ULTRASONIC FLOW METERS – PART 2

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Introduction

Part 1 of this paper provided basic information on the theory, application, and installation of ultrasonic flow meters to natural gas measurement. This paper covers additional information related to the interface and operation of ultrasonic meters.

Installation Effects

Multipath meters are designed to mitigate the effects of distorted velocity profiles that occur in many standard piping configurations used for field installations. The use of multiple paths can reduce the effect of a distorted velocity profile from certain piping configurations to less than a few tenths of a percent. However, most operating companies recognize that profile distortion is complicated by the presence of multiple piping elements upstream of the last/dominant element that is typically tested in the flow lab. The effect of the header arrangement or other field piping upstream of the meter run can change the profile from the profile that was present when the meter was initially tested.

Examples of velocity profile distortion are shown in Figure 1 and Figure 2, where the velocity profiles were measured 10 nominal pipe diameters (10ND) downstream of a single horizontal elbow, and two elbows out-of-plane, respectively (Grimley, 1998). The arrows in the figures indicate the secondary flows that are present for these conditions. It is important to understand that distorted velocity profiles can take 100 or more pipe diameters to return to a symmetric and fully-developed shape when the only means for reshaping the profile is pipe wall friction from straight pipe.

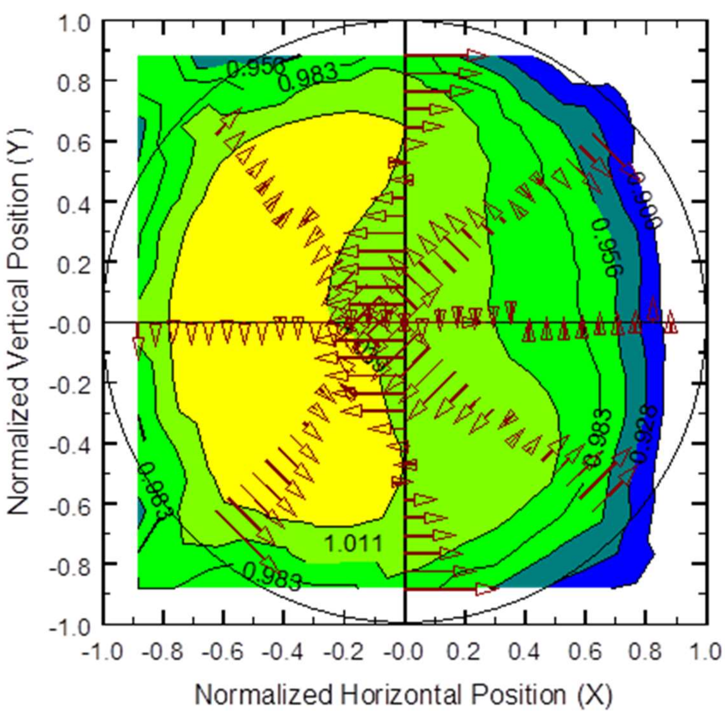

Figure 1. Contours of Measured Velocity Values 10ND Downstream of a Single Elbow

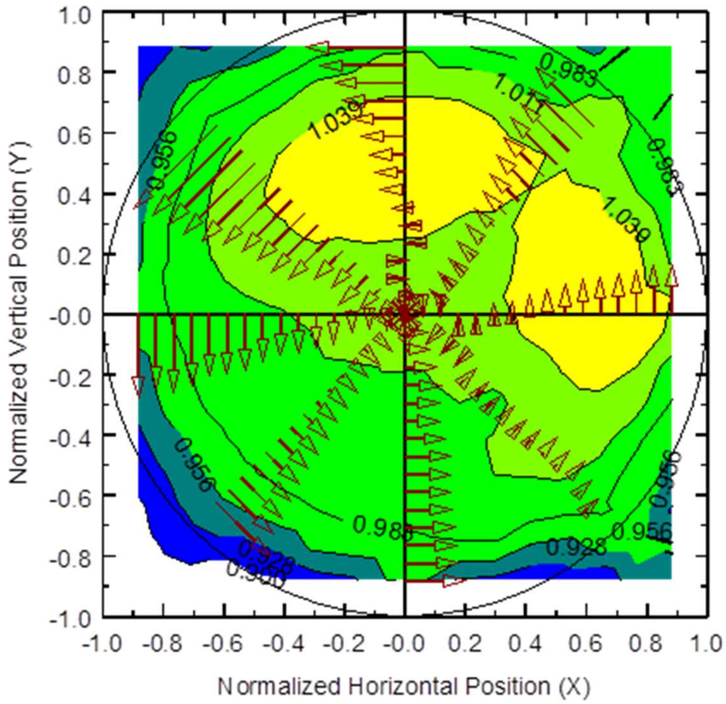

Figure 2. Contours of Measured Velocity Values 10D Downstream of Two Out-of-Plane Elbows

The typical method of dealing with velocity profile distortions is to utilize a perforated-plate flow conditioner to eliminate as much of the distortion as possible. The perforated-plate flow conditioners shown in Figure 3 utilize various hole distributions to re-shape the velocity profile towards an axisymmetric, fully-developed flow profile. While flow conditioners are quite effective, they are not perfect, and some level of distortion will exist even with a flow conditioner; however, the residual profile distortion is normally well within the range that the meter can accommodate. To minimize the effect of flow distortions on meter accuracy, it is recommended that the meter, flow conditioner, and as much of the upstream piping as practical be utilized during the flow calibration.

Figure 3. Perforated Plate Flow Conditioners (from left to right, CPA 50E, Profiler™, GFC®)

<u>System Integration</u>

Although ultrasonic flow meters include substantial calculation capabilities and many include some of the capabilities of a flow computer, the meters are commonly connected to a flow computer for calculation of the standard flow rate and for interfacing with the rest of the measurement system. A connection between the meter and the flow computer through the use of the frequency output function of the flow meter is the most common method. Frequency, output from the meter is scalable so that the meter creates an effective k-factor that can be entered into the flow computer to recover the volumetric flow rate. Originally, this method was used to allow the turbine meter calculation modules in flow computers to be used for ultrasonic meters.

Digital communications from the flow meter can provide much more information to the flow computer and are the basis for creating the pulse output. The digital communications allow path-by-path information on velocity, speed of sound, and other diagnostics to be accumulated outside of the flow meter. Some meters have the capability to store a limited amount of diagnostic data, so if the data are not being automatically retrieved and archived in the measurement system, then it is important to allow easy access for periodic downloads of diagnostic information. In most cases, diagnostic data should be recorded a more frequent basis than hourly to provide useful diagnostics.

As is the case with any volumetric meter, pressure, temperature, and gas composition are also needed to compute the standard (or mass) flow rate. AGA-9 requires that the static pressure be measured through a tap located on the meter body and that the temperature be measured within a few diameters of the meter. These additional measurements can be provided directly to the meter, but in most cases, they are connected to a flow computer.

Software Capabilities and Diagnostics

AGA-9 requires that all ultrasonic flow meter manufacturers provide a means of providing certain information about the operation of the meter. In most cases, this is accomplished through software tools that are able to interrogate the meter to display and log path-by-path information regarding the measured gas velocity, speed of sound, and other diagnostic information related to the operation of the meter.

As mentioned in the commissioning section, tracking the configuration and characteristics of the meter from the factory to the flow lab and to the field is an important function of the meter software. Every meter has a set of configuration values that document the characteristic physical and electronic measurements of the meter, as well as values that are used for specifying how the meter operates and how it calculates the overall flow rate. The meter configuration file may be changed at the flow lab to implement the calibration of the meter, and it may also be changed in the field to implement site-specific interface information (e.g., output frequency scaling or alarm configuration). The meter configuration should be controlled and traceable to the original file from the manufacturer so that the end-user can assess the effect on meter accuracy as a result of any changes made to the configuration.

The sub-sections that follow provide an overview of the types of diagnostic information that is available from the meter software.

Path Velocity

Path velocities can be used to assess the meter performance in several ways. The characteristics of the path velocities can be compared to previously recorded values to determine if there have been changes in the way the meter is operating that can suggest operational problems or meter performance degradation. The characteristics can be compared to those recorded at the time of the flow calibration to determine how representative the calibration is to the actual operation in the field. Typical factors that summarize path velocity characteristics are the “profile factor” and “symmetry factor.” The computation of these factors and other factors (e.g., swirl) is specific to the path arrangement of the meter and varies by meter manufacturer.

The profile factor is typically computed as a ratio of paths near the center of the pipe to those near the edge of the pipe. The profile factor is related to how well-developed the velocity flow is in the meter. Changes in the profile factor may indicate an increase in contamination on the meter and pipe walls. Other potential causes for profile factor changes may include changes in the upstream flow path.

The symmetry factor is normally a ratio of paths from one side of the pipe to the other side and provides another indication of the profile stability in the meter. Asymmetric flows indicate the presence of cross flow and are unstable in a straight pipe, since the flow should always be tending towards a symmetric, fully-developed profile. Changes in flow symmetry can be caused by blockages in the flow conditioner or other changes in the upstream flow path.

Path Speed of Sound

Individual path values for the speed of sound should all be within the limits specified in AGA-9 (each path within 1.5 ft/s under flowing conditions). The speed of sound values for individual paths should not be expected to match each other exactly, but the relationship between the path values should not change over time. Problems with path speed of sound deviations greater than those allowed by AGA-9 should be recognized and corrected by the manufacturer during zero-flow calibrations. The speed of sound agreement is also checked and may be corrected at the time of flow calibration. In the field, speed of sound deviations that are related to only a single path may indicate a variety of operational issues, including contamination, or may suggest impending transducer failure.

Path "Performance"

Path performance indicators generally provide information on the percentage of ultrasonic pulses emitted by a transducer that are deemed to have been properly received by the mating transducer according to criteria specific to the meter manufacturer. Since ultrasonic meters emit multiple pulses per second from each path, the performance level can be established and updated frequently for each set of pulses. As the velocity through the meter approaches or exceeds the largest rated velocity, path performance values may decrease below 100% because of signal distortion from the high velocities; however, in normal flowing conditions, performance values other than 100% may indicate problems with contamination, unstable flow/pulsations, ultrasonic noise, or impending transducer failure.

Gain Level

Ultrasonic meters use automatic gain control to ensure that the signals transmitted through the gas are of sufficient strength for proper detection. Although gain levels are affected by normal operational conditions like pressure and flow rate, they can be also be affected by elements that may be detrimental to the operation of the ultrasonic meter, such as liquid and solid contamination or ultrasonic transducer damage. When monitoring gain levels and making comparisons to previously obtained values, it is important to understand and track the operating conditions where the reference gain levels were obtained. For example, a decrease in operating pressure (density) will cause the gain level of a meter to increase. Without knowledge of the pressure change, this gain level increase could be confused with effects caused by contamination on the transducer face that would also cause an increase in gain value. Gain value changes that cannot be explained by operational changes should be investigated to determine the cause of the change and any potential corrective action required (e.g., meter cleaning and transducer replacement).

Turbulence

Although ultrasonic meters cannot measure what would be considered the textbook definition of turbulence, they can measure the variation in velocity that occurs at the path measurement location. The reported turbulence numbers can be used to assess flow stability.

Diagnostic Summary

Distinguishing between the various possible causes for "abnormal" meter diagnostics requires careful observation of the diagnostic patterns provided by the meter. The number of paths effected, the locations of those paths, and the types of diagnostics values that are out of range should all be considered, along with knowledge of the operational characteristics where the meter is located to determine the possible cause of diagnostic values that are out of range.

Commissioning

When a meter is installed in the field and first put into service, it is important to ensure that the meter is operating properly and that the meter configuration is consistent with that determined by the calibration.

In some cases, the meter manufacturer's software can be used to verify the configuration in the meter against the configuration file supplied at the time of calibration. If this option is not available, then the configuration files should be compared manually to ensure that the meter setup has not changed. It may also be necessary to alter certain meter parameters to reflect the differences between the operating conditions during the calibration and those at the field location (operating pressure is one common example of a value that may need to be set).

When flow is first established at the field location, it is critical to acquire the diagnostic information described in the previous section. These data serve two important purposes:

1. The initial field diagnostics can be compared to the data obtained during the calibration to determine any anomalies in the field installation compared to the original calibration.
2. The initial field diagnostics can be used as a reference for future field comparisons.

Trending of diagnostic values (compared to the initial values) can be used to trigger meter inspections or cleaning. The diagnostics can also provide indications of pending meter problems or operational upsets.

Operational Issues

Ultrasonic Noise

Ultrasonic transducers used for natural gas flow measurement operate at frequencies of well over 100 kHz, with the specific operating frequency depending on the design of the transducer. Other sources of ultrasonic energy can interfere with the ability of a meter to determine the transit time of the ultrasonic pulse by masking the signal received by the transducer. Figure 4 shows an example of an ultrasonic signal that has been obscured by ultrasonic noise from a pressure regulation valve downstream of the meter (Warner and Zanker, 1999). The labels in the figure are for the upstream transducer that faces the noise source and the downstream transducer that faces away from the noise source.

Figure 4. Ultrasonic Noise from a Regulator Downstream of the Meter

The most well-known source of ultrasonic noise is from valves used for pressure regulation where, to avoid a significant amount of audible noise from the pressure drop, noise-attenuating valve trim is used. The configuration of the noise-attenuating trim is such that noise in the audible range is shifted in frequency to the ultrasonic range. Although high-frequency noise (pressure pulsations) does not travel as far as low-frequency noise, the amount of energy dissipated in the valves is so large that it can interfere with the very low energy ultrasonic signals that are used in flow meters. It is important to understand that noise travels both upstream and downstream; however, installing the meter in the higher pressure (upstream) location improves the ability of the meter to operate properly by improving the acoustic coupling of the transducer.

Options for operating meters in the presence of ultrasonic noise include replacing the transducers with different (typically higher) frequency models, software compensation within the meter through filtering, averaging and/or ultrasonic pulse encoding, or through mechanical filtering through piping configuration modifications.

Piping configurations that include multiple tees and capped or blinded ends can be used to reduce the amount of ultrasonic noise that reaches the meter. An example of the type of configuration that has been found to be effective is shown in Figure 5 (Daniel Measurement and Control, 2003). While these piping geometries are effective with respect to ultrasonic noise, they can have a detrimental effect on the flow profile that reaches the meter.

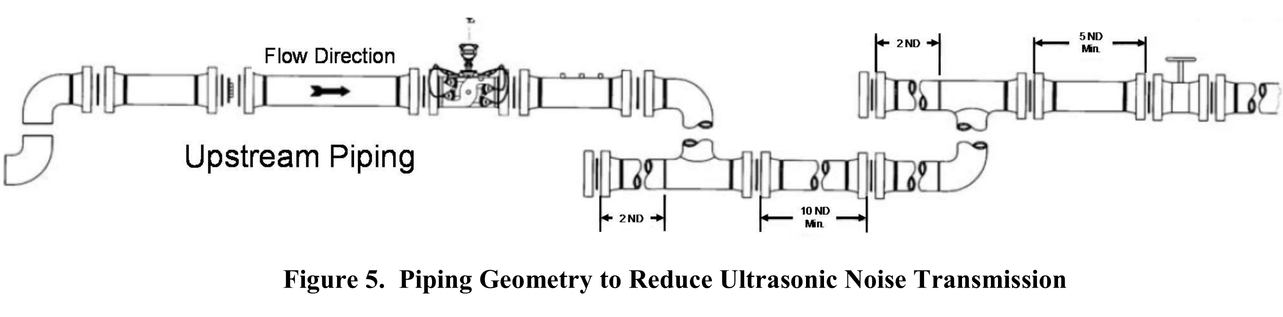

Figure 5. Piping Geometry to Reduce Ultrasonic Noise Transmission

Contamination

Typical pipeline materials that can cause problems with the proper operation of ultrasonic flow meters include "dirt" and black powder, compressor oil, valve grease, and condensates. While the materials typically do not cause permanent damage to the meter, they may cause shifts in the meter output until they are removed.

Materials that coat the inside of the meter and the transducers can cause changes in the meter geometry that result in calculation errors. However, the positive/negative response of the meter to contamination can vary depending on the path configuration of the meter and overall design.

The previously mentioned diagnostics are also affected by contamination and can be used in combination with knowledge of the operating conditions to assess the presence of contamination and the need for cleaning the meter. For example, increases in gain combined with a velocity profile factor indicating a more "pointed" velocity profile may suggest that there is a buildup of material on the transducer faces causing the increased gain and contamination on the walls causing increased apparent wall roughness that leads to the change in the velocity profile factor.

Pulsation

The presence of flow pulsations at the meter can have a detrimental effect on the meter accuracy. The two primary causes for ultrasonic meter error with pulsations are from:

1. Aliasing of the velocity profile that results from having too low of a sampling frequency. The measured path velocities may not be representative of the actual path velocity because the gas velocity is changing more rapidly than the meter can sample it.
2. Velocity profile distortion associated with pulsating flow. The varying velocity profile that occurs during pulsating flow does not match the velocity profile for which the meter algorithms and calculations have been tuned.

The pulsations may be caused by reciprocating compressors or from flow-induced pulsations that result from vortex shedding caused by pipe fittings or other piping geometries.

As is the case with other flow measurement technologies, flow pulsations should be eliminated to provide the most accurate readings. Depending on the severity of the flow pulsation at the meter, the meter error could be more than a few percent. The severity of the pulsation may be inferred from turbulence readings for the meter and if those readings are significantly different from the values recorded during the flow calibration, then the meter readings will be suspect.

Component Replacement

The ability of the meter to operate without a change in accuracy as a result of changing the electronics and/or the transducers is something that the manufacturers should be able to demonstrate with test data. The end-user should consider carefully if a flow calibration is warranted when making a wholesale update of meter electronics and transducers.

Ultrasonic meters commonly have the capability of having electronic components replaced in the field. This can be done for upgrade purposes or to replace failed systems. The replacements are generally done by either replacing entire circuit boards or entire electronic assemblies (that is, there are generally no replacements at the discrete component level).

Although ultrasonic transducers are much more robust today than they were when ultrasonic meters were first introduced, it is not uncommon to need to replace a transducer in the field. There can also be a desire to change to a different style of transducer because of operating conditions, such as ultrasonic noise or liquid contamination. To properly change the transducers without affecting the meter accuracy, the manufacturer's procedures must be followed. This often includes changes to the configuration of the meter electronics to account for slight physical differences in transducer lengths or for differences in the response characteristics of the transducer (e.g., delay time changes).

Recalibration

Ultrasonic meters do not explicitly require recalibration and there is no requirement in AGA-9 for a specific interval after which an ultrasonic meter should be recalibrated. If the initial calibration of the meter properly captured operating conditions and the installation geometry, then the meter calibration should be valid as long as the meter and the station continue to operate with the same characteristics.

However, given the monetary value of the gas that passes through most ultrasonic flow meters, the risk associated with mismeasurement should be assessed along with meter diagnostic values to determine if a flow check of the calibration is warranted. Diagnostics may go beyond values indicated by the meter itself. The system balance for a piping network may suggest that a particular meter station or zone should be reviewed for possible error. One way to provide confidence in a suspect flow meter is to remove it from service and send it back to a calibration facility for a re-calibration.

Conclusions

This paper has provided some additional insight into the application of ultrasonic flow meters and the operational and installation considerations that should be reviewed when building a meter station that utilizes an ultrasonic flow meter. There is a significant body of literature available that documents the numerous tests and developments that have taken place since ultrasonic flow meters were introduced to the natural gas industry in the 1990s that can provide a further understanding of the operation of ultrasonic flow meters.

References

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