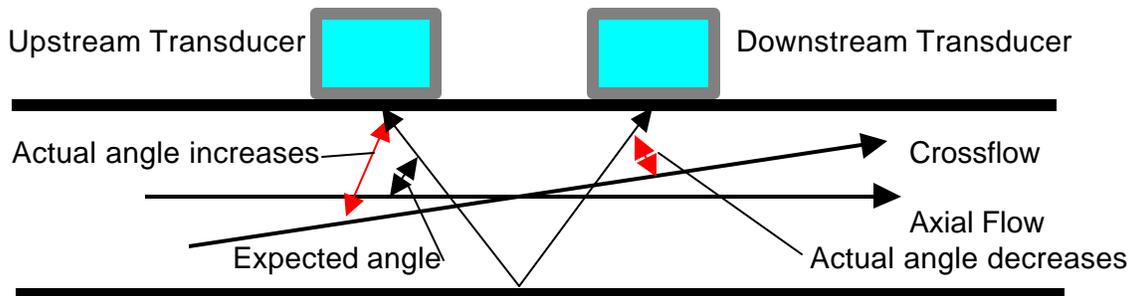


Figure 8
Crossflow Error Cancellation for Diametric Reflect mode transducer pairs

Field Performance

WideBeam, Field Installed Check Meters have been used successfully and tested at several customer facilities and testing labs. (Some of these have been presented above.) Examples of typical test results are shown for installations with good flow profiles (shown in Figures 9-13). Promising results have also been achieved for installations with swirl and distorted flow profiles at the Gasunie test. It is anticipated that the full details of those tests will be presented in another paper.



Figure 9a - Dual Path, Reflect Mode installation for a 20" pipe at Gasunie's Westerbork facility

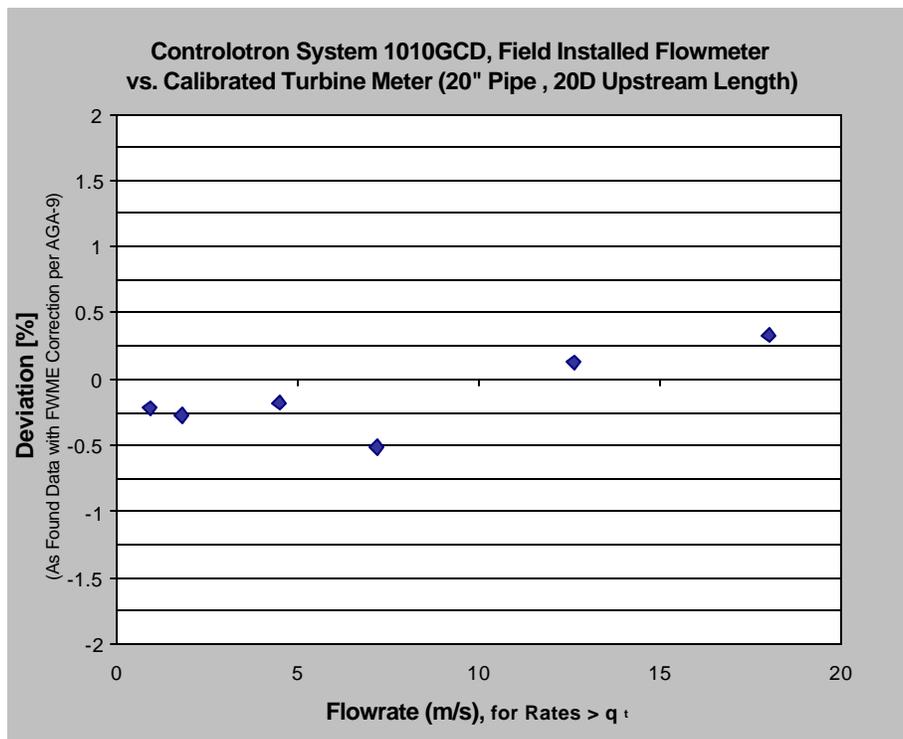


Figure 9b – Results of Testing for the 20" pipe shown above (with a distorted flow profile)

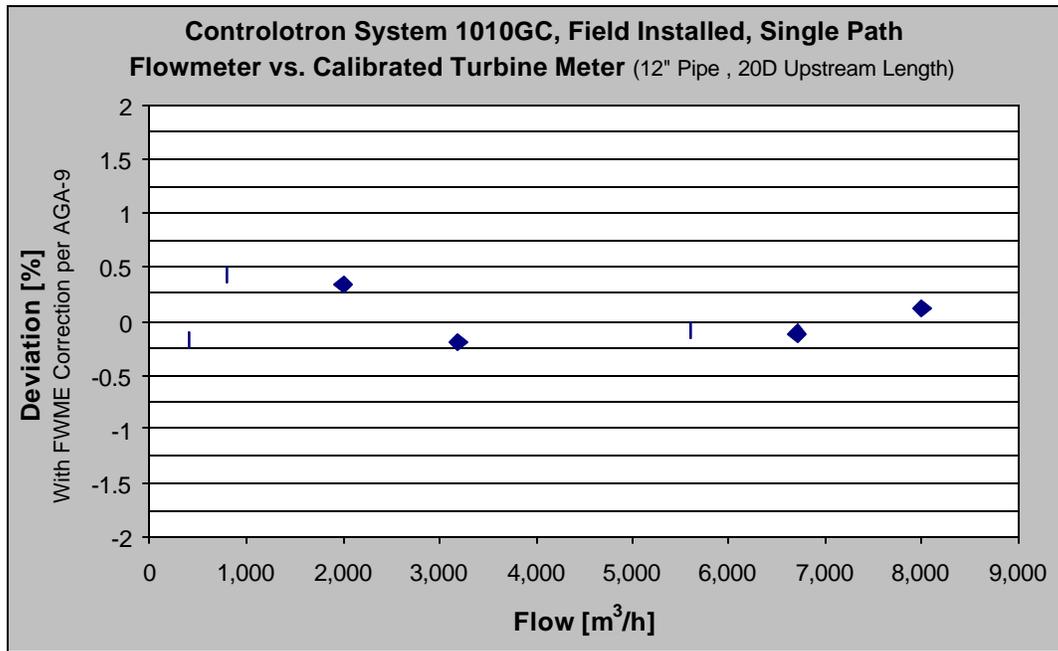


Figure 10 – Performance Test Results of Single Path Reflect Mode, Clamp-On Flowmeter (on 12" Pipe, at Gasunie's Westerbork Facility)



Figure 11 - Typical Installation of Field Clamp-On System with Protective Stainless Steel Enclosure (Enclosure may be tack-welded to pipe)

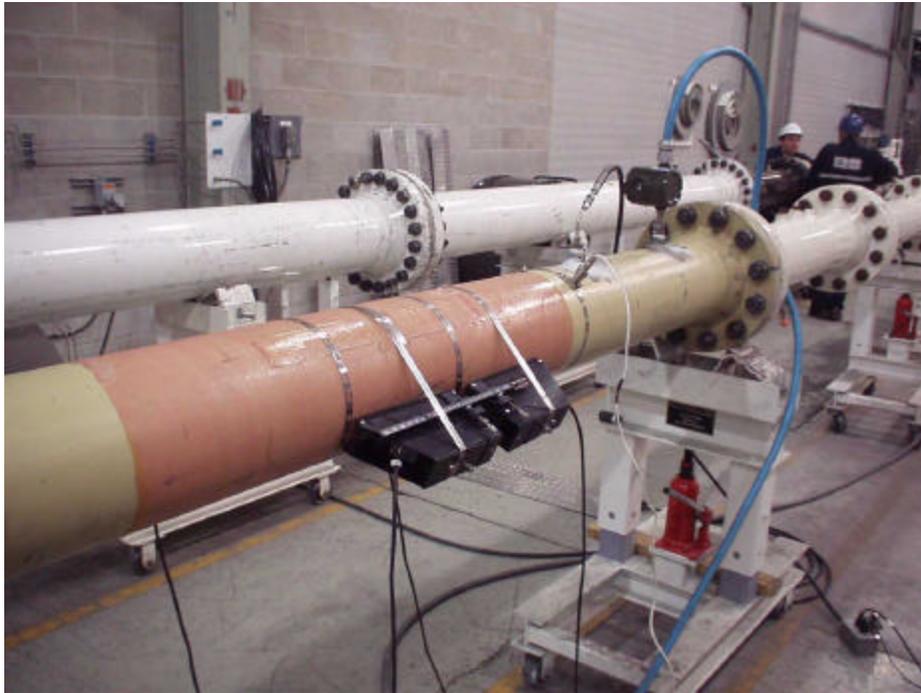


Figure 12a - Calibration set-up for Dual Path, Reflect Mode field clamp-on systems at TransCanada Calibrations (other pair of sensors not visible).

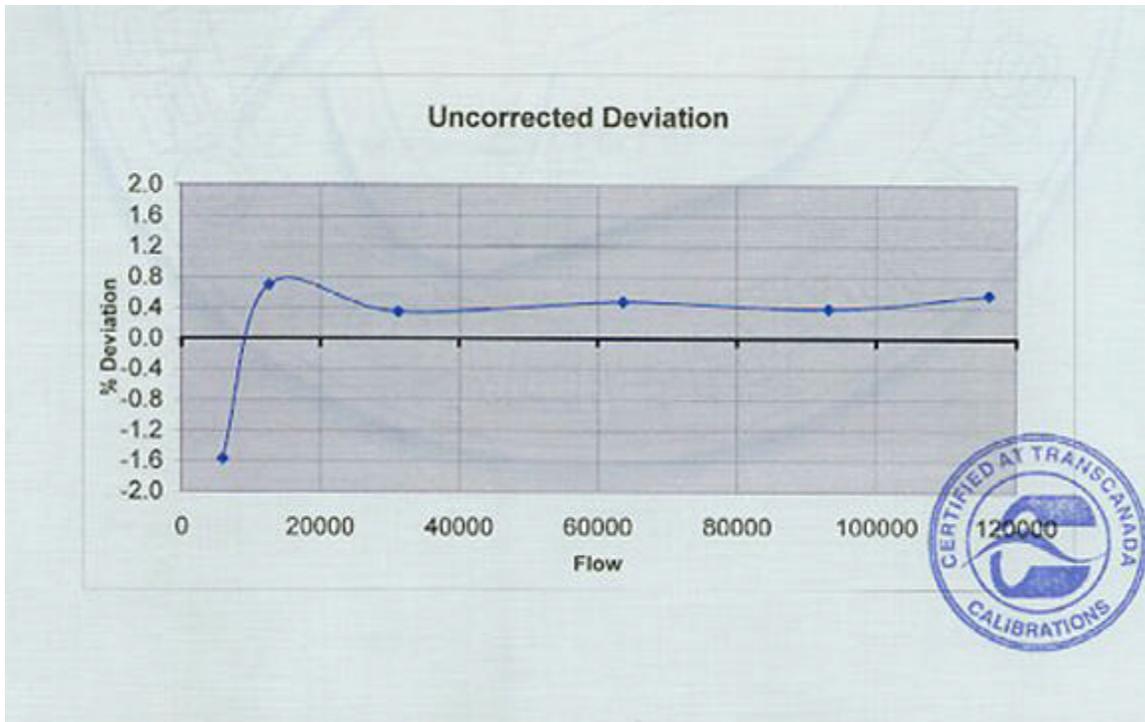


Figure 12b – Certified Results of TCC Testing



Figure 13a - Single path field clamp-on meter installation on 16" pipe at VNG's Leipzig facility (normally requires about 15 minutes for setup)

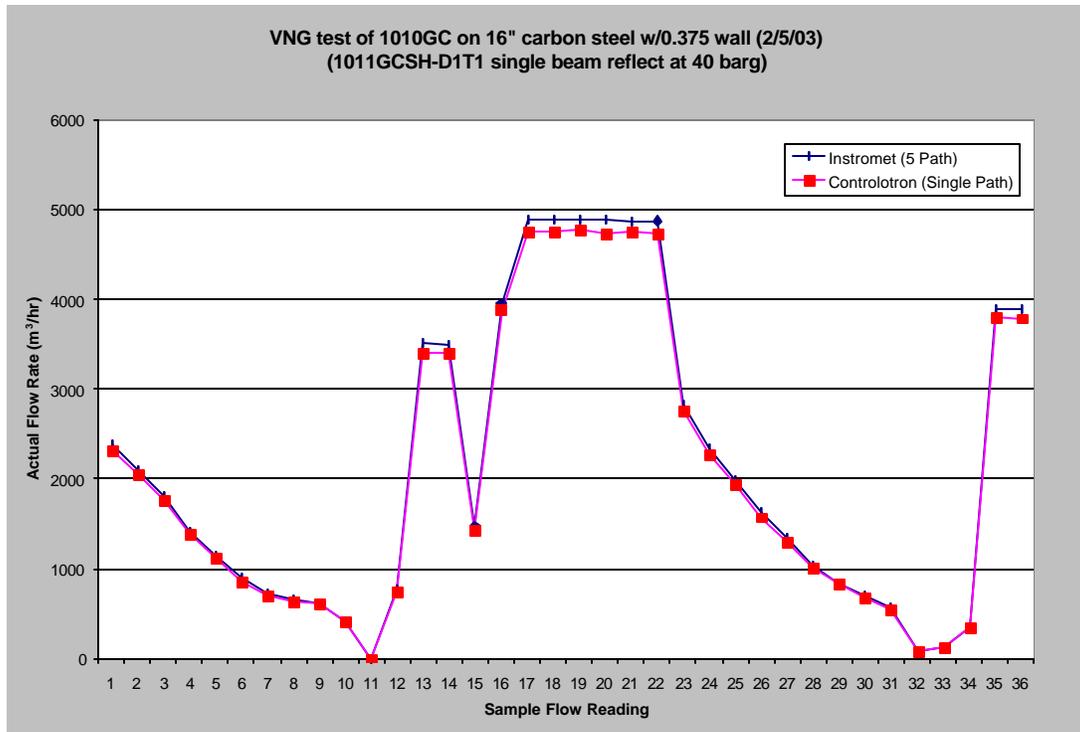


Figure 13b - Flow comparison of single path, Reflect Mode, field clamp-on, WideBeam system and Instromet, 5-path, chordal system

Future Developments

As this technology advances, it is expected to yield performance at lower pressures. Research and continuous development with cavity free spool and field clamp-on meters have shown that systems for steel pipes operating at pressures down to 5 bar or less will eventually be able to be offered. These meters would enable use on Fuel Gas lines for industrial and larger commercial facilities and lower pressure central power plants. Operation on higher concentrations of wet gas will also be available, based on future developments. Coupled with development of higher temperature capabilities, one design goal is to eventually provide clamp-on meters for steam applications.

Following the success of liquid pipeline management systems, leak detection systems for gas pipelines, based on the mass balance technique using distributed, field installable clamp-on meters, will be another area of growth for this technology.

All Ultrasonic Meters are expected to be able to take advantage of AGA 10, when it is approved, which will allow field verification and calibration confirmation of speed of sound measurements.

Conclusion

Externally Mounted Transducers or Refractive ultrasonic flowmeters are now a 30 year in the making 'overnight success' story and have come out of the shadows to take their place among the best custody transfer capable flowmeters. Offering advantages in cost and maintenance with cavity-free designs plus offering performance advantages like Zeromatic Path makes these meters worth considering. The advantage of being able to try this technology in the form of a field clamp-on version enables potential users to evaluate the basic technology quickly and easily.

At this writing, data was only available for the field clamp-on versions. Additional information covering the latest cavity free spool meter testing will be provided as a handout and included in the PowerPoint presentation.

External / refractive systems are not all alike and should not be lumped together. Technology differences – transducer design and signal processing techniques – matter. Depending on the type of application, features and specification differences like ease of use, cost, and pressure limitations may sometimes be more important than performance. For this reason, we encourage users to be heartened by the fast paced technical advances that these meters are making and to maintain awareness of all the manufacturers' successes and setbacks as these systems move into the mainstream of gas flow measurement.