Flow Calibration Laboratory Performance – What should your expectations be?

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Introduction

In recent years, there has been a growing demand world-wide for flow meter verification testing and calibration services. This increased demand is due in part to new flow measurement technologies making their way into the marketplace. In many instances, flow meter owners or operators are seeking calibration laboratory services for the first time. There are many aspects to producing accurate flow meter calibrations. Laboratory performance can vary significantly from one lab to the next, depending on the configuration of the laboratory and the experience of those who operate it. This paper explores the issues associated with selection of an acceptable flow calibration laboratory.

The authors work at the Gas Technology Institute (GTI) Metering Research Facility (MRF). This article is written from the perspective of a gas flow calibration laboratory, although the basic technical principles and operating philosophies discussed here are generally applicable to meter calibration labs of all types.

Measurement Uncertainty

Precision and Bias Measurement Errors

Meter accuracy or measurement uncertainty is almost always of paramount importance when a meter is to be flow calibrated. Most laboratory operators define their facility measurement performance in terms of *total measurement uncertainty*. *Measurement uncertainty* is the upper limit of the measurement error. *Measurement error* is the difference between the 'true' value and the measured value. One of the difficulties in determining measurement uncertainty is that the true value is almost never known. Only when a national or international calibration standard exists (e.g., mass, length, or time), can a measured value be compared to the 'true' value. Unfortunately, there are no national or international standards for flow rate.

Total measurement uncertainty includes two components: the uncertainty associated with *precision* (random) errors and the uncertainty associated with *bias* (fixed) errors. Figure 1 illustrates what is meant by the terms *precision* and *bias*. Assume the curves shown on Figure 1 represent plots of a number of flow rate measurements made consecutively under unchanging test conditions. In short, a meter owner is looking for a calibration that is precise and unbiased. The reader is referred to Coleman and Steele[1] for a more thorough treatment of experimental measurement uncertainty and the statistical evaluation of test data.

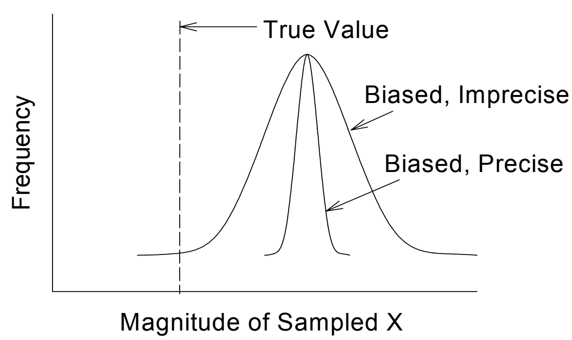

Figure 1. Example Statistical Representation of Flow Test Data

It is a good rule of thumb to select a calibration lab that has a total measurement uncertainty on the order of 5 to 10 times smaller than that of the flow meter being tested. However, this goal is not always attainable.

Flow Calibration System Types

There are two basic types of flow meter calibration systems. They are *primary* and *secondary* systems. (The reader is referred to Behring, et al.[2] and Gallagher[3] for a more thorough treatment of meter prover systems.) Primary systems are those that determine flow rate from fundamental measurements of mass, length (or volume), and time. Examples include gravimetric (weigh tank) systems; bell-type provers; piston-type (swept volume) provers; and pressure, volume, temperature, and time systems (PVTt). Measurement uncertainty (i.e., the 95% exceedance level value) for a primary system is typically in the range of ±0.01 to ±0.25%. Figure 2 shows a weigh tank system from the GTI Metering Research Facility located in San Antonio, Texas.

Figure 2. Example High-Pressure Natural Gas Weigh Tank System

Secondary systems are those calibrated using a primary system. Total measurement uncertainty is usually in the range of ±0.20 to ±0.75%. Secondary calibration systems typically include experimentally determined calibration coefficients that take into account modeling simplifications. Examples of secondary flow standards include turbine meters and critical flow Venturi (sonic nozzle) meters. Figure 3 shows a critical flow Venturi system from the GTI Metering Research Facility. This particular reference flow standard includes five Venturis plumbed in parallel.

Figure 3. Example High-Pressure Natural Gas Critical Flow Venturi System

One key feature to look for in a flow laboratory is multiple flow references. When a meter is being flow tested and the results are not as expected, the question usually arises as to whether the problem lies with the test meter or the facility. If the facility has two or more flow reference meters to compare against the test meter, the job of determining the source of the problem can be made easier.

Repeatability and Reproducibility

The terms *repeatability* and *reproducibility* are both important when assessing the performance of a flow meter calibration laboratory. Repeatability refers to the closeness of agreement among a number of consecutive measurements made under the same operating conditions. Reproducibility refers to the closeness of agreement among a number of consecutive measurements made under the same operating conditions *over an extended period of* time. Many factors, including the test equipment, instrumentation, data acquisition system, and test personnel, can affect the level of repeatability and reproducibility that can be achieved by a particular calibration lab. The preferred lab is one that has good repeatability and reproducibility.

A test lab should maintain a consistent performance level over time. If the uncertainty of a lab varies significantly over time, then performance differences observed when a meter is re-calibrated may be due to test facility changes, rather than meter changes. It is also important to have a meter re-calibrated at the same lab that did the original calibration. This avoids problems associated with laboratory-to-laboratory bias differences.

Laboratory reproducibility is illustrated in Figure 4, which shows an orifice meter data set that was acquired over a four year time frame at the GTI Metering Research Facility. The test meter was removed from the facility between each test. This test series gives an indication of the test reproducibility, or operational consistency, of this particular test facility and meter.

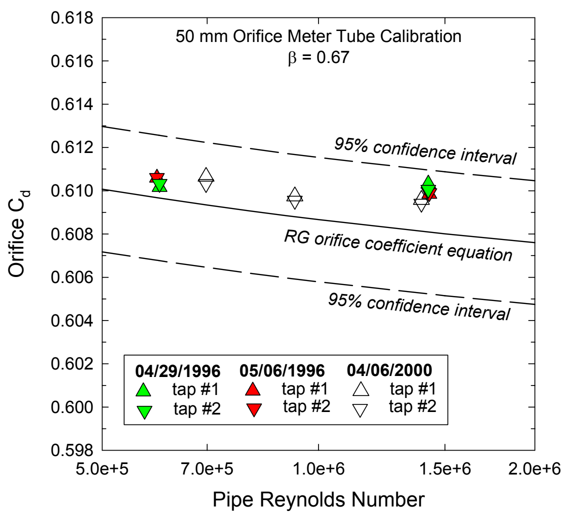

Figure 4. Lab Reproducibility Illustrated by Calibration of a 50 mm Diameter Orifice Flow Meter

Operating Range/Characteristics

Operating conditions can affect different meter types in different ways. Some of the factors that can influence meter performance are the test fluid (e.g., compositional makeup, density, viscosity, etc.), operating conditions (e.g., line pressure and temperature, flow rate, etc.), and geometry (meter and piping). When calibrating a meter, the preferred approach is to identify the performance parameters that affect meter accuracy and then match the lab test conditions to these as closely as possible. Meter manufacturers can assist with test planning. Experienced flow labs can also provide advice on test methodology. In some cases, there are industry or governmental standards for the test protocols.

Reference Measurement Standards and Traceability

No national or international standards exist for flow rate. National and international standards do exist for mass, length, and time. Primary flow meter calibration systems can be 'traced' to national or international standards in the sense that mass, length (volume), and time measurements can be directly compared to existing standards. Secondary calibration systems can be indirectly 'traced' to existing standards via calibration by a primary system. It is important to note that the more links in the traceability 'chain,' the greater the measurement uncertainty in the meter calibration.

Inter-lab Comparisons

One way to judge lab performance is through inter-lab comparison testing. Unfortunately, there are no industry standards for this type of testing. Consequently, the rigor of the test protocols used for these comparisons can vary considerably from one to the next.

Results from inter-lab test programs can be presented in a variety of ways. Figure 5 (called a Youden plot) shows test results for one inter-lab comparison that involved seven labs. In this test program, an ultrasonic meter and a turbine meter were installed in series and flow tested simultaneously. Figure 5 compares the measurement errors of the two flow meters used in the test. Data points lying along a 45° line running from the lower left quadrant to the upper right quadrant of the plot indicate laboratory biases. Data points not lying along this line are due to precision errors.

Another means of verifying lab performance is to compare results of a particular meter test to those contained in an existing database. Figure 6 is an example of how a number of flow labs compare with regard to the orifice discharge coefficient calculated using the Reader-Harris Gallagher (R-G) equation.

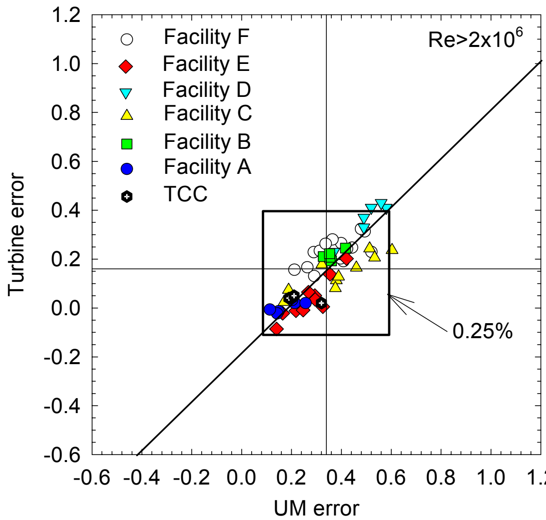

Figure 5. Example Inter-lab Test Results (Youden plot)

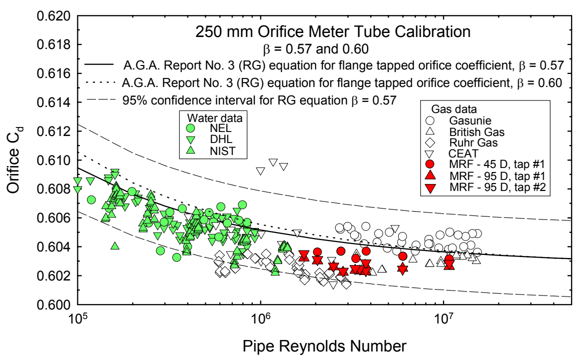

Figure 6. Comparison of Discharge Coefficient Values for Various Orifice Flow Meter Tests

Quality Assurance

Most flow meter calibration laboratories have developed and implemented their own Quality Assurance (QA) program. However, the scope and implementation of the QA program may vary from lab to lab. In some instances, lab clients may impose their own QA requirements.

Formal QA programs typically require a written manual that defines the elements and procedures of the program. Supplemental procedures may also be necessary. Documentation of compliance usually requires extensive record keeping. The laboratory may be periodically audited by an independent agency to ensure compliance. If independent audits are performed, audit reports should be available for review by clients. The cost of maintaining a formal quality assurance program varies, depending on the scope of the program, but is typically in the range of $20,000 to $100,000 per year.

Lab Accreditation / Certification

Some meter owners may require that their flow meters be tested only at 'accredited' or 'certified' test labs. In some instances, there may be governmental requirements. Some of the more commonly known lab accreditation programs include the following:

- ISO/IEC 17025: 1999 - "General Requirements for the Competence of Testing and Calibration Laboratories" (i.e., an International Standards Organization program)
- NVLAP: National Voluntary Laboratory Accreditation Program (i.e., a United States federal program that encompasses the requirements of ISO 17025)
- A2LA: American Association of Laboratory Accreditation (i.e., a United States program that exceeds ISO 17025)

Working Knowledge / Experience

The calibration lab should have a good working knowledge of the types of meters being tested, familiarity with the appropriate meter inspection procedures, the ability to quickly diagnose meter or test facility problems, and the ability to properly assess meter performance. An experienced lab will know the best way to calibrate a particular type of meter. Most labs work closely with meter manufacturers, so a well equipped test lab will typically have spare parts from the meter manufacturers and will be trained in repair procedures. The lab may also have the necessary instrumentation to assist with the diagnosis of meter problems.

Timeliness of Results

In many instances, a meter owner or operator may witness a meter calibration. A good calibration lab should be able to provide test results in a timely manner so that the acceptability of a meter calibration can be quickly assessed. In order to provide timely results, most calibration labs have automated data acquisition and reduction systems in place. Many labs are able to provide test data to clients in real time or near real time.

Test Cost

Meter calibration cost is a critical issue for most companies. Flow verification of a meter is, in a sense, an insurance policy. The owner of the flow meter must determine if the cost associated with calibrating a meter (which includes not only the fee charged by the test lab, but also the expenses for shipping the meter, witnessing the test, and the downtime at the meter station while the device is away for testing) is a sound business decision. Typically, the meter owner must make an assumption regarding the approximate performance (i.e., accuracy) of an un-calibrated meter and then weigh the potential risk associated with any metering errors. Sometimes, the monetary risk can be quite high; sometimes not.

Test cost varies from lab to lab and is generally a function of measurement uncertainty level, test conditions, meter size, and availability of the lab. Most test labs can give clients advice on ways to minimize the cost of a meter test. Many labs have standard rate sheets for routine meter tests.

Scheduling Issues

Test scheduling can be an issue. Market demands can sometimes create significant test lab backlogs. When demand is high, some lab operators may also impose financial penalties on clients who miss a scheduled test date. Furthermore, rescheduling of a test can result in a significant delay for a meter owner. Good advance planning is the key to avoiding scheduling problems.

Seasonal circumstances may also arise that affect a test schedule. For instance, a number of high-capacity natural gas flow labs are side branches on gas transmission pipelines. These labs may experience seasonal limitations on flow rate capacity. Thus, some (large) meter sizes can only be tested during a portion of the year.

Closing Thoughts

Following are some closing thoughts to keep in mind when considering selection of a flow calibration laboratory. At the outset, define the test goals and objectives. Plan ahead as much as possible. Include the meter manufacturer and test laboratory from the outset of the planning process. Make sure the test plan is cost-effective before proceeding. Sometimes the cost of a meter calibration is not justified, based on the expected benefits from an incremental improvement in meter accuracy. Ask lots of questions to understand how the meter is to be tested. If a meter needs re-calibrating, do so at the same lab that did the original calibration. Finally, give lab management feedback on their performance. Lab operators are very interested in satisfying their customers and are always looking for ways to improve service.

References

1. Coleman, Hugh W. and W. Glenn Steele, Experimentation and Uncertainty Analysis for Engineers, John Wiley & Sons, Inc., New York, New York, 1989.
2. Park, J.T., K.A. Behring II, and P.J. Krueger, “Metering Research Facility Program: Review of Field Meter Provers,” GRI Topical Report No. GRI-95/0209, GRI Contract No. 5086-271-2197, Gas Research Institute, Chicago, Illinois, December 1995.
3. Gallager, James E., “Flowmeter Calibration Technology for Natural Gas,” Presented at the 1999 Committee on Petroleum Measurement Spring Meeting, American Petroleum Institute, New Orleans, LA, March 29-April 2, 1999.