ULTRASONIC METERS FOR COMMERCIAL APPLICATIONS

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INTRODUCTION

An ultrasonic meter falls into the classification of inferential meters. Unlike positive displacement meters that capture volume to totalize volume, inferential meters measure flowing gas velocity to totalize volume. Ultrasonic meters use sound waves to measure flowing gas velocity to infer volume. Ultrasonic meters have been around for many years, primarily in liquid measurement. However, we are seeing more and more applications in the natural gas industry.

ULTRASONIC THEORY

An ultrasonic flow meter normally operates based upon the time-of-flight or the Doppler principle. A meter utilizing the Doppler principle requires "particles" in the flow stream to reflect waves. When people think of the Doppler principle, they think of weather and police radar. The rain and your car are the "particles" used to reflect the waves. This sort of meter is common in liquid measurement because bubbles can be introduced into the liquid to reflect the waves.

Ultrasonic meters used for gas measurement typically utilize the time-of-flight principle due to a lack of "particles" to reflect the sound waves. Meters that utilize the time-of-flight principle are basically a very accurate clock. The meters measure the very small difference in the time that it takes an ultrasonic pulse to travel a known distance with and against the gas stream. Transducers typically are capable of both generating and receiving ultrasonic pulses. An ultrasonic meter for distribution applications will typically use one pair of transducers to measure the speed of gas. Higher capacity meters used in transmission applications will typically use multiple pairs of transducers to measure the velocity of the gas. An ultrasonic meter that has at least two independent pairs of measuring transducers is called a multipath meter. While differences in the flow profile are generally insignificant for distribution customers due to the small flow area, they can dramatically affect measurement in transmission pipeline applications. Larger pipeline ultrasonic meters use multiple pairs of transducers to obtain a better sampling of the flow profile. The more pairs, the better definition of the flow profile, the better estimate of the true velocity measurement, while small distribution piping single path ultrasonic meters can accurately estimate the flow velocity from a single pair of transducers.

A simple explanation of the theory of a single path meter (multipath meters operate the same way, except that they use multiple pairs of transducers to sample the velocity profile) starts with the gas flowing through the meter with a speed of v. The transducers take turns producing and receiving ultrasonic pulses that travel with and against the flow of the gas. While one transducer is sending a pulse the other transducer is acting as a receiver. The difference in time it takes for the pulse to reach the transducers is used to calculate the speed of the gas. The simplified derivation of the formula is as follows:

$\mathbf{t_1}$ = time it takes pulse to reach the transducer in the direction of flow
$\mathbf{t_2}$ = time it takes pulse to reach the transducer against flow
L = length of measuring chamber
c = speed of sound in the gas (approx. 1400 ft/sec)
v = velocity of the gas

$$t1 = \frac{L}{(c + v)} \quad (1)$$

$$t2 = \frac{L}{(c - v)} \quad (2)$$

By rearranging the terms, and then subtracting equation (2) from equation (1), one can determine the velocity of the gas from:

$$v = \left(\frac{\Delta t}{t_1 \times t_2} \right) X \; \frac{L}{2}$$

Once the velocity of the gas is calculated, v, the volume of flow is calculated by multiplying the velocity times the cross-sectional area of the flow tube.

The speed of sound of the velocity of the gas can be calculated by rearranges the terms and then adding equations (1) and (2). The speed of sound in the gas is then determined from:

$$c = \frac{L}{2} \; X \; \left(\frac{t_2 + t_1}{t_2 \times t_1} \right)$$

By periodically checking the speed of sound, the meter can verify that the gas has not changed dramatically, or that the measurement has not drifted. It can also be used for tamper detection if a meter is exposed to air.

Composition, temperature, and pressure can all affect the speed of sound in the gas.

TRANSDUCERS

Transducers are composed of several parts (Figure 1.). Piezoelectric elements are the heart of any ultrasonic meter transducer. They are typically made from PZT (lead zirconate titanate). They exhibit the property of becoming electrically charged when subjected to mechanical stress. That is, they generate a small electric charge when they are compressed due to a force acting on them. Conversely, they will expand when they are excited with a small electric charge. The electrical leads are used to transmit the electrical charges to the meter's electronics. Since a piezoelectric element is a poor conductor of motion, a low density material is put on the face of the piezoelectric element to amplify the waves of energy. This material is called the quarter wave plate. Behind and around the sides of the piezoelectric element is a dense backing material. This material is use to minimize the flow of energy towards the back and sides of the transducer. A Cap is put on the face of the quarter wave plate to protect the material from anything in the gas stream (contaminants, moisture, sand, and debris).

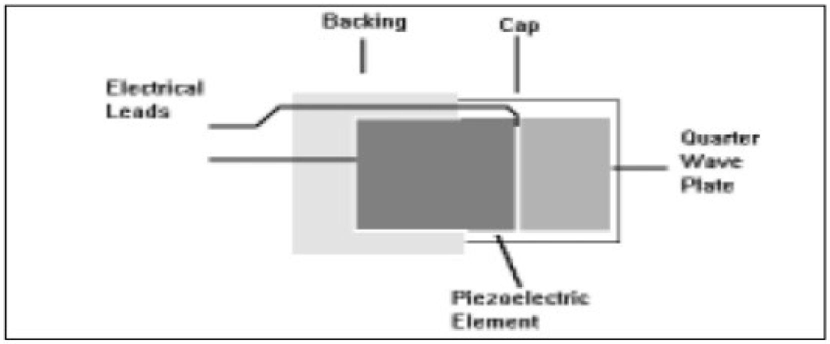

FIGURE 1

RESIDENTIAL ULTRASONIC METERS
The residential ultrasonic meters we see being sold today were designed to meet British Gas Requirements. In the mid-1980's, British Gas decided that they wanted a new meter that would address their future measurement needs. British Gas said the following four important issues should be addressed with the new meter: (1) The design accuracy of the meter was to be better than the diaphragm meter; (2) The new meter should be compact; (3) The meter should be easily upgradeable; and (4) The meter should be a modular design so that the metering packaging is aesthetically pleasing.

HISTORY OF THE BRITISH GAS DESIGN
In early 1987, a meeting was held to announce a competition sponsored by British Gas for the development of the "next generation" domestic gas meter. British Gas announced the meter's basic requirements and performance specifications. A deadline of September 1987 was set for design proposals. Of the thirty-five companies that attended the meeting, twenty-one design proposals were submitted. After careful review of the proposals, four were selected for further development and the companies were offered financial support by British Gas. The four designs selected included two ultrasonic meters, one fluidic meter, and one, utilizing silicon beams produced by micro-engineering. Six other designs were identified as feasible; however they were not offered funding.

Prototype meters were due to British Gas by January 1990. Three of the four companies that were offered funding supplied meters, as did one of the six secondary firms, and one other firm submitted a design. The prototype meters were tested in a laboratory for a period of six months. After the initial testing, two ultrasonic meter designs were selected for further development. The meters were supplied by Siemens and Gill Electronic R&D.

In May 1991, a limited filed trial of 100 meters of each of the designs was initiated. The meters were installed in homes throughout the UK. The purpose of the field trial was to see how the meters performed in real world conditions. The trial configuration consisted of three meters in series. The first two meters were one of each ultrasonic design and the third meter, which was used for billing, was a new specially calibrated diaphragm meter with a pulse output. A special data logger was developed to collect the data. The information from, the three meters was analyzed and it was found that the ultrasonic meters were a little bit more stable than the diaphragm meter.

In addition to the field testing, extensive laboratory testing was taking place. The two companies also started to work on production designs of their meter. Low volume production began in early 1993. The Siemens meter was provisionally approved by GOMB in 1993. It has subsequently been fully approved. The Eurometers meter was fully approved by GOMB in 1994. Outside of the United States, there is typically a national approval required before you can use a meter for custody transfer. GOMB was the national approval agency in the UK (it is now called Ofgas)

THE GILL ELECTRIC R&D METER
The "British Gas" meter, developed by Gill, is classified as an E6 meter because it has nominal capacity of 6 m3/h (212 cfh). The meter is less than half the size of traditional diaphragm meters. The low flow cutoff point is <0.15

cfh. The meter is flow calibrated the same way a diaphragm meter is. That is, the meter is checked against a reference standard. The meter proof curve is adjusted using the change gear principle. Because the meter is electronic, it is felt that the meter will maintain its accuracy over time; thereby, reducing the need for in-service accuracy allowances. The meter is battery powered. The battery is housed in a secure, replaceable cartridge. Based upon laboratory and field results, it is anticipated that the battery life will be in excess of 10 years. The meter has a fire safety shut-off incorporated into the inlet of the meter. The shut-off devise is spring loaded. When the meter sees a sustained temperature above 193 Degrees F, the device is triggered.

The Gill designed meter utilizes three piezoelectric transducers for accuracy. All three of the transducers are out of the gas stream; therefore, they do not have gas or contaminants flowing over them which help increase transducer life and accuracy of the meter. Two transducers are used to send and receive transmitted pulses (Figure 2.). The third transducer is used to measure the speed of sound for verification and to correct for transducer drift. It is located just off the outlet side of the measuring tube. The transducer emits a pulse into an area of no gas flow.

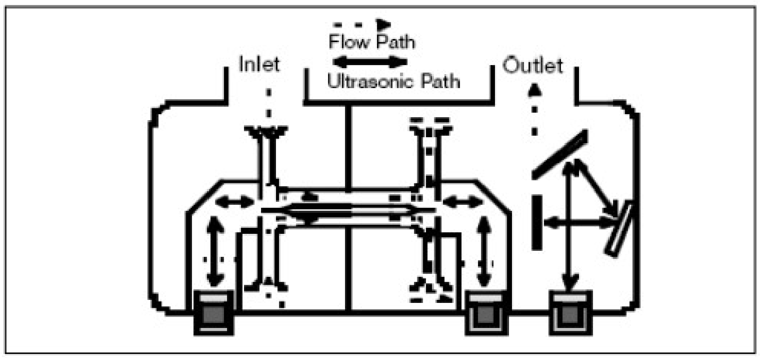

FIGURE 2

Because the E6 meter is electronic, the design lends itself to the addition of value-added features such as AMR and pre-payment systems. These options can be added via software changes and through board changes versus having “add-ons” attached to the case and index of the meter.

There are four competitors in the UK that have a license to sell the British Gas ultrasonic meter designed by Gill Electric R&D. British Gas owns the patents and rights to the design because they funded the meter development performed by Gill electric R&D. The competitors are: Eurometers Limited (started by Gill electric R&D, now a BTR company), Schlumberger, George Wilsons (most recently a diaphragm meter repair company), and UGI (a large manufacturer of diaphragm and rotary meters). All of the other British gas licensees are working from the Eurometers 1993/1994 production design. There is only one licensee of the British Gas Technology in North American at the present time, Equimeter.

OTHER RESIDENTIAL METER PROJECTS

Siemens is the “other” major ultrasonic meter competitor. Siemens was one of the four companies offered funding by British Gas during the development of the meter. The Siemens design was derived from a heat meter manufactured by Siemens in Germany. This design utilizes two transducers. The ultrasonic waves are sent along a “W” shaped path (Figure 3.). The path design was selected to minimize the effect of changes in the flow profile. Siemens has developed the second generation of their meter. It is called the Adaptive meter. It is designed to adapt to the customer’s requirements for value-added features.

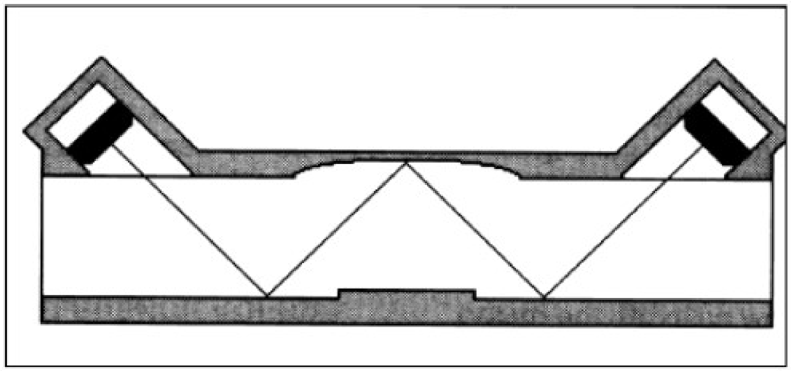

FIGURE 3

CSIRO/AGL is an Australian consortium that is also working on a domestic meter. It was originally scheduled to be in production in 1993. This meter is also a “dog bone” type. It has potential gas composition and contaminant problems because the transducers are in the gas stream. Figure 4 shows a “dog bone” type design.

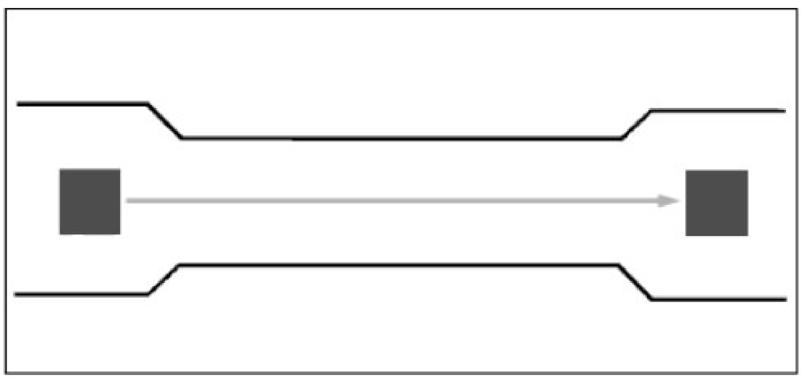

FIGURE 4

Kromschroder (part of the Elster Group) is also working on a domestic ultrasonic project. The meter is a “dog bone” type meter (two transducers in the gas stream). The meter is metal cased and powered by two “AA” size batteries.

Turin University in Italy is working on a meter project sponsored by Italgas. Their meter is also a “dog bone” type meter. This project is in the early stages of development. It was started in 1990.

LARGE ULTRASONIC METERS

As mentioned previously, large ultrasonic meters can be single path or multipath. Single path meters are generally not as accurate as multipath meters. Single path meters are also generally considerably less expensive than multipath meters. Some of the benefits of large ultrasonic meters is their ability to measure flow in both directions, potentially lower station costs (when multiple meter runs are required), and reduction in the pressure drop across the meter, and the ability to pig a pipeline (if the transducers do not extend into the flow stream).

Large ultrasonic meters can be dry calibrated or flow calibrated. In a dry calibration, the meter geometry is measured and the transducers (temperature and pressure) are verified against standards. This provides a theoretical calibration. Recent testing by NOVA indicates that dry calibration is generally not an acceptable means of calibrating meters. Three people from NOVA presented a paper (Karnik et al.) at the AGA Operations Conference in May 1997. The paper presented test data that showed that a dry calibrated meter may be as accurate as ± 1.0%; however, they also had meters ± 6.0%. The meter that was ± 6.0%, had problems with its electronics. The only way to detect the problem was to switch electronics and compare the meter against a standard (basically flow calibrate the meter).

The meters can also be flow calibrated against a reference standard. Flow calibration will provide a more accurate calibration. The calibration pressure should be as close to operating conditions as possible to provide the best information on in-service meter performance. The proposed Canadian standard states that meters must be flow calibrated at a minimum of 40% of rated capacity.

Several manufacturers of large capacity ultrasonic meters have entered into the North American natural gas industry since the initial writing of this paper.

Some multipath meters are four path. Their transducers send and receive pulses across four planes using an "X" pattern. A simple schematic of the Daniel design can be seen in Figure 5. Their original design was developed from British Gas technology.

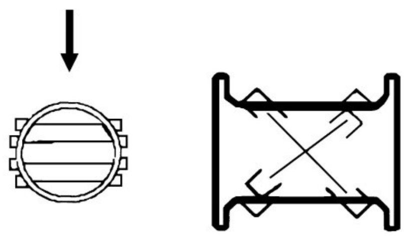

FIGURE 5

Other multipath meters are three or five path (pairs of transducers). The five path meters use a combination of single and double reflection paths. The three path meters use at least one single reflection path.

INDUSTRIAL AND COMMERCIAL APPLICATIONS

Since the development of the residential E6 meter for Europe, and the residential SONIX215 for North America, Sensus has been expanding the single path ultrasonic meter into industrial and commercial sizes. The SONIX600 and SONIX880 were introduced in North America in 2003 and a SONIX2000 introduced in 2008. The SONIX600 and SONIX880 still contain the 3 transducers design, with 2 transducers doing the measurement, and the third transducer providing health checks, tamper detection, and improved measurement accuracy. The SONIX600 has a capacity of 600 cfh at ½" differential and 1130 cfh at 2" differential with a 20 psig maximum operating pressure. The SONIX880 has a capacity of 880 cfh at ½" differential and 1625 cfh at 2" differential with a 20 psig maximum operating pressure. The newest addition to single path ultrasonic measurement in North America is a SONIX2000. This meter actually uses two flow tubes, with two pairs of transducers to do the measurement, and a 5th transducer providing health checks, tamper detection, and more accurate measurement.

The SONIX2000 is rated at 2000 cfh at ½" W.C. differential and 3000 cfh at 1.3" W.C. differential. It has a 60 psig maximum operating pressure with the option to add a live pressure transducer for volume correction.

CONCLUSIONS

While ultrasonic meters have been used for many years in liquid measurement, they are relatively new to the natural gas industry. Multipath meters appear to be more applicable to larger pipe sizes where flow profiles may vary, and more velocity samples are required to provide accurate results. This does make Multipath meters more expensive, but they are measuring greater volumes at higher pressures. The single-path ultrasonic meters appear to be settling into distribution applications where the volumes and pressures are considerably less than their Multipath counterparts. This permits single path measurement of the smaller flow areas to be very applicable. There are nearly 1.3 million Residential ultrasonic meters being used in the UK at the present time.

However due to costs, residential single-path ultrasonic meters are fitting into niche applications in North America. Coming on stronger are the single-path ultrasonic meters for industrial and commercial applications. I&C single path ultrasonic meters appear to be very cost competitive, much smaller and lighter weight, more accurate initially and over time, and have lower flow capabilities. Doubling up on the flow tubes and transducers has permitted the expansion of the single path ultrasonic technology to increase the capacity to 2000 cfh, and opening the possibilities of going even higher. The electronic platform of ultrasonic meters not only makes the meters very reliable over their operating range and life, it also readily adapts to value-added features, diagnostics, data logs, and configuration changes better than other technologies. Because ultrasonic meter are flow rate based devices, calibration on flow rate based provers such as sonic nozzle provers is ideal. The worldwide natural gas industry appears to be embracing single path ultrasonic technology rapidly due to the benefits these meters offer.

REFERENCES

American Gas Association, *Engineering Technical Note: Ultrasonic Flow Measurement for Natural Gas Applications*, American Gas Association, (Arlington, VA), March, 1996.

Chapman, N.R., Etheridge, D.W., and Sussex, A.D., "Ultrasonic Domestic Gas Meters — From Concept To Realisation". IGE, 130th Annual General Meeting, 1993.

Corpron, G., Time-of-Flight Ultrasonic Flowmeter Operating Principle, Equimeter, 1996.

Karnik, U., Studzinski, W., and Rogi, M., "Performance Evaluation of 8 inch Multi-Path Ultrasonic Meters". AGA Operating Section Operations Conference, May 18-21, 1997