CLAMP-ON ULTRASONIC FLOW METER APPLICATION AND PERFORMANCE

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This paper is directed to ultrasonic natural gas meters using transit time across the gas pipe as the measurement variable. Custody transfer meters using sensors wetted with gas are the more familiar meter format. Clamp-on meters are quite similar.

General

Clamp-on meters are specified to achieve one to three percent uncertainty. Manufacturers cannot control the quality of a given field installation and must provide latitude. Lab testing has demonstrated many installations perform at an accuracy level range of 1%. If a reliable installation technique is maintained, the clamp-on meter will often perform better than manufacturer standards. Further, the meter control units have piecewise linear error correction schemes such that they can be adjusted to reference flow rates as afforded at a flow lab.

Clamp-on repeatability is very precise. Often the exact flow volume is not as important as repeatable data before and after an experimental change such as a meter cleaning. Changes as small as 0.1% can be detected. There is a learning curve or experience effect. New users may have no confidence in the clamp-on technology. Training helps and repeated installation in known settings aids user confidence. Clamping on at a flow lab where flow rate is known is helpful. In fact, a useful application is clamping on a custody meter as it is flow calibrated at a lab and collect clamp-on data at the same time. The clamp-on meter can later be installed in the field setting and compared to the custody meter to identify relationship shifts between the two meters as found at the flow lab.

Meter Basics

Both wetted sensor and clamp-on meter types send ultrasonic pulses across the gas stream at an angle to sense the flow field. Both use quartz crystal or other piezoelectric materials as acoustic impulse sources.
The difference is the mount. The clamp-on is outside the pipe and is not exposed to conditions within the pipe. It can't be fouled as wetted sensors have a tendency to do.

While wetted sensors are fixed at an angle to the pipe axis, clamp-on meters rely on physics to establish the angle. The ultrasonic pulse bends as it enters the gas stream caused by the index of refraction between the steel pipe and the gas within the pipe. The angle across the pipe rather than a normal square diameter path is necessary to develop a component of gas velocity in the transit time. The gas velocity traveling downstream makes the transit across the stream faster than simple speed of sound in the gas. Similarly, the moving gas makes transit time longer when the ultrasonic beam is traveling upstream. The ability to send pulses both downstream and upstream cancels out many gas variables and simplifies gas measurement to just precise measurement of time.

There are two types of clamp-on transducers, Lamb wave and Shear wave. Lamb wave transducers sometimes called wide beam, are easier to work with. Refer to Figure I.

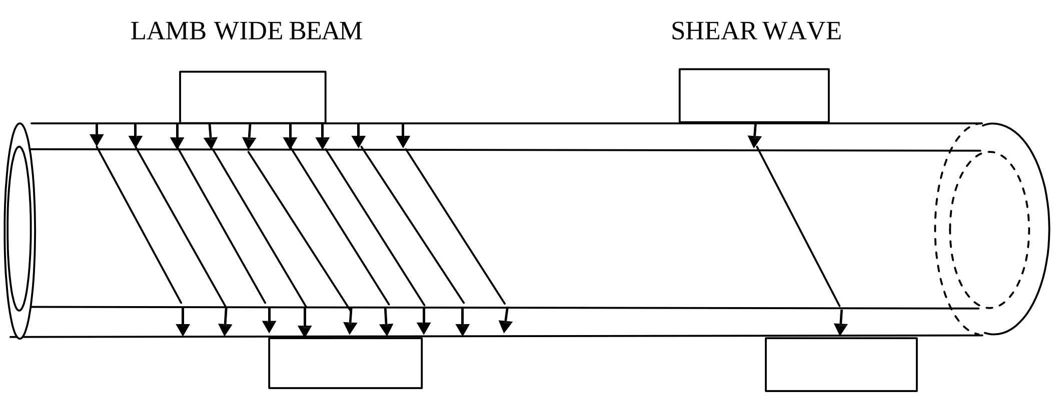

Figure I. – TRANSDUCER TYPES

The Lamb wave transducer has its crystal parallel to the pipe wall. It produces a large coherent pulse with many rays launched at the same angle. The receiving transducer only needs one of the rays to operate so that exact transducer spacing is not critical.

Shear wave transducers have the crystal normal to the pipe wall or sort of vertical. This produces a small beam and alignment is important. Shear wave transducers will function on heavy pipe walls more than an inch thick.

The piezoelectric effect in quartz rock crystal or other piezoelectric material is used to produce a short acoustic pulse. An electrical pulse excites the transducers and the crystal responds with a physical ringing response much the same as a hammer on a bell. That sound level is transferred to the pipe wall and throughout the gas stream.

An electronic control unit provides the transducer pulse excitation and allows for many forms of measurement output. Gas velocity is the base variable but this can be readily multiplied by pipe cross sectional area to develop actual flowing volume. Accumulation of actual volume is available and there are interface programs that run in a laptop to extract data and provide diagnostics. Some of the interface programs such as Siemens Si-Ware and Flexim FluxDiag provide views of the operating waveforms showing timing detection points for help with measurement quality assurance. See the following Figure II. On the envelope waveform, the leading baseline should be clean and the pulse should have a well-defined sinusoidal form with an exponential rise and fall in about eight cycles.

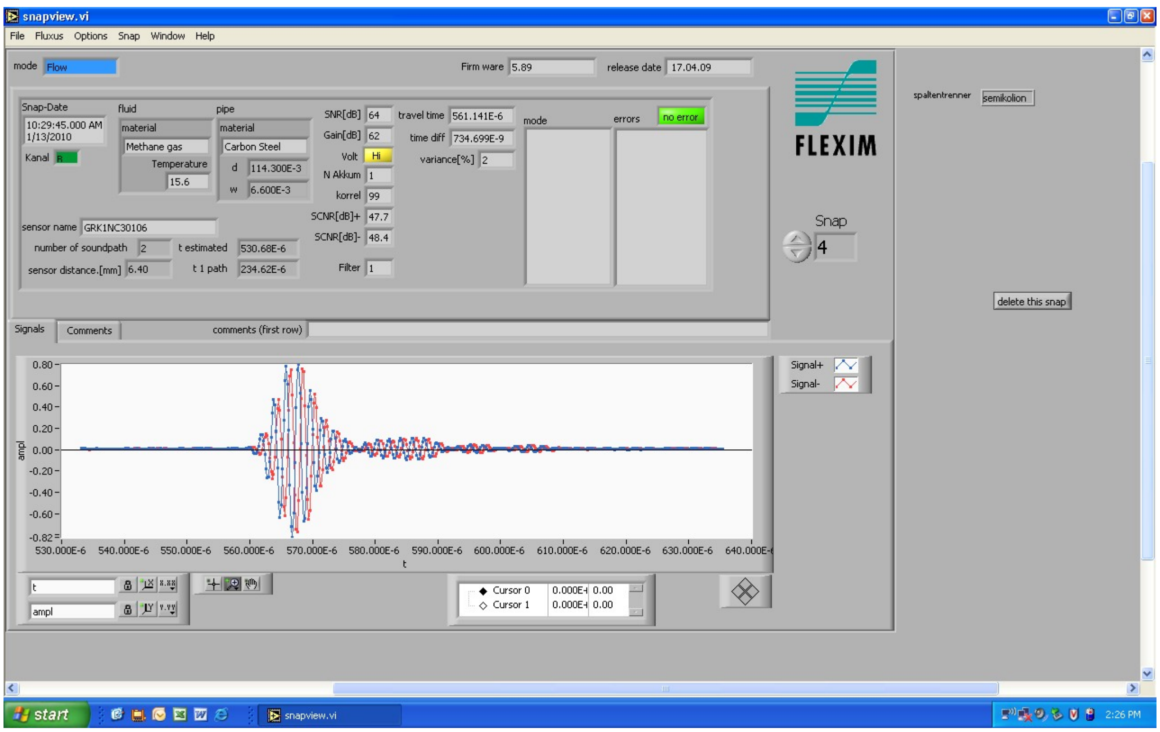

Figure II. – CLEAN BASELINE, PULSE WAVEFORM

Flows can be measured using clamp-on metering without interruption of service. Ultrasonic signals penetrate the pipe walls and determine flowing velocity and volume. Diagnostic information from the same technology helps to validate the measurements. Some of the real time diagnostics are shown below in figure III. The live view verifies measurement integrity and it can be used to locate optimum transducer positioning on a pipe. A typical meter station installation is shown in figure IV on a four-inch pipe.

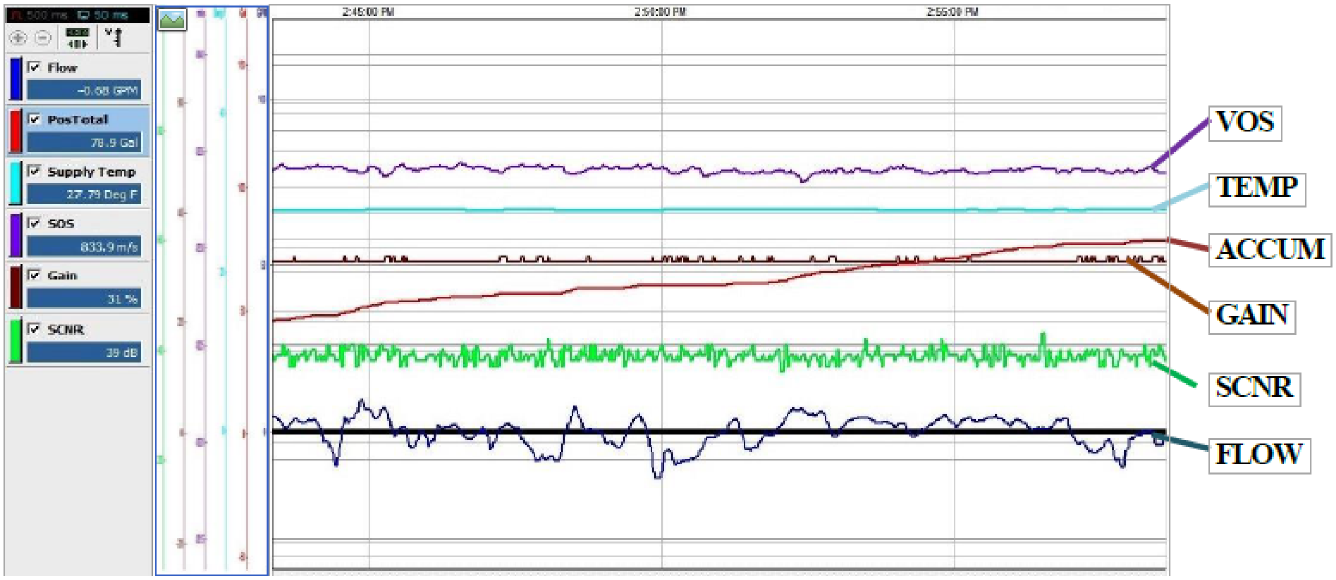

Figure III. - REAL TIME DATA FROM CLAMP-ON METER

Figure IV. - CLAMP-ON METER INSTALLED ON PIPE

Installation

Pipe wall thickness must be measured to install a clamp-on meter. Use an ultrasonic thickness gage or Flexim provides the wall thickness measurement within the control unit. Transducers operate over a range of wall thickness. A set of three of four types will cover common piping. Once a transducer is selected, pipe size and wall data is entered into the control unit and transducer spacing is determined. There may be damping material required for a given transducer. Damping material is a self-adhesive flexible membrane that provides an impedance match between the pipe and the high impedance transducer. Damping material also reduces synchronous noise that might be reflected from some pipe discontinuity such as a flange or weld and returned through the pipe wall to a sensor but at a random time. Signals can also travel around the pipe circumference and arrive at the receiving transducer at random time. This kind of interference can be seen in the waveform as leading baseline noise or distortion in the pulse envelope.

The transducers are usually fixed to the pipe with large hose clamps and mounting frames. The photograph below, Figure V, shows two transducer pairs in reflect mount. Each beam bounces off the opposite side of the pipe and travels through the gas twice. Each pass is in an opposite direction providing some cancellation of flow profile defects and is the best manner for accurate volume determination.

Figure V. – TRANSDUCERS MOUNTED ON PIPE IN REFLECT MODE

The black material under the transducers (damping material) is helping to match the transducer to the pipe. Couplant grease is used on the active transducer face. Both the couplant and the damping material are used to improve signal transfer to the pipe.

Once the transducers are mounted, and wired to the control unit, measurement can begin. The control unit can provide data files as output to a laptop computer, similar to log files on custody meters, and it can provide pulse rate output to feed an RTU for correction to standard conditions. The real challenge is in choosing the experiment. It is important to have a plan and know what is expected before data is recorded. Wise placement of the clamp-on meter can make use of its excellent repeatability for before and after kinds of test data.

Liquid measurement results in better average performance than gas phase service because ultrasonic signal conduction impedance is lower in liquids. Liquid measurement tends to demonstrate about 1.2 percent uncertainty and often better. Some low pressure gas phase settings do not conduct the acoustic signal effectively. But if gas density is adequate, then combined uncertainty for gas service has been seen to be one to three per cent of reading or better.

CLAMP-ON Liquid Lab Tests

Flexim specifies 1.2% performance for liquid measurement. That is represented below in figure VI by the normal distribution curve at a 95% confidence producing two standard-deviation criteria at 1.2%. The normal distribution is selected because of its common appearance in nature. More precisely, the expanded uncertainty of measurement is stated as the standard uncertainty of measurement multiplied by coverage factor, k=2, which for a normal distribution corresponds to a coverage probability of approximately 95%.

Independent test data can demonstrate the validity of the manufacturer statement. Actual test data from accredited flow laboratories in The United States and The Netherlands is added to the Figure VI. The data is plotted as percent error using the same scale as standard deviation. Observe the thirty test value columns from Alden Labs on sixteen-inch pipe and the sixteen test value columns from Delft. If the meter does operate with 1.2% uncertainty, we would expect to observe data points under the normal distribution out to and beyond two standard-deviations. But the actual test data is much less varied and of less range than expected at about 1 standard deviation, not two. This data is evidence that under laboratory conditions, in liquid service, the clamp-on meter is capable of exceeding its specified uncertainty. Field installation conditions normally approach the same clamp-on installation factors as at the flow labs and can be expected to reach about the same uncertainty level. There are those 5% exceptions that fall outside of two sigma and those are guarded against in the field by careful observation of clamp-on diagnostic factors such as measured speed of sound compared to expected speed of sound, signal waveforms, signal to noise levels, and data continuity on two independent measurement channels.

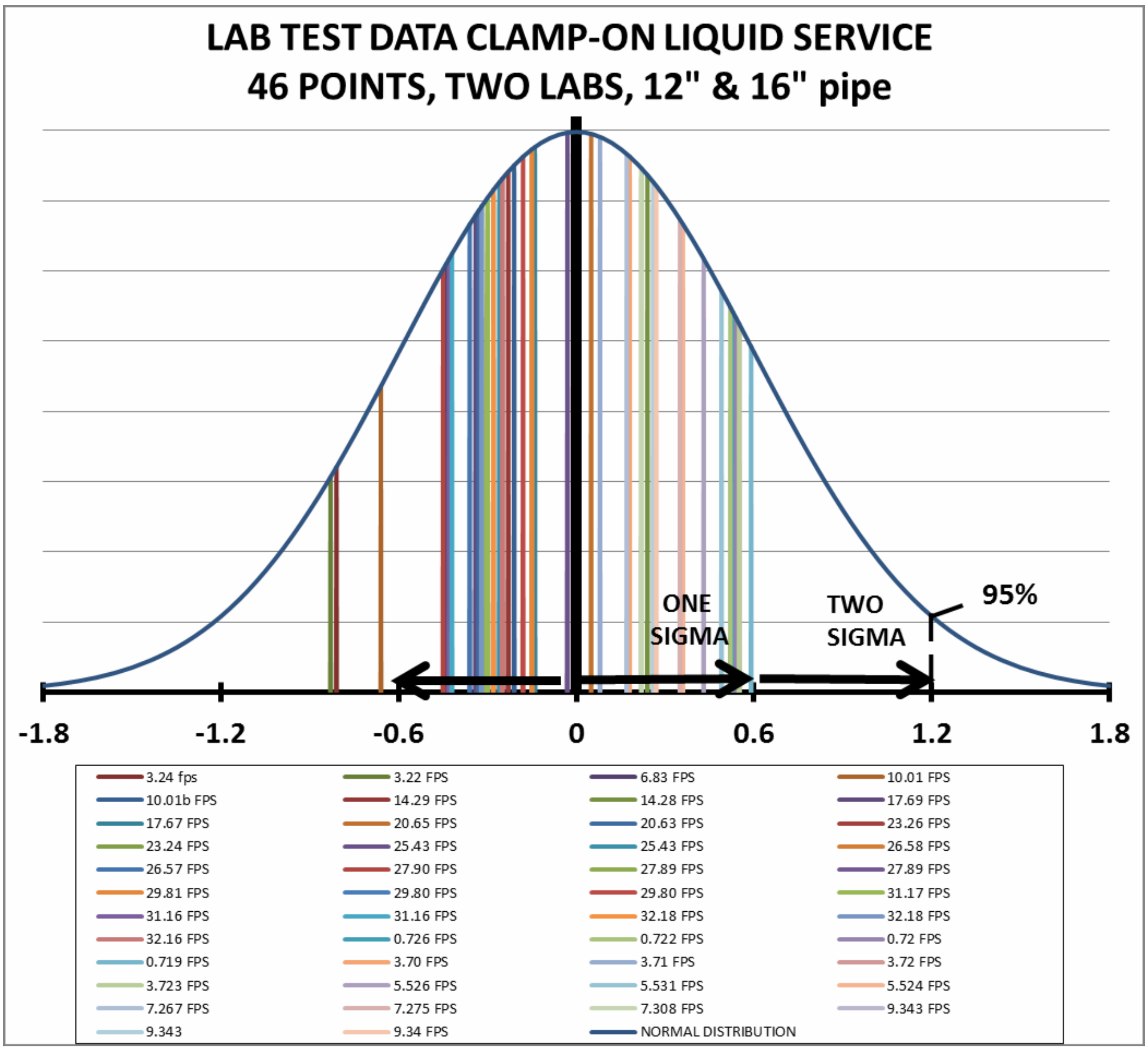

Figure VI. - FLOW LAB CLAMP-ON TESTS, LIQUID SERVICE (ref 1, 2)

CLAMP-ON Gas Lab tests

Clamp-on meters can function in gas service if ultrasonic signals are enhanced to overcome the ultrasonic propagation attenuation in gasses. Some gasses such as carbon dioxide absorb the beam energy. Other gasses like hydrogen have such light molecules that measurement can be difficult. For gas service, the transducer signal energy must be acoustically matched to the pipe for effective signal transference. Damping material is applied to the pipe as an acoustic transformer to couple the high impedance transducers to the pipe.

Further, transducers are selected for frequency of operation near pipe wall resonant frequencies. With control of dimensional data, the technology can be made to function in gas service. Flexim specifies a range of one to three percent performance in gas service. That is represented below in figure VII by the normal distribution curve at a 95% confidence producing two standard-deviation criteria at three percent. The manufacturer includes worst case and unknown installation conditions in that specification. All data would be expected to be distributed in the entire interval with Normal frequency. Actual test data from the accredited CEESI Iowa Flow Laboratory is added to the Figure VII. These were recorded during cold weather under non-ideal conditions over a range of pipe sizes and for normal flowing velocities between ten to seventy feet per second. The data is plotted as percent error using the same scale as standard deviation. Observe the eighteen test value columns on pipe sizes ranging from four-inch to twenty- inch. The twenty-inch pipe was heavy wall in excess of 1".

If the meter does operate with three percent uncertainty, we would expect to observe data points under the normal distribution out to and beyond two standard-deviations. But the actual test data is much less varied and of less range than expected at about 1 standard deviation, not two. This data is evidence that under laboratory conditions, in gas service, the clamp-on meter is capable of exceeding its specified uncertainty. Field installation conditions normally approach the same clamp-on installation factors as at the flow labs and can be expected to reach about the same uncertainty level. There are those 5% exceptions beyond two sigma and those are guarded against in the field by careful observation of clamp-on diagnostic factors such as measured speed of sound compared to expected speed of sound, signal waveforms, signal to noise levels, and data continuity on two independent measurement channels.

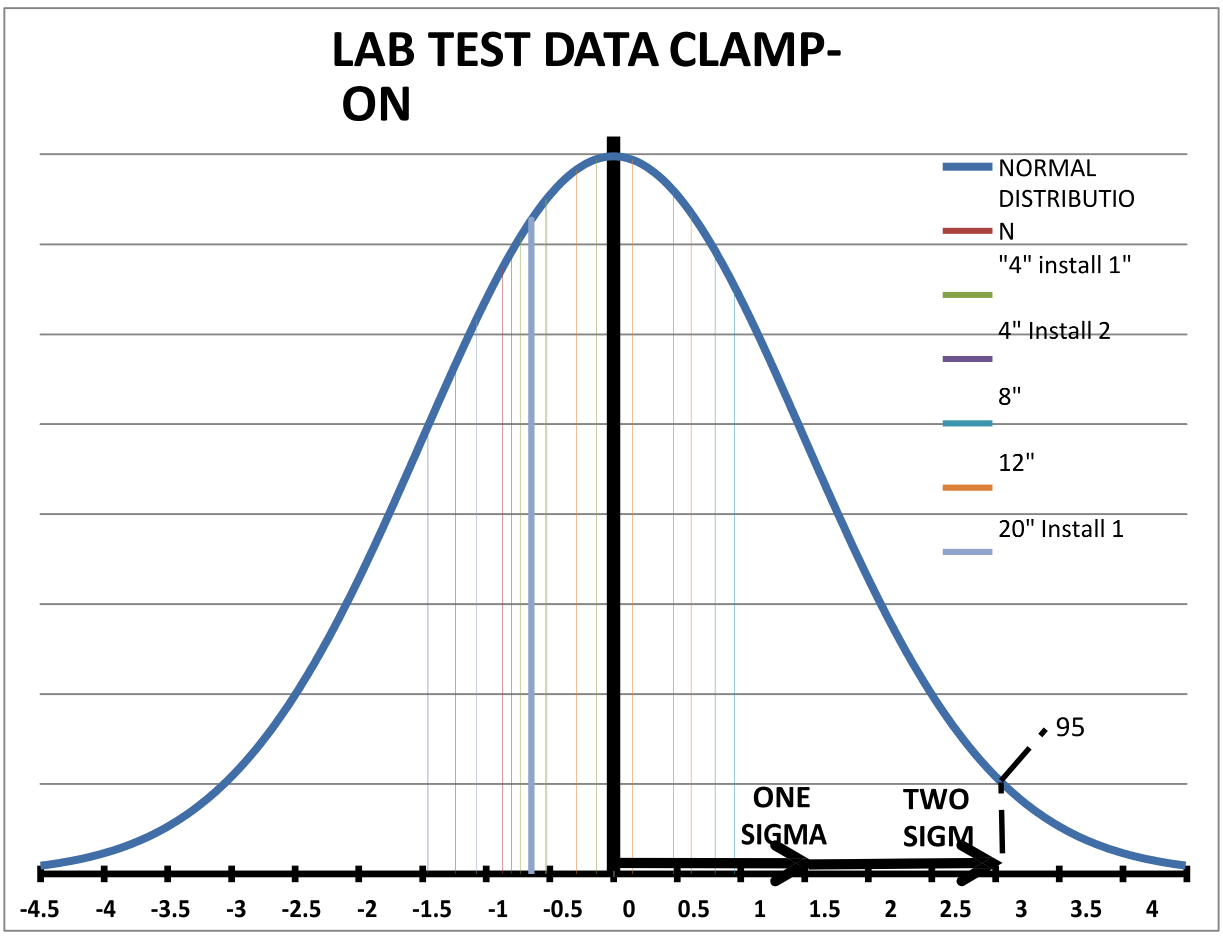

Figure VII. - FLOW LAB CLAMP-ON TESTS, GAS SERVICE (ref 3)

It is interesting to observe that most gas service test data falls within one standard deviation. That is significantly less range than would be expected from the manufacturer three percent specification. Now overlay the lesser uncertainty specification at one percent to the same graph as below in figure VIII. Given eighteen data points, and normal probability density, 17.1 points should lie within two standard deviations. The point at -1.078 is "on the cusp" and might be considered as the "0.1" point.

That leaves two data points on the eight-inch meter outside of two sigma in the third standard deviation. These could be called normal Deviates! While this deviation could represent experimental error, it is acceptable to think about the 5% occasional occurrences that are indeed outliers. Then in view of this gas service test data, it is reasonable to expect clamp-on uncertainty to be close to one percent in most suitable field installations.

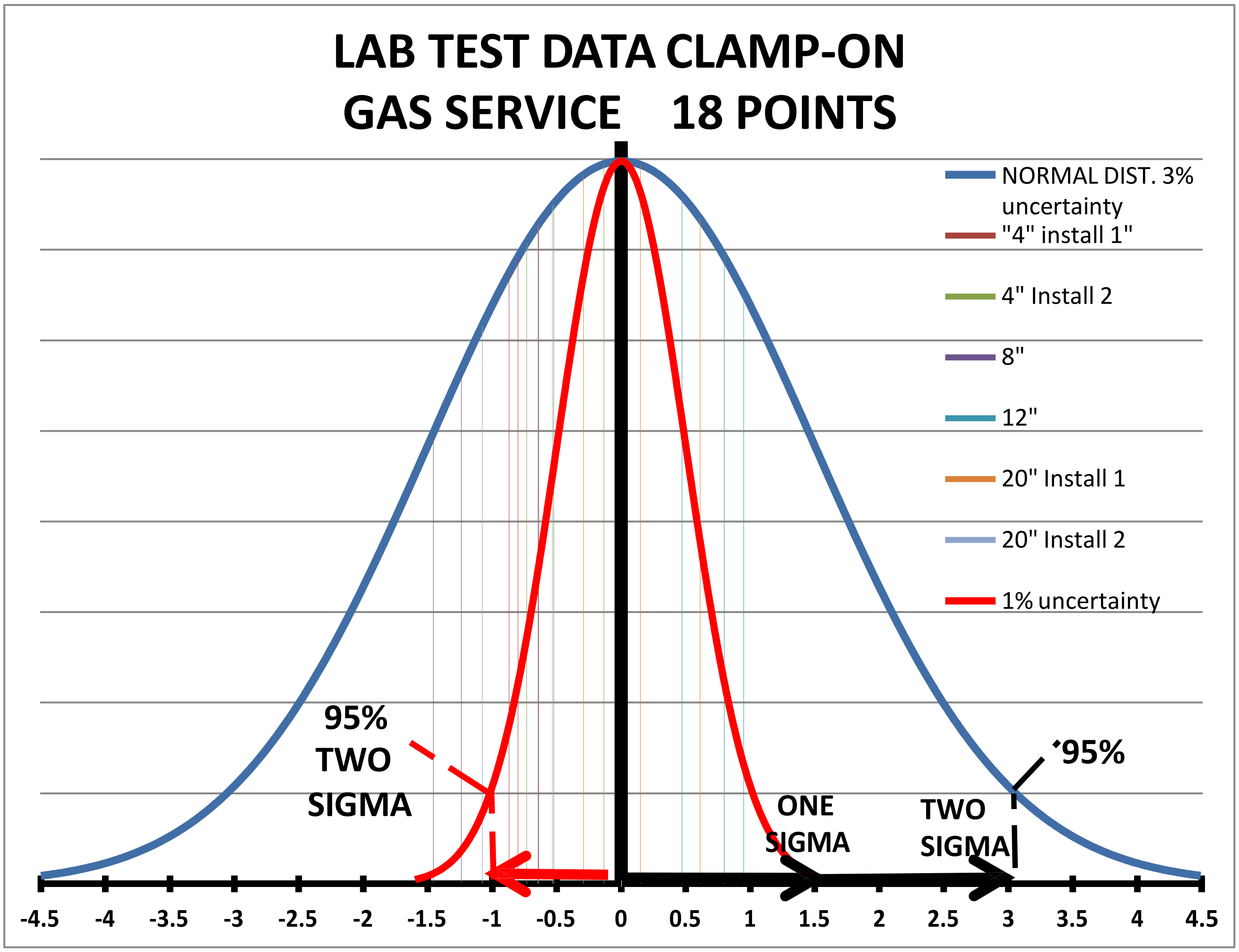

Figure VIII. - FLOW LAB CLAMP-ON TESTS, GAS SERVICE (ref 3)

Meter Error Assessment

Simple comparisons between the clamp-on meter and a custody meter provide assessment of the custody meter operation. In most installations, I expect the clamp-on to provide field velocity and actual volume data with a 1.0% uncertainty and repeatability is excellent. Then if we experience greater deviation between the clamp-on and the meter under test, we can begin to suspect the meter under test. We must understand that some clamp-on settings will produce greater error if piping conditions are poor.

Figure IX is a Texas clamp-on setting downstream of an orifice fitting. This location developed 3% deviation between the two meters. That deviation level is my threshold for detailed investigation. A delta between meters of 2.3% is significant. The orifice fitting was operating with a plate seal gap and under measuring.

Measurement parameters of a wetted Sick ultrasonic meter and a Siemens Clamp-On ultrasonic meter are compared in Figure X. User interface data for both meters are shown on the laptop screen.

Figure IX.-Clamp-on Compared to Orifice Meter

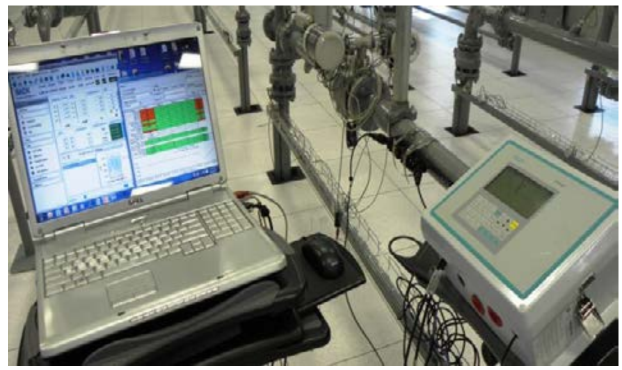

Figure X. - Siemens Clamp-On and Sick USM

A series of meters of various types were investigated and Figure XI illustrates findings. The first meter is a commercial ultrasonic meter with a transducer problem. The second meter bar is a rotary four-inch positive meter. The sixth bar approaching two percent error has installation effects. That permanent clamp-on 8-inch check meter is installed in a straight pipe but there are four elbows out of plane with little separation and a final reducer immediately upstream. Profile distortion was confirmed by the clamp-on test meter in a fashion similar to a later section in this paper. The deviation of the blue and fuchsia orifice meter bars of Figure XI. was related to use of the prior month's gas composition data.

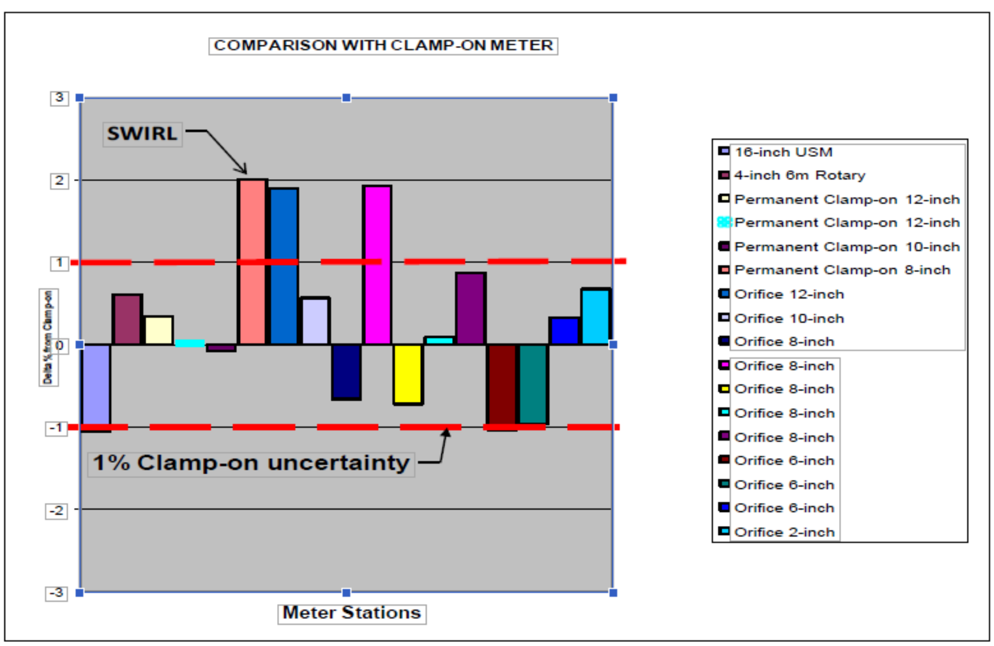

Figure XI. - FIELD COMPARISON BETWEEN CLAMP-ON AND REFERENCE METER.

Profile Indicator

Beyond simple volume measurement, the unit can detect flow profile defects through rotational analysis. This technique operates the unit in a direct single pass through the pipe and then measurements are taken at multiple positions around the pipe. If the flow is fully developed and symmetrical as required for custody transfer, all of the measurements at any position will produce the same flow rate. Velocity profile distortions will show up as variable flow rate for the different positions around a pipe. Eight positions are recorded and reference flow rate must be held constant or the data can be normalized to average flow rate during the data collection period. The polar plot, Figure XII below shows typical field data for a twelve-inch meter. The clamp-on was mounted near the outlet of the ultrasonic meter. This data resulted from a side inlet elbow and short meter run lengths. Measurement error is likely for this profile.

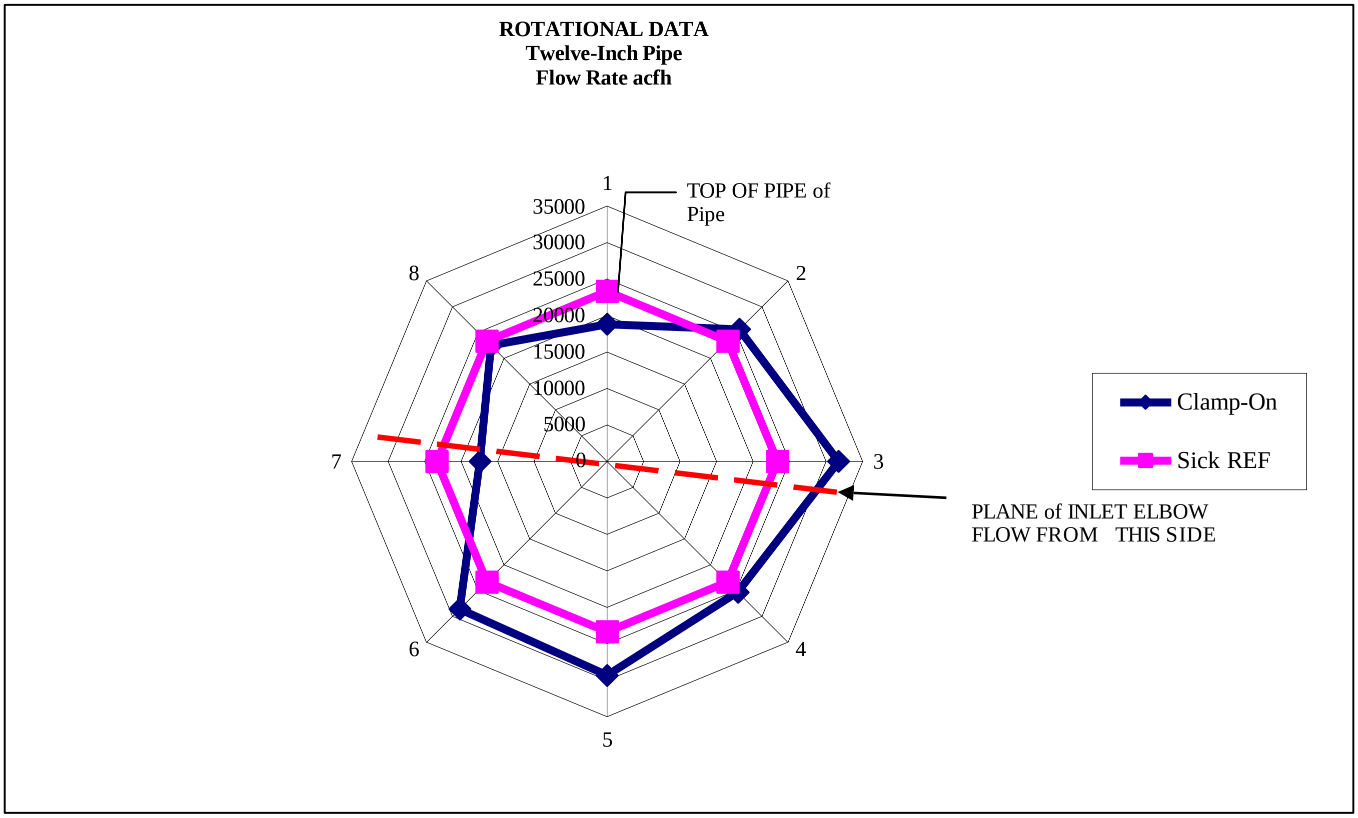

Figure XII. – ROTATIONAL DATA LOOKING UPSTREAM

Leakage Check

The clamp-on meter has a true zero. It makes use of the acoustic path through the steel pipe wall compared to the acoustic gas path to find zero flow. The threshold of low velocity detection in the clamp-on is about 0.02 feet-per-second. Above 0.02 feet-per-second, gas is flowing It is feasible to hand hold a pair of transducers for leak checking. That is a quick way to sample various positions. If velocity is indicated, a complete installation can be performed to obtain reliable data. Low velocity, even a fraction of a foot-per-second accumulates to significant gas value over time.

Figure XIII. – CLAMP ON DETECTION OF LEAK

One site was found where three closed valves in series were leaking between Companies. The site had been unused for many years and likely was leaking all those years.

Another turbine meter station was found where the small summer load was not enough to cause the turbine meter to turn. The clamp-on meter registered the take and the flow went to zero as soon as the customer became aware that the flow rate was visible.

A custody delivery station was shut-in but the photo Figure XIV below shows evidence of flow.

Figure XIV. - ICE IS CERTAIN LEAKAGE EVIDENCE

The clamp-on meter was installed and detected the flow rate. Other tests confirmed the flow quantity even though the actual velocity was less than one foot per second.

Reference for New Meter Calibration

Ultrasonic custody meters are routinely flow calibrated prior to field installation. That is an opportunity to acquire data to help ensure that the final field installation functions correctly. The method involves installing the clamp-on meter on the meter under test at the flow lab during calibration activities. See Figure XV below. Flow test data and meter log files are recorded for each flow rate test point for both the meter under test and the clamp-on meter. Then later at the field site, similar tests can be performed to identify any relative changes between the custody meter and the clamp-on meter. This is one procedure to evaluate field installation effects.

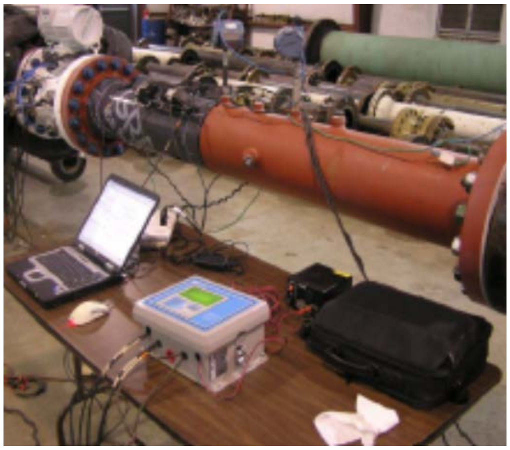

FIGURE XV. – CLAMP-ON REFERENCE AT CUSTODY METER CALIBRATION

Comments and Conclusion

There are a few installations that are difficult. Paint can be a problem if it is extensively cracked and crazed. One epoxy coating was not fully cured and it absorbed ultrasonic energy. Even an ultrasonic wall thickness gage would not function with the spongy coating. However, most pipeline epoxy coatings provide effective damping. Sometimes it is necessary to re-grease the transducers and try again. Some pipe steel seems to have regions where the grain structure is a problem. Often moving a few inches corrects the problem.

Once an installation is working, it will function for a long time. Some have eight years on line. There are some installations that must be made below grade on mainline applications such as segmentation meters. Invariably, the pit fills with water but the units continue operating. The photograph below, Figure XVI, shows permanent transducers mounted on a submerged mainline and the clamp-on meter functions the same as when dry.

Also in pipeline segmentation meter application and in storage fields, the flow may change direction. That is no difficulty at all. The flow just indicates flow direction with a plus or minus sign.

Clamp-on metering can do anything a wetted ultrasonic meter can do. The limit is user imagination.

Figure XVI. SIEMENS INSTALLATION IN SERVICE UNDER WATER

REFERENCES

1. Report ARL NO. 122-05/C1167 Alden Research Laboratory, Inc. Holden, Mass. April, 2005.
2. Report NKO Certificate 1631 Delft Hydraulics, The Netherlands, March, 2006.
3. Report 10CEE-0015 CEESI Iowa, USA January 2010