ULTRASONIC FLOW METER CALIBRATION – CONSIDERATIONS AND BENEFITS

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INTRODUCTION

Since their introduction to the natural gas industry in the mid-1990s, multipath ultrasonic flow meters have developed a large installed base and have become the meters of choice for a variety of reasons. While one of the initial goals of the manufacturers was to develop a meter that did not require flow calibration, the accuracy requirements of most measurement applications dictate that ultrasonic flow meters need to be flow calibrated. This paper provides an overview of the calibration process and elements that should be considered by those responsible for the calibration.

REASONS TO CALIBRATE

Meter calibration is essential to minimizing the potential measurement error in an ultrasonic flow meter. American Gas Association Report Number 9, *Measurement of Gas by Multipath Ultrasonic Meters* (AGA-9) specifically requires flow calibration for all meters used for custody transfer. With any meter that passes large quantities of gas, there is an inherent financial risk associated with even small measurement errors. The dollar value associated with a measurement error for even a single meter can be quite large. For example, a 12-inch diameter meter operating at a static pressure of 900 psi and flowing at a velocity of 50 ft/s passes roughly 200 MMscfd. At $2.75 per Mscf, a 0.2% error amounts to just over $400,000 in a single year.

Even with improvements in meter manufacturing and quality control of attributes that affect the “out-of-the-box” meter accuracy, a flow calibration verifies aspects of the meter that cannot be determined by any other means and allows the meter baseline diagnostic information to be established in a controlled flowing environment. For example, the zero-flow tests performed by the manufacturer verify operation of the transducers and electronics and some fundamental geometric measurements, but zero-flow tests cannot be used to infer the meter factor required for accurate operation under flowing conditions.

In addition to the meter’s initial calibration, meters are often recalibrated at regular intervals. In some cases, regulatory agencies require meter recalibrations at specific intervals, but users may also choose to recalibrate meters on a regular basis to reduce the risk associated with any changes in the meter performance over time. The more severe the meter’s operating environment, the more frequent meter inspections and recalibrations should occur.

GENERAL CONSIDERATIONS

Meters are typically calibrated with the piping that will ultimately be used for the field installation, including a flow conditioner. The choice of the amount of additional piping to include in the calibration depends on a number of factors, including the type of flow conditioner, the complexity of the piping geometry, the type of meter, and the amount of acceptable risk/uncertainty in the ultimate measurement. The user’s prior experience with the piping configuration can also be a significant factor in establishing which elements of the piping may need to be present for the calibration.

Research and common sense suggest that minimizing the differences between the calibration and the field operation will result in the most representative calibration. This can include matching operating conditions, as well as the mechanical installation. However, from a practical standpoint, there are limits to what can be done without incurring unreasonable costs. For example, leaving a meter and upstream piping assembled for shipment from the calibration facility assures that there will be no error introduced into the meter from a difference in flange alignment at the time of calibration versus when the meter is installed in the field. However, for a large meter run, it may not be possible to handle or ship the meter and piping as an assembly.

Ultrasonic meters can be calibrated using either the digital interface or one of the other output interfaces (i.e., frequency or analog current). The frequency output is commonly used since it is relatively easy to interface to a flow computer and produces results that are normally identical to that from the digital interface. Since the meter generates the frequency output from the same flow value that could be read from the digital interface, it is reasonable to expect these values to result in the same meter calibration and tests have shown this to be the case. Analog current values may be useful for control applications, but are generally not recommended for calibration use because of the possibility of signal noise and drift that can lead to an inaccurate meter calibration. Since calibration adjustments are normally entered into the meter electronics, and the analog current and frequency output values are scaled internally by the meter electronics, the output scaling can be altered after meter calibration without affecting the accuracy of the calibration. Changes in the output scaling only require that a corresponding change is made in the device (e.g., flow computer) reading the output from the meter.

When removing a meter from the field for recalibration, the condition in which the meter is tested should be considered. Meters and piping that have been contaminated during field service and have an internal build-up of material are sometimes tested as-is (with the coating) prior to being cleaned and recalibrated. This process can be used to establish any bias resulting from the contamination. Calibration facilities may limit the type and amount of contamination that can be tested in the facility, so it is important to consult with the facility prior to arranging a test. A similar procedure is sometimes used when upgrading electronics and transducers, where the meter is tested as-is, then upgraded and re-calibrated with the latest components.

Scheduling a meter calibration is an activity that should be planned in advance. Flow calibration facilities often have a one- or two-month-long backlog. Waiting until the last minute to arrange the meter calibration can result in delays or additional charges for overtime efforts. Meter manufacturers or meter packagers normally arrange the initial flow calibration when requested, so the burden of scheduling is often transferred to the manufacturer or packager.

Some end-users prefer to witness the meter calibration. Experienced users can use the witnessing time to check that the meter, piping, installation, and testing are all as expected. New users can use this time to familiarize themselves with calibration procedures and for a training opportunity with the meter software applied to a live meter. This provides a better understanding of the meter operation in a controlled environment, prior to installation in a less-controlled field environment. Calibration facilities typically welcome this type of activity, as long as it does not interfere with the calibration.

CALIBRATION FACILITIES

Calibration facilities utilize a reference meter to which the test meter is compared. The type of meter used as the reference varies with the facility's measurement and traceability approach. Turbine meters and critical flow nozzles are commonly used as working reference standards for meter calibrations. The working reference standard meters are normally secondary standards since they have been calibrated against a primary standard device where the flow is determined by fundamental measurements (mass, length, and time).

Primary standard devices for flow measurement include piston provers, pressure volume temperature time (PVTt) systems, and gravimetric (weigh) systems. The primary system from which the secondary meter derives its measurement uncertainty may be onsite or may be located elsewhere, but the important consideration is that the traceability to the primary system allows an assessment of the uncertainty of the flow measurement reference for the meter to be calibrated.

Existing flow calibration facilities operate either by diverting gas from an existing pipeline (an open-loop system) or as a closed-loop system. Maintaining a fixed gas composition and static pressure is simplified with a closed-loop system. A closed-loop system can typically test at a user-selected pressure, which allows calibration of meters with flanges rated at pressures below the facility's design value and allows the calibration to match the anticipated operating pressure. Open-loop calibration facilities normally require meters to be pressure rated for at least the same value as the facility (for safety reasons), so those facilities are typically limited to testing ANSI 600 (and higher) meters and typically do not have control of the static pressure. However, the flow capacity of open-loop facilities typically exceeds that available from closed-loop facilities because of the economics of supporting the closed-loop facility equipment.

Flow calibration facilities participate regularly in inter-lab comparisons to demonstrate their performance relative to other facilities. The results of the inter-lab comparisons provide calibration users with an understanding of the equivalence of meter calibrations obtained from different facilities. Facilities may also demonstrate their performance through comparisons with an established database, such as that which exists for orifice meters.

METER INSTALLATION

As mentioned previously, the meter installation may include the final station piping and flow conditioner (Figure 1~~Figure 1~~) or may be built up from facility-owned components. In some cases, the meter run piping may be installed in combination with piping meant to simulate the geometry of the final installation (Figure 2~~Figure 2~~).

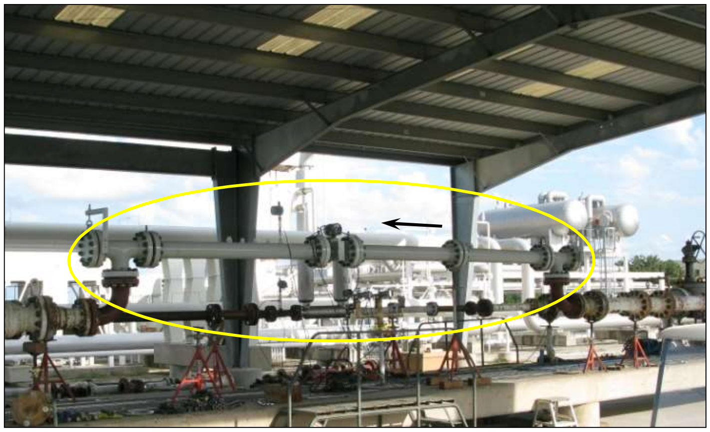

Figure 1. Meter Installation with Inspection Tees

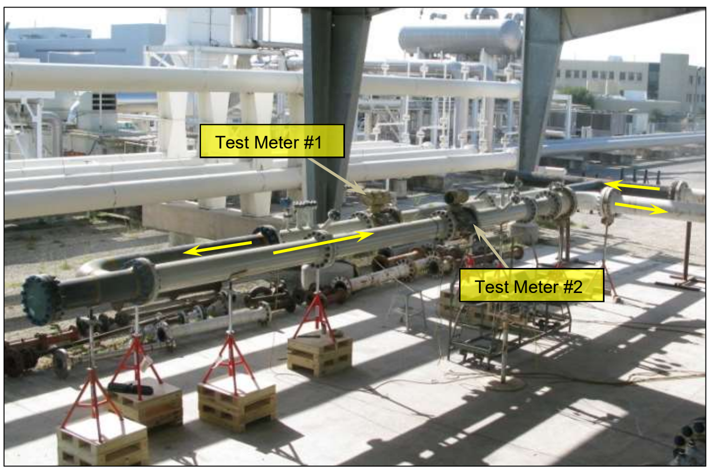

Figure 2. Series Flow Meter Installation Simulating Header and "Z-meter" Configuration

The meter station piping is sometimes delivered to the flow facility pre-assembled as a single meter run, or it can be built up component-by-component by the flow facility staff. Normally, the flow facility will need to know in advance if the meter run is to be shipped out as a single unit, or to what level the piping should be broken down after the calibration. This information is needed at the time of installation so that the facility can choose whether or not to use the bolts and gaskets supplied with the meter. When the piping is built up by the flow facility prior to calibration, it is normally built starting with the upstream piping so that the internal flange alignment can be observed as each pipe downstream spool is added.

Once the meter and its associated piping are installed, the pressure and temperature measurement transmitters are added to the test setup per AGA-9 requirements. The pressure tap on the meter body is used for static pressure measurement, and the temperature measurement sensor (typically an RTD) is installed in a position three to five pipe diameters downstream of the meter. Flow facility owned and maintained pressure and temperature instrumentation are normally used for the meter calibration.

After meter connections for power and communications are established and the meter is purged into natural gas service and pressurized, the basic operation of the meter is checked using software from the meter manufacturer. Initial checks of the meter operation include observations of the performance on a path-by-path basis. The percent acceptance/performance of ultrasonic pulses, speed of sound values, velocity values, gain levels, and other critical parameters are examined for consistency. The initial configuration of the meter can be captured at this point and any modifications to the meter setup needed for calibration should be performed and documented. Flowing briefly through the meter prior to calibration also provides a check of the symmetry of the meter's path velocity values and can also be used to verify the proper configuration of the calibration facility's data system.

CALIBRATION DETAILS

Flow meter calibration normally starts by establishing stability in the measuring system by flowing gas at a high rate for the meter under test. In a closed loop system, the bulk system pressure is established prior to circulating and then adjusted as the temperature reaches its set-point condition. For any system, flowing at the highest flow rate condition allows the meter and its associated piping to soak at the temperature of the flowing gas and stabilize prior to starting the meter calibration.

It is common practice to test first at the higher flow rates and gradually decrease the flow to cover the calibration range, since this typically provides the best stability. The flow rates to be tested can be taken from AGA-9, or established by other suitable methods that are acceptable to both parties involved with the measurement that the meter will provide. AGA-9 recommends calibration flow rates equal to 100%, 75%, 50%, 25%, 10%, 5%, and 2.5% of the maximum flow rate.

At each flow rate, there are a number of discrete test points recorded where each test point consists of an average over a sample period of 90 seconds to 300 seconds. Different flow labs use different sample periods and different numbers of repeat points, but all labs provide a sufficient sampling of the meter performance to establish the meter error relative to the lab's flow reference. Data collected include flow rates, pressures, and temperatures for the test meter and reference meter(s), and gas composition data for the system. Average values for all of the measurements are included in the test report.

During each calibration test point, data are collected not only to determine the measurement accuracy of the meter, but also to provide a reference for future diagnostic evaluations of the meter. The software from the meter manufacturer is typically used to log the performance of the meter so that path-by-path values for speed of sound, velocity, gain levels, and any other diagnostic parameters can be captured. In some cases, this may include capturing the waveforms received by the transducers.

Another comparison made during the meter calibration is between the speed of sound reported by the meter and that computed using AGA Report Number 8, Part 1, *Thermodynamic Properties of Natural Gas and Related Gases, DETAIL and GROSS Equations of State* (AGA-8), and the pressure, temperature, and gas composition measured at the meter. The AGA-9 specification for speed of sound agreement is 0.2%, but the speed of sound error is typically only a fraction of the allowable error.

METER ADJUSTMENT

There are various methods that can be used for adjusting the meter after the meter calibration data have been obtained. There are three common adjustment methods indicated in AGA-9:

1. Adjust based on the Flow-Weighted Mean Error
2. Adjust using a polynomial algorithm
3. Adjust using a multi-point linearization

Other methods are also acceptable as determined by the parties involved in the measurement. The selection of the best method depends on the meter's characteristics, as well as the application.

~~Table 1~~ provides an example of meter calibration data. The entries in the table are the averages of the values shown for the "as found" curves in Figure 3~~Figure 3~~, Figure 4~~Figure 4~~, and Figure 5~~Figure 5~~. ~~Table 1~~ includes the computation of the flow-weighted error (FWE) that is used in determining the flow-weighted mean error (FWME).

$$FWE = \frac{Flow\ Rate}{Full\ Scale\ Flow\ Rate} \cdot Error$$ (Equation 1)

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~~Table 1. Example Meter Data Summary~~

Point	Velocity (ft/s)	Error (%)	Full Scale Fraction	Flow Weighted Error	FWME Corrected Error (%)
1	94.558	-0.169	0.946	-0.160	0.212
2	70.983	-0.190	0.710	-0.135	0.191
3	52.117	-0.414	0.521	-0.216	-0.034
4	37.820	-0.570	0.378	-0.216	-0.191
5	23.628	-0.648	0.236	-0.153	-0.269
6	14.217	-1.023	0.142	-0.145	-0.646
7	9.443	-1.338	0.094	-0.126	-0.961
		Sum =	3.028	-1.151	

Table 1. Example Meter Data Summary

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The FWME is computed from:

$$FWME = \frac{\sum FWE}{\sum \frac{Flow\ Rate}{Full\ Scale\ Flow\ Rate}} = \frac{-1.151}{3.028} = -0.38\% \quad \text{(Equation 2)}$$

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When the FWME method is used, a single correction factor is entered into the meter configuration. The meter factor is the amount by which the meter output should be multiplied to match the reference flow rate. To convert from the FWME to a meter factor, the following equation is used:

$$Meter\ Factor = \frac{100}{100 + FWME} = \frac{100}{100 + (-0.38)} = 1.00381 \quad \text{(Equation 3)}$$

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~~Table 1~~ and Figure 3~~Figure 3~~ show the expected meter performance when the meter is adjusted based on the FWME. The use of a single meter factor only shifts the error curve. Because of the flow-dependent error for this example, the error remains at both the high and low flow rates, but since the correction was flow-weighted, the residual error at the high flow rates is significantly less than that for the low flow rates.

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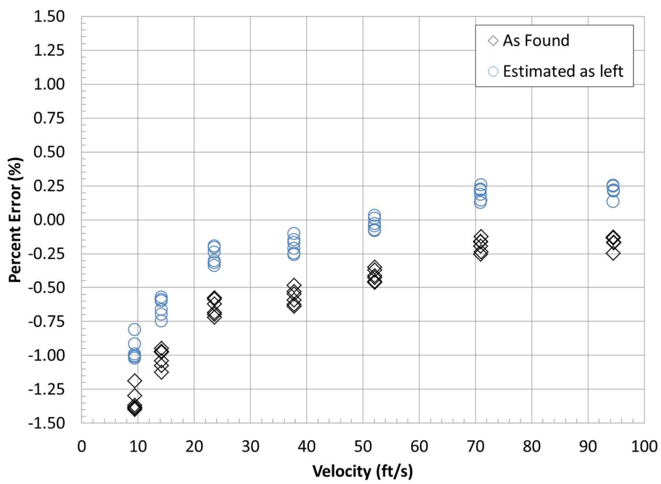

Figure 3. Flow-Weighted Mean Error Correction

Because the use of a single meter factor cannot compensate for the flow-dependent error, polynomial corrections are sometimes applied to a meter. While the specific form of equation implemented by different meter manufacturers can vary, the polynomial correction takes a form similar to the equation below, where the meter factor is a function of the meter velocity (V) and a set of calibration constants (A_0, A_1, and A_2):

$$Meter\ Factor = A_0 + A_1 \cdot V + A_2 \cdot V^2 \qquad \text{(Equation 4)}$$

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The result of a polynomial correction is shown in Figure 4~~Figure 4~~. In this example, the mean error is zero with a slight negative bias at high flow rates and a positive bias at approximately 25 ft/s. Flow or other weighting methods can be used with the polynomial fit to force the curve to better characterize the meter in critical areas, such as near the normal operating range or at high flow rates. The polynomial fit can be used to smooth out some of the point-by-point variations that can occur in calibrations.

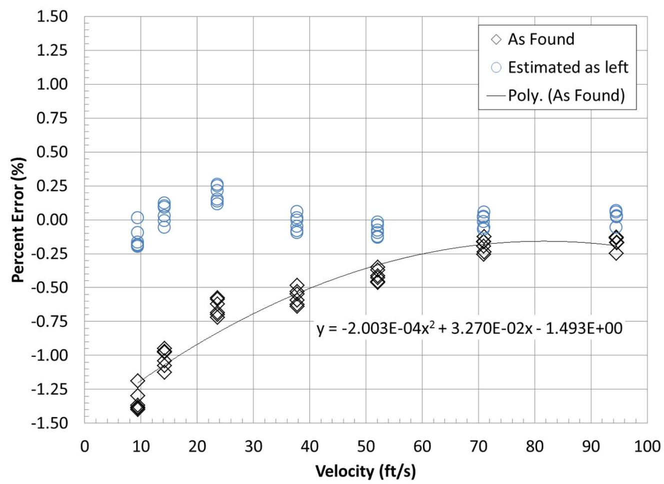

Figure 4. Polynomial Curve Correction

A point-by-point linearization is another method of correcting a meter. The average meter factor, or average error, is entered into the meter electronics along with the corresponding average test flow rate. Those points are used by the meter electronics to adjust the meter by performing linear interpolation to establish the correction at any non-tested flow rate. The result of a point-by-point linearization is that the average error at any tested flow point is expected to be zero, as shown in Figure 5~~Figure 5~~.

Figure 5~~Figure 5~~ also includes verification points that were collected after the point-by-point correction values were entered into the meter. The purpose of performing verification points is to confirm that the meter was properly adjusted to reflect the calibration values. Often, verification points are tested at rates slightly different than those used for the calibration, but in this case, the points were collected at the same rate as two of the test points.

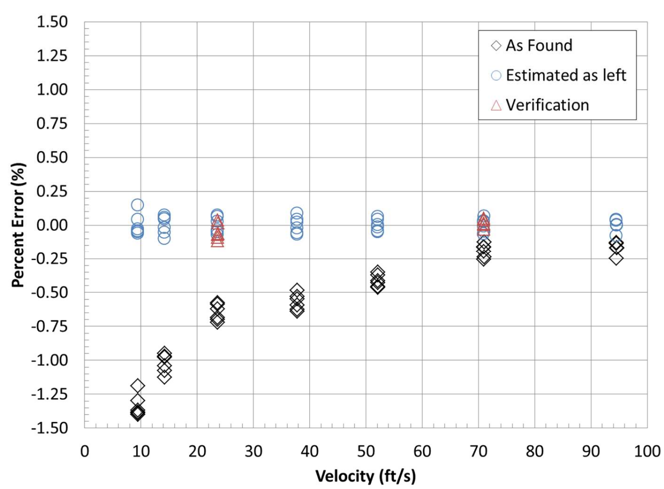

Figure 5. Point-By-Point Correction with Confirmation Points

The AGA-9 limits for unadjusted meters with a diameter of 4-inch and larger are shown in Figure 6~~Figure 6~~. Since the example meter falls into the medium meter category (from 4-inch to 10-inch nominal diameter), the error limits are ±1% above the transition flow rate of at least 10% of the maximum flow rate. This particular example clips the bounds of the error specification since the error at 14% of the max flow rate is -1.023%, as shown in Figure 7~~Figure 7~~. The linearity of the meter is also on the edge of the performance specification since the peak-to-peak error above the transition rate is 0.85%. However, most users would accept this meter because it shows good repeatability and has a well-behaved calibration curve. The adjusted curves for the example meter will provide accurate measurement throughout the meter's operating range. In this particular example, arguments can be made for using either the polynomial or point-by-point calibration curves. For other meters with better linearity, the use of FWME correction can provide similar calibrated accuracy; for example, the meter shown in Figure 8~~Figure 8~~.

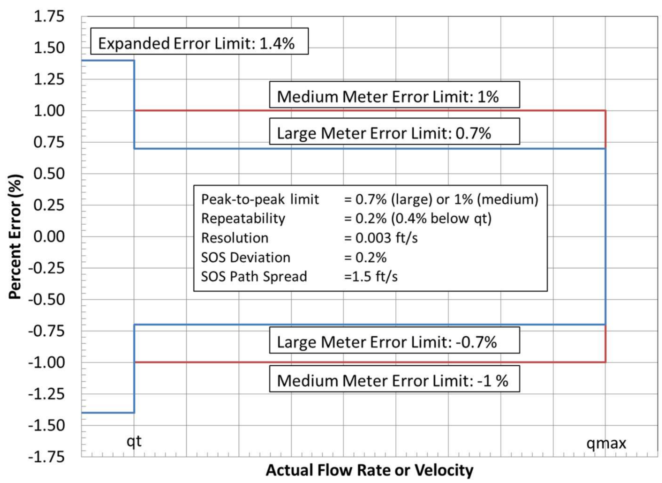

Figure 6. AGA-9 Meter Performance Specification Summary

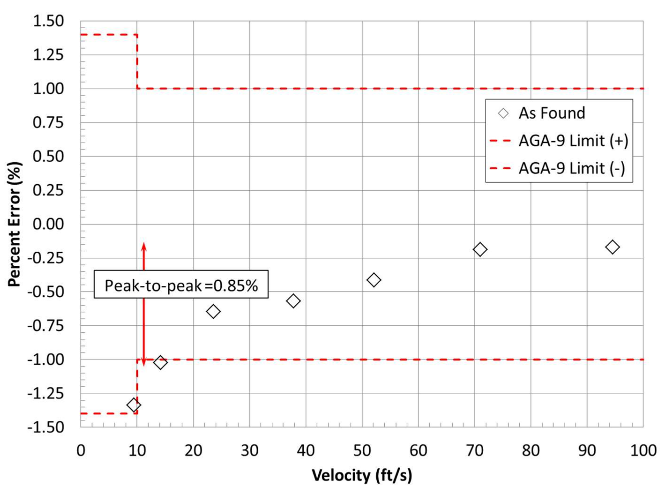

Figure 7. Average Meter Data with AGA-9 Limits

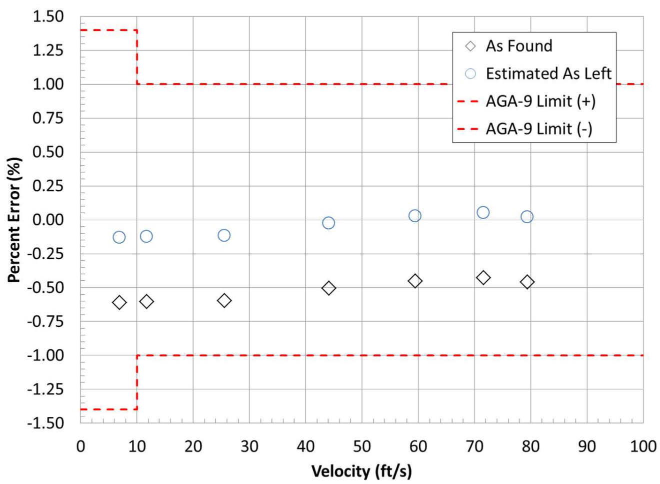

Figure 8. FWME Correction for a Medium Diameter Meter with a Semi-Uniform Offset

DOCUMENTATION

At the end of the calibration, the preliminary results, which typically include an error curve, can be provided immediately to the user. The formal calibration report, which includes an additional review of the data and provides the full documentation of the results, may take one or two weeks to produce. AGA-9 recommends that the calibration report include:

1. The name of the manufacturer.
2. The name and address of the flow calibration facility.
3. The model and serial number of the meter.
4. The meter firmware version number.
5. The date(s) of the calibration.
6. The name and title of the person(s) who conducted the calibrations.
7. A reference to the facility calibration procedures.
8. The upstream and downstream piping configuration used during the flow calibration to include any user specified ancillary components, like filters, end treatments (tees), etc.
9. The serial numbers of all piping and flow conditioners, when available.
10. The “as-found” and “as-left” configuration parameters.
11. All calibration data, including flow rates, velocities, errors, pressure, temperature, and gas composition.
12. A statement of uncertainty for the test conditions with reference to the method used.
13. A list of primary element(s) used at the flow calibration facility for meter calibration, when requested.
14. An identification of adjustment method applied and adjustment factors applied.
15. Number of pages in the calibration document, such as 1 of 3.
16. Typed names below signatures of all people who signed calibration document.

AGA-9 requires that manufacturers ensure that the meter calibration report is available for at least ten years, but in practice, the calibration facilities typically maintain copies of all meter calibration reports and make them available to the manufacturer and/or end-user as needed.

The calibration documentation should be made available to those responsible for commissioning the meter, since it provides vital information for the commissioning process.

METER COMMISSIONING

When the 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 differences between the operating conditions during the calibration and those at the field location (operating pressure is one common example that may need to be set).

When flow is first established at the field location, it is critical to acquire a set of diagnostic information on the meter for two purposes:

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

One of the benefits of ultrasonic meters is the diagnostic information that is integral to the meter operation. Trending of diagnostic values, as 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. Different meter manufacturers provide slightly different tools for assessing the meter performance through the diagnostic measurements, but the basic functionality exists for all meters.

CONCLUSIONS

Users should be knowledgeable on the factors that can influence the performance of an ultrasonic meter and consider those factors when specifying the calibration requirements for their application. Calibration facilities and meter manufacturers can provide the benefit of their experience in helping the user establish the calibration approach and in interpreting the results.

Properly calibrated ultrasonic flow meters provide an accurate means of measuring gas in critical applications. The initial meter calibration establishes not only the accuracy of the meter, but also provides a critical reference point for meter diagnostic parameters that can be used to assess the operation of the meter over time.

REFERENCES

1. AGA Transmission Measurement Committee Report No. 9, *Measurement of Gas by Multipath Ultrasonic Meters*, American Gas Association, 2017, Washington, DC.

2. AGA Transmission Measurement Committee Report No. 8, Part 1, *Thermodynamic Properties of Natural Gas and Related Gases, DETAIL and GROSS Equations of State*, American Gas Association, 2017, Washington, DC.