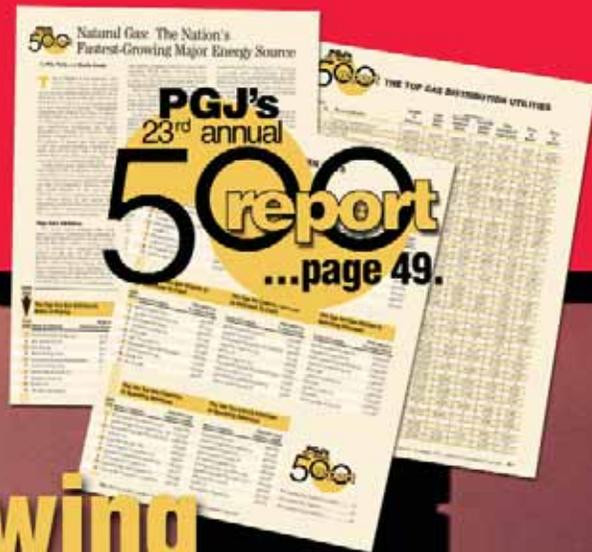


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Ultrasonic Solution For High Pressure Gas Service

By Mike Hopkins, Manager of Engineering, Williams International, Tulsa, OK

Twenty ultrasonic meters today are successfully operating in high-pressure, demanding gas service for Williams International in Venezuela as the result of a development project that started about seven years ago.

In 1996, much of the natural gas industry was just beginning to consider accepting ultrasonic meters for custody transfer measurement. At that time, the American Gas Association, Transmission Measurement Committee was writing what would eventually become AGA Report No. 9 (AGA-9), titled Measurement of Gas by Multipath Ultrasonic Meters, and published in June 1998.

Technical information relating to the use of ultrasonic meter performance in 1996 consisted primarily of a limited number of magazine articles and published papers, some of which would later become part of AGA-9, primarily in Appendix C. Therefore, at that time, orifice meters or turbine meters appeared to be the only industry-accepted options since both meter types were covered by well-accepted, and well-documented, gas industry measurement standards.

Because of safety concerns about repeated depressurizing of orifice and turbine meters in this application, Williams International, a wholly owned subsidiary of The Williams Companies of Tulsa, OK, working with their WilPro Venezuela Joint Venture, chose to pursue ultrasonic meter technology and began searching for natural gas meters that would measure gas flow to an operating pressures up to 7,705 psig for its El Furrial Project in Venezuela. This search led to a partnership with Daniel, to work together for a solution.

Ultrasonic meters are inferential meters that derive the gas flow rate by measuring the transit times of ultrasonic sound waves passing through the flowing gas. Transit times are measured for sound pulses traveling at an angle with respect to the pipe axis. Each path has two transducers, which act alternately as a transmitter and a receiver, one downstream with the gas flow and one upstream against the gas flow, permitting the upstream and downstream gas flow transit times to be measured. The difference in these transit times is a measurement of an average angular gas flow velocity along the transducer acoustic path. Mathematical equations are then used to compute the average axial gas flow velocity and the gas volume flow rate through the meter.

Daniel agreed to manufacture the 10,000 # API ultrasonic meters and provide ongoing technical support for the meters and their



development. This work was beyond existing applications and required going "outside the box" but reliable results seemed achievable.

Success of the work is now evident by the 20 meters in high-pressure, demanding service today.

El Furrial Project

Commissioned in 1998, El Furrial is a high-pressure gas compression facility (113,000 site horsepower) that receives gas via two pipelines (30-inch and 24-inch) at about 1,100 to 1,000 psig. Centrifugal and reciprocating compressors then compress the gas up to an MAOP of 7,705 psig before discharge seven miles down a 14-inch pipeline delivering gas to five injection wells along the route. Gas is then injected into the oil zone, enhancing the oil recovery rate. By keeping the reservoir pressurized, operators minimize the formation of asphaltene crystals within the oil zone and facilitate accelerated crude oil recovery.

PIGAP II Project

Commissioned in 2001, PIGAP II is a

high-pressure gas compression facility (233,600 site horsepower) that receives gas via two 36-inch pipelines at around 1,100 psig. Twenty-four centrifugal compressors then compress the gas up to a MAOP of 9,750 psig. Gas is then discharged to a central manifold in the station. Out of the manifold, it goes in two 12-inch and two 10-inch pipelines for about two miles each to four individual macollas (a "ma-coy-ya" is a pod of well surface facility equipment for horizontally drilled wells) surrounding the plant. It is then further distributed via manifold to as many as four injection wells per macolla.

Since Williams International, via WilPro Energy Services, provides this compression and distribution service on a per MMscf/d fee, it is imperative that high-quality gas measurement be achieved. Typical daily station flow rates for El Furrial range from 450 MMscf/d to a maximum of 650 MMscf/d. Flow rates per injection meter range from 30 to 80 MMscf/d.

At PIGAP II typical daily station flow rates are in the range of 1,100 MMscf/d with a maximum of 1,500 MMscf/d. Flow rates per injection meter range from 50 to 120 MMscf/d. Gas is individually measured as it is injected into each well for both projects to maximize reservoir management efficiencies.

El Furrial Problems

At El Furrial, the key questions in 1996 related to whether ultrasonic gas measurement could be achieved at the high pressures involved, and could it be done safely.

Investigations of high-pressure metering found that there was a non-custody transfer ultrasonic meter installed in the North Sea operating in the 6,000-psig range and several orifice flange units in service at these higher pressures. It was recognized that maintenance of the orifice meters for orifice plate inspections and plate sealing for routine inspections would be an issue. No differential pressure transmitter was available on the market that would provide acceptable accuracies required at static pressures up to 7,705 psig. Turbine meters would be cumbersome to work with due to safety concerns over the weight of the materials and yearly inspections. Meter-factor stabilities of turbines at these high pressures were also a concern. All of these factors contributed to progressing with ultrasonic metering development.

In early 1997, five 6-inch, 10,000 # API Daniel JuniorSonic Meters were ordered. Meter skids were constructed and shipped to Venezuela for installation and initial operation in 1998.

Start-up went off as planned, but when

the 10,000 # API ultrasonic meters first saw flow, their electronics were unable to determine transit times. The Daniel Technical Specialist utilized the advanced meter diagnostics to gather ultrasonic waveforms and perform frequency spectrum analyses of the signals from the transducers at different flowing conditions.

These revealed that meter failure was caused by ultrasonic noise radiated from the control valves located directly downstream of the downstream meter tube. Two options were proposed — an acoustic dampening configuration of four blind tees between the downstream meter tube and control valve, or move the control valve. Because of availability difficulties for 6-inch high-pressure tees and time constraints, moving the control valve appeared to be the best solution. After being moved downstream by 80 feet, the meters began to work and the noise from the control valve was no longer evident.

The meters worked fine for several months. However, WilPro was experiencing initial start-up problems in the final stage of compression. Failures in the reciprocating compressor valves due to poor lubrication, dust and metallurgical properties were causing shutdowns of the compression units and thus pressure fluctuations of 3,000 psig or more on the pipeline at the ultrasonic meters. Failures in the ultrasonic meter transducers, mostly ones that had been depressurized, became evident. The problem was amplified with the plant compressors experiencing many start-up and shutdowns early on in the project.

Daniel, after determining that the failures were coming from mechanical stress on the transducer and decompression of transducer materials, identified a wide range of materials with varying desirable properties that could be used in transducer design. Relying upon data from the material suppliers, the most viable materials were utilized to build replacement transducers. Due to the limited amount of supplier data on the materials identified as a whole, samples of the other materials were installed in a test container, which was placed within the filter basket at one of the injection wells.

After six months of service, initial failures of the replacement transducers began to occur. At this time, the failed transducers and test container were retrieved from the system. The samples were then analyzed for the effects of pressure, temperature, gas composition, and mechanical stress. Utilizing the analysis, data materials were selected and the transducer was redesigned to create new transducers. After replacement of the transducers with the new design, the meters met required performance levels.

PIGAP II Problems

In 1999, the key questions related to ultrasonic gas measurement with high levels of accuracy at high pressure, and how to prove the accuracy.

Experience at El Furrial showed that high-pressure ultrasonic meters would work. However, maximum pressure at PIGAP II was 9,750 psig, 25 percent higher than before, and operating temperature

was 200°F.

In 1999, twelve 6-inch 10,000 # API Daniel JuniorSonic Meters were ordered. These meters were built to the AGA Report 9 Guidelines for dimensions, performance, and tolerances.

To confirm meter performance, Williams International independently defined a test plan. The validity of the test program was maintained through Williams retaining an unbiased and independent flow measurement consultant, Stark & Associates, Inc., and later the retaining of Colorado Engineering Experiment Station Inc. (CEESI) as an independent and unbiased laboratory. However, there was no test facility in the world that could flow test the meters at 9,750 psig. Therefore, separate tests were designed for static and dynamic conditions. By knowing static test results at 200, 1,100 and 9,000 psig, a dynamic test performed at 1,100 psig could potentially be extrapolated to 9,000 psig factoring in statistical analysis.

Static testing was done at CEESI. An oven was constructed which could hold temperature at 200°F. To allow for the varying composition of natural gas, known gases of nitrogen, CEESI Iowa gas, methane, and PIGAP II gas were used to allow correlations to the actual field conditions. Speed of sound checks were completed at pressures of 200, 1,100 and 9,000 psig on each gas.

Results were encouraging. The Daniel thick-wall metal meter construction was not growing, twisting or changing transducer separation distance with pressure changes. Measured speeds of sound were within the known uncertainties of calculated values. However, several individual transducers quit working at lower pressures after having been cycled to the highest pressure. They became operational again when high pressures were reinstated. Daniel found the problem was caused by methods used in transducer assembly prior to encapsulation. The fabrication procedure was modified accordingly.

Little data was available for theoretical speed of sound at 9,000 psig. CEESI contracted independently with Lomic Inc to perform a study to compare the actual versus theoretical speed of sound. Their report states, "the AGA 8 has a tendency to under-predict the speed of sound in the specified pressure and temperature range" when compared to the calculated value. Magnitude of under-predictions ranged from about -0.1 percent to -1.0 percent with larger errors occurring in mixtures containing heavier hydrocarbons.

Speed of sound, important as a diagnostic tool, does not enter into the velocity calculation for an ultrasonic meter because the speed of sound component in the gaseous mixture cancels out of the transit-time equation. Thus the 0.1 - 1.0 percent difference between theoretical and experimental speed of sound values does not impact the measurement accuracy of the meter.

Ultrasonic gas flow meters do not measure speed of sound directly. Instead, they derive speed of sound by accurately and precisely measuring the times required for ultrasonic signals to travel in opposing directions between sets of ultrasonic transducers whose distance from

each other is precisely known. The times-of-flight in the upstream and downstream directions and the distance between the ultrasonic transducer pairs can be used to calculate the speed of sound in the gas.

The following equation helps explain the relationship between speed of sound and ultrasonic meter components.

$$C = (L/2) * (t2 + t1) / (t2 * t1)$$

Here, L is the distance between the surfaces of the transducers, t1 and t2 are the downstream and upstream times-of-flight, and C is the speed of sound in the gas.

The above formula applies for a single set of transducers. For multi-path ultrasonic meters, the above calculation would be performed for each set of transducers, and then an average speed of sound value would be calculated as the weighted sum of the speed of sound values for the transducer pairs. For example, for a four-path meter this would be:

$$C_{avg} = w1 * C1 + w2 * C2 + w3 * C3 + w4 * C4, \text{ (where } w1 + w2 + w3 + w4 = 1 \text{)}$$

Although speed of sound does not directly affect the velocity calculations, it can be used as a method to validate mechanical and electronic components of the meter within accepted tolerances. It also provides on-line verification of a meter's transit-time measurement.

These static tests confirmed that a flow calibration test completed at 1,100 psig should have merit to improve the accuracy of a meter operating at 9,000 psig. Therefore dynamic testing was instituted.

Dynamic Flow Tests performed at the CEESI Ventura, IA facility compared Daniel meters with traceable reference meters. The following graphs show test results. Meter identification numbers are on the right. The y-axis shows percent error of the tested meter against the Iowa reference meter. The x-axis is velocity at which the accuracy measurement was taken.

Flow weighted mean error contraction factors that were applied to Composite Plot 2. (The CEESI Iowa facility was certified to an uncertainty level of +/- 0.3 percent of reading to 95 percent confidence level.)

After testing, the meters were skidded and shipped to Venezuela for installation and initial operation in 2001. The meters are now in service and meeting the required contract performance levels. They were installed with the four blind tee configuration, separating each meter from its control valve.

Conclusions

- These ultrasonic meters perform within their contracted tolerances in this high-pressure application.
- Ultrasonic transducers may be susceptible to decompression affects if exposed to pressure cycling.
- Static tests indicate that ultrasonic meters should be able to perform in gas mixtures where the speeds of sound are up to 3,000 feet/second.
- Static tests indicated that meters should perform better at 9,000 psig if correction factors from a flow test at 1,100 psig are applied. **P&GJ**