Paper 13

Latest advances in Ultrasonic Flow Measurement of Natural Gas using Externally mounted, Non-Intrusive Sensors

Peter G. Espina, Douglas Baumoel, Controlotron Corporation, USA

Impact of Flow Profile Effects on Controlotron WideBeam, Clamp-on Flowmeters

By Douglas Baumoel
Executive Vice President
Controlotron Corporation
155 Plant Ave.
Hauppauge, NY
USA 11788
1-978-922-5442
dbaumoel@controlotron.com

Introduction:
In July of 2003, Controlotron had the opportunity to participate in tests run by Nova at the Didsbury facility in Canada. The purpose of the tests was to investigate the impact of flow profile distortions on field clamp-on ultrasonic gas flowmeters. We are pleased to present the results for the Controlotron WideBeam™ system.

Controlotron WideBeam technology uses sound that passes diametrically through the fluid – not in chordal mode, as is the case for most insertion type meters. Consequently, meter behavior is expected to be quite different from other ultrasonic meter types under conditions of flow profile distortion. Controlotron's externally mounted WideBeam sensors also interrogate a very large percentage of flow volume within the measurement section. This produces more flow profile averaging than shear mode, clamp-on, or insertion type sensors. For these reasons, it was anticipated that the Controlotron WideBeam system would be highly tolerant of flow profile variability.

Test Criteria:
Five data points were taken for each test condition, and the average of each set of five trials was used for each data point presented. A single example of the typical measurement spread between these five trials is presented in Figure 4, to show the typical repeatability of each test cast. The standard deviation among the five trials was between 0.02% and 0.10%.

The test variables were:

- Flow **Rate**
- Meter installation **Distance** from a range of prevalent pipe elements that are well known to distort flow profiles
- **Type** of flow profile distorting elements

For each piping case, three flow rates were explored. The piping cases included three different flow profile distorting pipe element configurations and five different meter location distances from the pipe elements.

In order to eliminate the influence of transducer removal and re-attachment to the pipe, the transducers were installed on a spool section, and the spool section was moved upstream and downstream according to the test plan. A 2-beam, Reflect-Mode system was tested with transducers mounted at 10 o'clock and 2 o'clock. While this might not have been the recommended orientation for each specific installation, this orientation was maintained throughout the test so as not to introduce another variable.

The three cases of flow profile distortion elements were:

1. Simple single 90^o elbow
2. Dual, out of plane 90^o elbows
3. Dual, out of plane elbows with CPA plate flow conditioner

The CPA plate was installed 3D after the double elbow except for the 44D meter placement where the CPA plate was installed 21D from double elbow.

The flowmeter was installed at five different distances downstream from these elements: 5D, 9D, 13D, 23D, and 44D

Three flow rates, expressed in terms of average speed (nominal approximate values) at each flowmeter installation distance were investigated: 5 m/s, 8.5 m/s, and 13 m/s

Unfortunately, pipe flow profiles at the meter installations were not independently measured. However, NIST conducted measurements downstream from these types of pipe elements and results can be found in the NIST technical paper, *Flowmeter Installation Effects Due to Several Elbow Configurations*, written by Dr. George Mattingly and T. T. Yeh. In these NIST studies, where the pipe Reynolds Number was at least 100,000, the flows entering these elements were fully developed. Therefore, the distorted profiles downstream were due to the elements themselves. In the Didsbury results, the pipe flow distortions may be influenced by the flows entering the pipe elements.

In these tests, the flow entered the variable flow elements from a pipe 'T' and through an open gate valve, both within approximately 10 feet of the flow elements. The outlet of the 'T' induced an additional bend in the same plane as - but in the opposite direction from - the first elbow. It was thought that this would not induce Swirl. However, it did impact the flow profile being generated for the tests.

The fact that flow profiles were, to some degree, uncertain and not necessarily classic 'single elbow' or 'double out of plane elbow,' is not germane to the outcome of the tests. The fact is that the flow profiles were dramatically distorted, and the results generated were a fair test of each flowmeter's sensitivity to flow profile distortions.

The Flowmeter:

The Controlotron flowmeter under test was a 1010GC field clamp-on model attached to a facility-supplied 8" CS40 stock pipe. It was left attached for the duration of the test. No pre-calibration or factory fine-tuning was done for this unit. Performance should be viewed as that of a field clamp-on device, not a Controlotron supplied Custody Transfer capable spool piece unit. The standard specification for the Controlotron field clamp-on gas meter is 0.5% to 1% of rate accuracy with 0.1% repeatability under good flow profile and application conditions. Under typical field application conditions, we anticipate performance of 1% to 2% of rate.

This should be contrasted to a spool type Controlotron ‘Cavity Free’ Gas Flowmeter that is pre-calibrated, linearized, and fine-tuned at the factory for optimal performance. Typical specification for this device is within 0.15% of rate and 0.05% repeatability over a 100:1 turndown ratio.

The Technology:
The externally mounted WideBeam transducers transmit sound waves diametrically through the pipe. However, this is not the only difference compared to insert chordal types. The WideBeam transmission technique is ***also*** quite different from typical shear-mode clamp-on flowmeters. The WideBeam design resonates the pipe wall in a way that samples a much larger percentage of the flow in the measurement section of the meter.

WideBeam transducers are selected to match the pipe material and wall thickness of the pipe. When transmitting, the resonance induced in the pipe wall effectively extends the active area of the transmitting transducer several times. On the receive side, the pipe becomes a collecting antenna for the receive transducer.

Figure 1 shows this resonance pattern being generated in the pipe wall.

Figure 1

Figure 2 shows the WideBeam being collected for sensing by the receive transducer.

Figure 2

Figure 3 illustrates the resulting beam pattern in the pipe for a 2-beam, Reflect-Mode, WideBeam system, as was used in this test program.

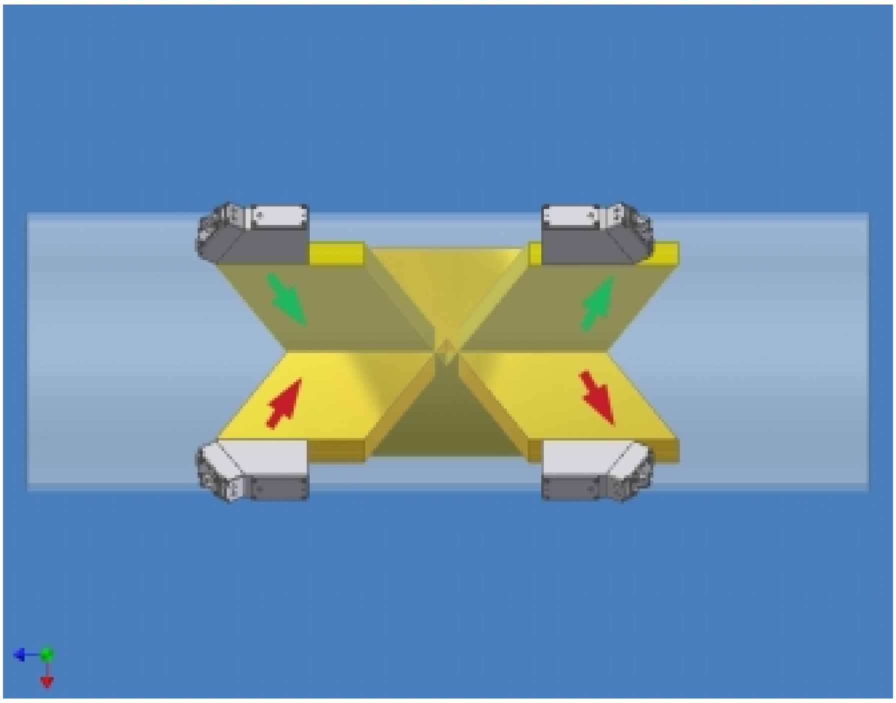

Figure 3

This illustrates how the WideBeam technique samples a larger percentage of the gas within the measurement area. Typically, the number of paths is chosen to provide a volume sampling between 10% and 50% - depending on pipe size, expected degree of flow profile distortion, and performance requirements.

Results Summary:
With one exception, the Controlotron meter essentially met its 1% to 2% of rate performance expectation for the 'Field-Installed, Uncalibrated' meter. The one exception was a case where the transducer orientation was clearly not in accordance with the manufacturer's recommendations for that particular piping arrangement (sensors not located in the plane of the bends).

Under good flow profile conditions (meter installation a sufficient distance from distortion elements), the test results show that the Controlotron WideBeam, clamp-on systems meets its 0.5% to 1% of rate accuracy specification. The data also show that the repeatability of the meter fell well within the 0.10% of rate specification in **all** cases; it was within 0.05% in **most** cases. This implies that even this 'check-meter' can be calibrated to each unique piping arrangement to achieve custody transfer performance.

Detailed Results:
Figure 4 shows the repeatability of the system for five different trials; each at one of three different flow rates for the case where the meter was mounted 23 diameters downstream from a single elbow. This repeatability was typical for the other cases as well.

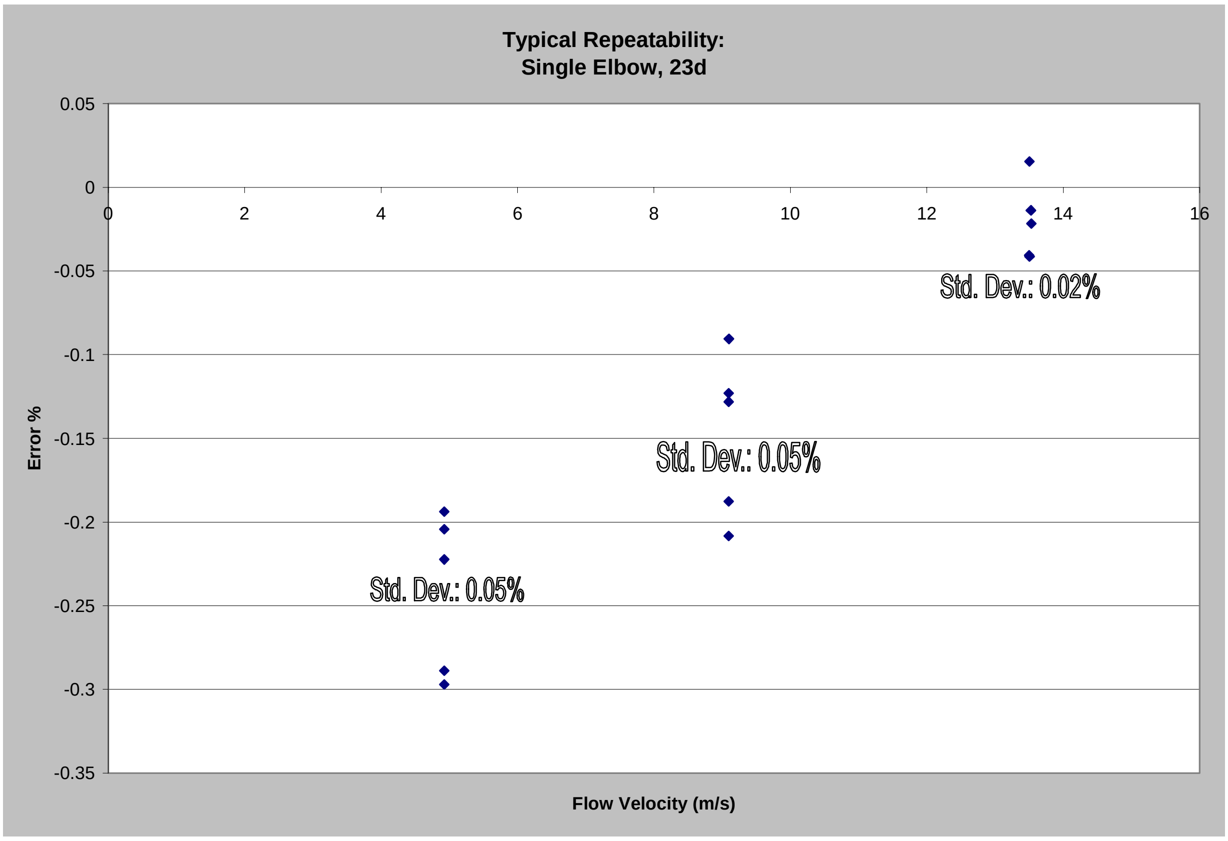

Figure 4

Figure 5 shows results for the Controlotron Meter as a Function of Flow Rate (Average Speed) for Specified Distances Downstream from the Single Elbow, the Double Elbows Out-of-Plane, and the Double Elbows Out-of-Plane with the CPA Flow Conditioner.

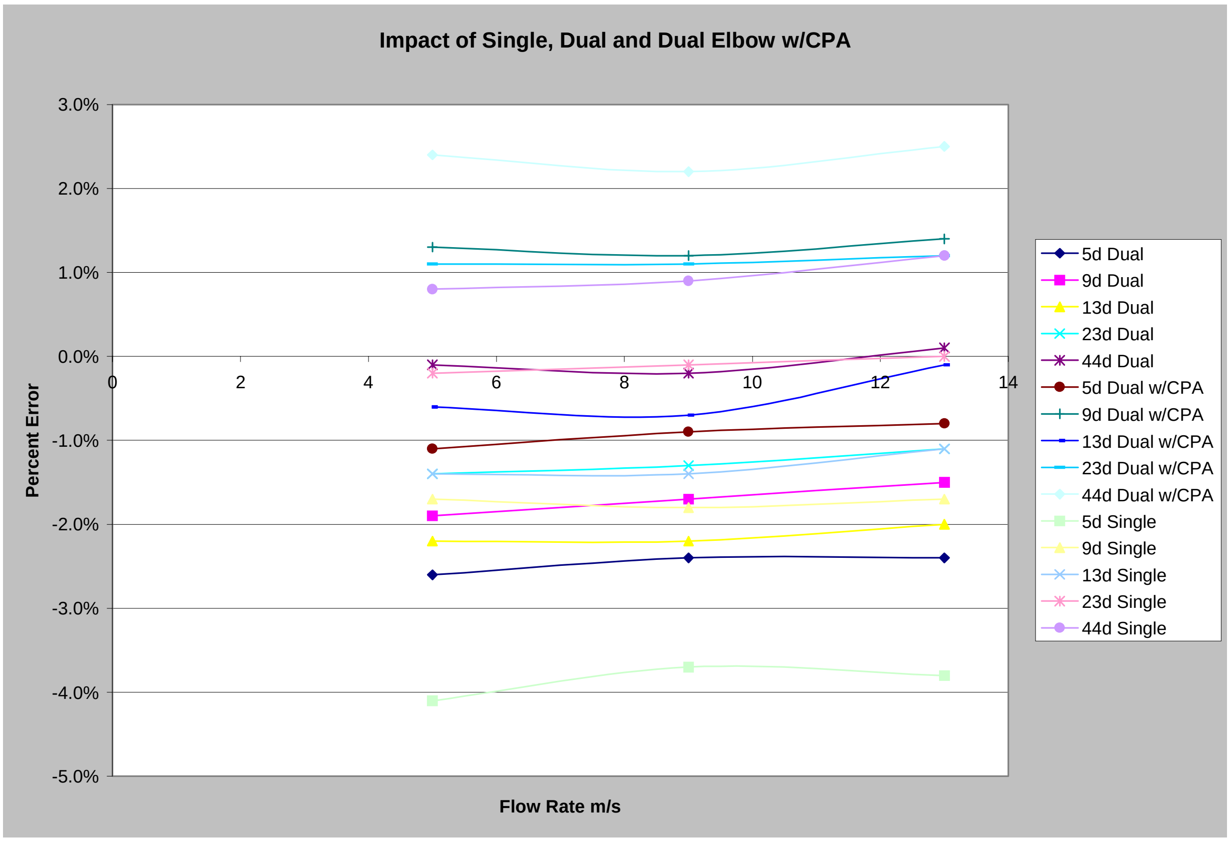

Figure 5

This chart shows the exceptional inherent linearity of the meter at each individual distance from the various flow profile disturbances. It should be remembered that these curves are generated from an Uncalibrated, Non-linearized flowmeter installed in the field on a facility supplied spool section.

The individual plots lead us to the following conclusions:

a. In all cases without a flow conditioner, when the meter is at least 10 diameters (approx.) downstream from the exit of the elbows, the meter meets its performance expectation and shows exceptional inherent linearity and repeatability.
b. The worst 'outlier' is for the case of 5D downstream from a single elbow that showed a -4% calibration offset (low). This is probably due to a very slow center core flow if the flow at this location resembles that measured in the NIST study of the single elbow effects. Had the meter been oriented such that the sensors transmitted energy in the plane of the bend, we believe this data would have come in within the 1% - 2% of rate performance.

Figure 6 tracks meter accuracy as the meter is moved downstream from the flow profile distortion elements. Each curve represents a different flow rate and each group of similar curves represents a unique flow profile distortion element configuration. We surmise that the undulating nature of the swirling flow profile is exposed in Figure 6.

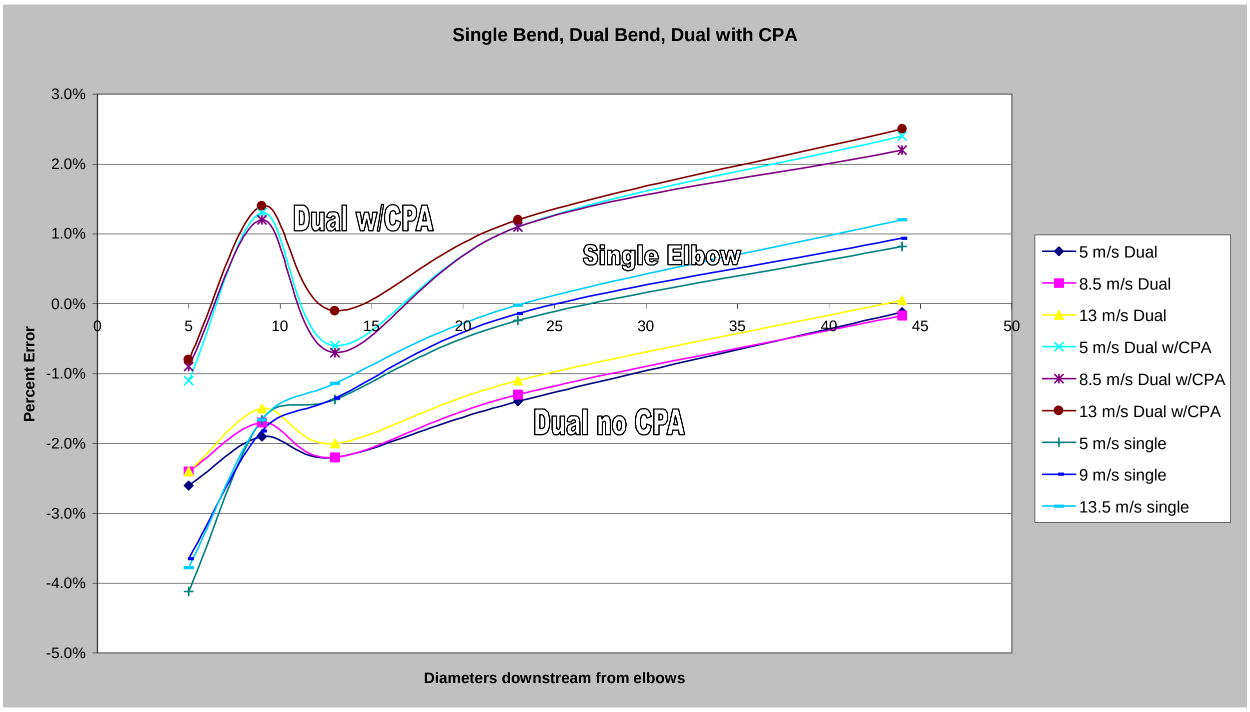

Figure 6

For the case of the single elbow, it was noted that no attempt was made to position the sonic beams in the plane of the bend in order to ensure cancellation of cross-flow error. Upon review of the tests, it was determined that the flowmeter was installed in an orientation that ***maximized*** error due to cross flow. This is especially evident during the testing done close to the elbow. We expect that proper orientation of meter would have enabled the meter to fully meet its specification.

For the case of the Dual Elbows, the highly non-linear impact of swirl is evident with distance. This is probably due to the undulating center cone of flow at various positions along the pipe. When the center cone is more compressed or inverted, the meter reads lower. The data shows this phenomenon to correlate closely with distance. Please note that this is merely speculation and that more detailed studies are suggested.

In the case of the Dual Elbow with CPA Plate flow conditioner, we can see that the impact is a simple shift of about +2% in the calibration factor. However, the plate did nothing to mitigate the variation in calibration along the length of the pipe. Speculation regarding this behavior is provided below in the section on 'Flow Conditioners.'

When looking at the graphs, the excellent grouping of results within each flow profile distortion element type is very apparent. This clearly shows the impact of the flow profile averaging capability of the WideBeam, Diametric, Reflect-Mode signal injection technique. It implies that this technology can be reliably calibrated for a variety of piping configurations and conditioner types. The important factor in calibrating this unit to a custody transfer performance level is to duplicate the piping configuration. This becomes more evident in the simplified Figure 7.

Figure 7 restates the data from Figure 5, however the results obtained with the CPA plate and the results obtained at meter location 5d from the single elbow are removed.

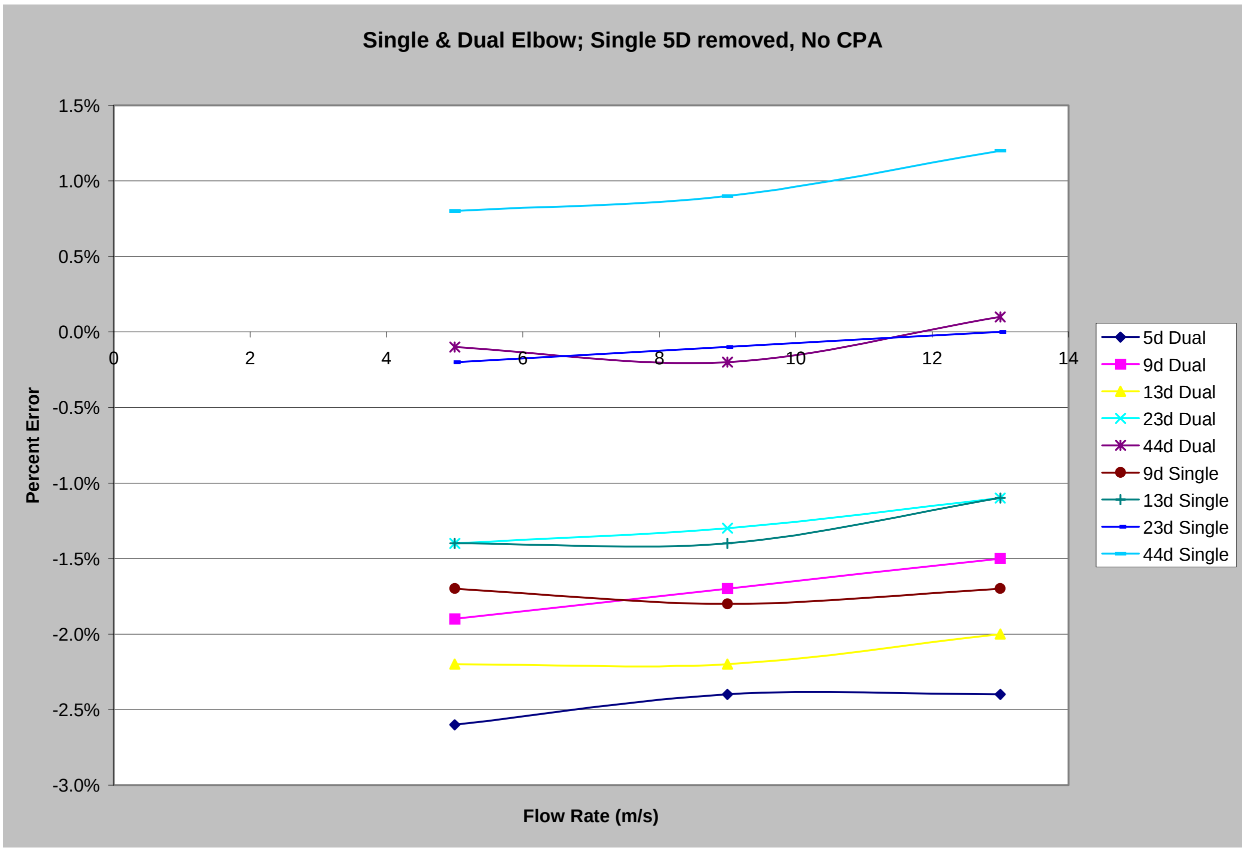

Figure 7

For reasons which will be explained below, the use of a CPA Flow Conditioner or similar type elements may not be ideal for Controlotron's WideBeam, Diametric flow measurement technology – unless meter calibration is specifically adjusted for that particular conditioner. In addition, the one set of data for the single elbow case at 5D from the elbow has been eliminated as this is considered a misapplication of the product due to incorrect meter orientation. Transducers should have been mounted at 3 o'clock and 9 o'clock when located very close to a horizontal elbow.

This Figure shows that the 'out of box,' uncalibrated meter, basically met its specification even under extraordinary conditions of swirl and crossflow without factory fine-tuning. The only two curves outside of the 2% band were for 5D and 13D away from a double elbow. Yet, these curves were still within 2.5%.

Practical Meaning of Data:
The data presented show that the WideBeam, Reflect-Mode mounting technology provides excellent flow profile averaging and is highly tolerant of crossflow and swirl. This field clamp-on meter can be used with a high degree of confidence that it will meet its accuracy specification even under conditions of significant flow profile distortion.

The data also imply that this technology can be calibrated to specific piping configurations with distorted flow profiles, due to its excellent repeatability. In addition, since known piping configurations have been shown to have predictable flow profile impact (refer to NIST paper mentioned on page 2), it is possible to specifically program a flowmeter for these piping conditions. In other words, if a pre-calibrated, flowmeter (i.e. within 0.25%) is intended to be used at 10D from a single elbow or 8D from a double elbow, for example, a calibration factor can be determined from theoretical and historical data that will optimize accuracy for that application. This is made possible by the extremely good flow profile averaging offered by WideBeam systems in Reflect-Mode mounting.

A Word About Flow Conditioning:
Most flow conditioners for ultrasonic flow meters have been designed to restore a conical, symmetric flow profile. This is required for optimal performance of insert-type, chordal ultrasonic flow meters. Insert chordal type meters are impacted less by Reynolds number effects because they have the ability to measure the shape of the flow profile and compute a weighted average. The challenge when using diametral or clamp-on flowmeters with this type of flow conditioner is that the conical profile may not reflect the shape of the flow profile normally associated with the viscosity, flow rate, and pipe characteristics of the application. In other words, while these types of flow conditioners do a good job of straightening out the flow, they may produce a flow profile that would normally be associated with a different Reynolds Number. The result is a false or forced Reynolds number for that particular flow rate.

A diametral system relies on the predictable nature of flowrate and Reynolds Number, and it has no means of determining the Reynolds Number through path analysis since all paths go through the center of the flow stream. Therefore, if the shape of the flow represents an artificial N_{re} – not predicted from the flow rate, viscosity and pipe conditions, an incorrect N_{re} Compensation value will be used and the meter may show errors. The flow conditioner adds an element for which there is typically no compensation. However, it is certainly possible to calibrate the meter specifically for any individual flow conditioner.

WideBeam, Reflect-Mode systems do such a good job of flow profile averaging that the impact of flow profile distortion is inherently minimized, and making the flow more symmetric or conical is not crucial. (Proper meter orientation is assumed for crossflow applications.)

Controlotron recommends a different type of flow conditioner. WideBeam, Reflect-Mode technology benefits from a conditioner that compresses or flattens the flow profile. This serves to reduce the criticality of the Reynolds Number Compensation and makes the meter more immune to changes in viscosity of the liquid or gas. (Note: Controlotron offers viscosity tracking software to deal with viscosity changes in liquids.) Controlotron manufacturers a variety of flow-flattening type flow conditioners. This device is essentially an aggressive reducer that serves to mix the flow and flatten the profile. The result is a dynamic expansion of the 'flat' area of the Reynolds Number Compensation curve.

Although extensive testing on Gas applications has not yet been accomplished with various flow conditioners, Controlotron ***does*** have experience with flow flattening elements for liquid applications. These seem to bear out the theory, and we see no reason why this should not carry over to gas applications.

When a flow conditioner is used with a WideBeam system – or any diametral flowmeter – calibration must be done either with the conditioner in place or with the known impact of the conditioner accounted for in the programming of the flowmeter.

It is our expectation that if an aggressive concentric reducer type of flow conditioner was used as the conditioner, the data would have shown markedly less of the characteristic non-linearity with distance caused by the double elbow. There still would have been some calibration shift, of course, but the shape of these curves (Figure 6) would have been much more flat and the range of calibration factors (Figure 5) would have been more compressed. To repeat, when using any flow conditioner with a diametral system, the system must be calibrated to that conditioner.

It should also be noted that the proper position for such a flow-flattening conditioner would be very close to the inlet of the flowmeter. Controlotron actually offers its Profiler conditioning element built in to the spool itself. This is due to the limited range of the flattening effect as flow quickly regains its characteristic conical shape.

It is hoped that further testing of flow conditioners with WideBeam technology can be done in the next few months.

Conclusion:

The most important aspect of a flowmeter is its ability to meet its specification – whatever that specification may be. This test exercised a field-clamp-on meter over a wide range of installation and flow profile conditions. The instrument not only met its specified accuracy and repeatability range, but it exposed the potential of the technology to achieve custody transfer accuracy in its pre-calibrated spool configuration.

NOTE

A special thanks to Dr. George Mattingly of NIST for his technical assistance in reviewing and interpreting some of the data in this paper.

Addendum:

Photos of the Test:

Single Elbow

Dual Elbow

Other Test Site Photos

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.