Calibration of a Coriolis Flow Meter and the

Importance of the Calibration Measurement Uncertainty in Mass Flow Rate

The performance that the Coriolis flow meter has in measuring fluid flow inside a closed pipe is unmatched and is arguably the most advanced and reliable technology on the market for process, testing and custody transfer. It measures direct mass flow rate, fluid density and is not affected by variations in fluid properties such as pressure, temperature, viscosity and flow patterns. The acquisition cost is fairly higher than other types of flow meters but the total cost of ownership becomes a valuable option as it diminishes the need for installation of additional instrumentation. Because it has no moving parts, it requires minimal maintenance, and offers long-term stability and reliability. It is increasingly used in critical applications such as fuel measurement in the aerospace industry, pharmaceutical manufacturing and mass transfer in oil and gas processes.

It implies that, after a certain period of operation, it is necessary to verify instrument performance, and more specifically the measurement accuracy. There are several reasons why a flow meter falls out of calibration: physical modifications can occur due to corrosion within the process; internal parts gradually degrade and eventually affect the meter’s performance or it can potentially receive impacts that result from process variations, initialization or inadequate procedures.

Integrated electronic diagnostics, in-situ proving and validations are reliable methods which ensure meter efficiency but periodic calibration in a laboratory is always essential as it:

- ensures homogeneity and repeatability of the instrument’s performance
- reduces process variations over time (measurement errors)
- avoids product recalls
- respects the company's quality system or government body requirements

MEASUREMENT UNCERTAINTY OF A CORIOLIS FLOW METER

Most manufacturers publish an accuracy of ±0.1% or better. That is very impressive considering that some provers and primary standard rigs do not even match that level of accuracy. For instance, the leading brand in the Coriolis meter market claims a standard accuracy of ±0.1% and optional ±0.05% on their high-end model, including the combined effects of repeatability, linearity, hysteresis, and orientation.

However, it is really important to understand the difference between the meter’s accuracy and total uncertainty of the measured value. The meter’s accuracy has been calculated by evaluating the performance of the meter’s output while the total uncertainty includes the error generated by the transmitter, improper zeroing, fluid properties and environmental conditions.

In a laboratory with controlled environment and optimal conditions, the errors generated by external sources, fluid properties and installation effects are negligible. Extended uncertainty of measured value equals Accuracy (whichever is greater, between zero stability and meter's stated accuracy) + Error generated by the transmitter. Notably, most manufacturers do not mention the output tolerance into their product specifications which can create misconception of the total uncertainty. Also, transmitters offer a better total uncertainty using the frequency and digital outputs over the analog output, which is still frequently used in the industry despite its low resolution.

Another important factor affecting the accuracy is the zero stability which is an inherent characteristic of a Coriolis flow meter. It has a significant effect on the accuracy when the measured flow rate approaches the low end of the full range. Typically, it begins to have an effect when the turndown is greater than 20:1. Above the threshold of 20:1, the accuracy equals zero stability / flow rate x 100%.

ISO 17025 ACCREDITATION AND CALIBRATION MEASUREMENT UNCERTAINTY

ISO 17025 is an international standard for evaluating laboratories and specifies the requirements for the competence to carry out calibrations. It ensures that the entire calibration process is traceable to national and international standards. The accrediting body ensures that the personnel remains technically competent and that the laboratory implements a quality system whereby measurements consistently produce valid and repeatable results within the scope of accreditation.

The accreditation procedure always includes the evaluation of the measurement uncertainty of each component on the calibration rig and inter-laboratory proficiency testing with other ISO 17025 accredited labs. The "*expanded calibration measurement uncertainty"* is required in order to issue a calibration certificate with a statement of compliance. In other words, it indicates whether each test point "passes" or "fails".

The laboratory then calculates what is called a Test Uncertainty Ratio (TUR). The TUR is the ratio between the accuracy of the device being tested and the total uncertainty of the reference measure. If the TUR is greater than 4:1, there is a good probability within the confidence interval, that all measured values are compliant or non-compliant (pass or fail).

The ISO 17025 standard requires that the guardbanding technique be applied for each test point when the TUR is less than 4:1. The primary objective for this technique is to control the risk of accepting an out-of-tolerance unit or rejecting an in-tolerance unit. It restricts compliance limits based on certain criteria and can lead to situations by which it becomes impossible to determine the statement of "*pass" or "fail"* for the device being tested. When the test measurement is too close to the upper or lower limit, it could be declared "undetermined". This "*too close"* tolerance depends on the established confidence level and the guardbanding strategy used by the laboratory.

CALIBRATION METHODS

There are many measurement methods in calibrating a flow meter. From high-end primary standards to transfer standard meters, the selection in the calibration method and the importance of the uncertainty of the measures become essential criteria in the decision-making process for the selection of the calibration laboratory.

One fairly common mistake is to accept a volumetric calibration when the flow meter is used for measuring mass flow. The correlation between a volumetric flow and a mass flow is density. If the lab measures volumetric flow rate and does not have a density measurement, then there is no traceability in the mass flow rate and the calibration has no value for a Coriolis meter used for mass transfer.

It is very challenging to find a laboratory capable of achieving a better uncertainty than the accuracy of a Coriolis flow meter. In fact, a highly accurate Coriolis can be used as a transfer standard meter to calibrate other types of flow meters and even other Coriolis meters. These meters are proficiency testing artefacts and they are traceable to a primary flow stand. They can achieve impressive ±0.03% total uncertainty although not quite achieving the 4:1 TUR.

Another approach used in achieving very high accuracy levels is the use of a primary standard rig by gravimetric method. Gravimetric calibration consists of weighing the quantity of fluid during a certain period of time, consequently measuring mass flow rate. Some of the calibration laboratories who use this method have been able to achieve a calibration uncertainty of ±0.02% or better. It is highly recommended that the calibration of a highly accurate Coriolis flow meter be done by this method to ensure optimal calibration measurement uncertainty.

CALIBRATION BY THE MANUFACTURER OR INDEPENDENT LABORATORY

There is an ongoing debate about whether or not meter calibration performed directly by the manufacturer warrants better accuracy.

There are obvious advantages to the calibration services of a manufacturer. The laboratory offers additional services like extensive repairs and rebuilds of defective units. The manufacturer, a specialist of his own product, is more apt in identifying sensor failures as well as wears and tears of the tube. The manufacturer also has access to advanced features and diagnostic tools.

On the other hand, independent labs often provide calibration adapted to the customer’s specific needs and can evaluate the true meter’s metrological performance (total uncertainty of measured value), providing a whole system (including the transmitter) and/or source-to-screen calibration. The manufacturer usually performs a default factory calibration as a standard service, sometimes generating new meter factors or just resets with original factory settings.

So it all comes down to: *How important is the flow rate measurement in your process or test?* You have purchased a Coriolis flow meter with a high price tag. You have done a cost analysis and identified the cost of a failure or shifted measurement. If you are regulated by a governing agency, you are ensuring compliance and respecting calibration requirements.

Ultimately, there are 4 necessary conditions in order for a laboratory to perform optimal calibration on Coriolis flow meters. The laboratory must be:

- ISO 17025 accredited with a calibration procedure by gravimetric method specific to Coriolis flow meters
- competent in calibration performance with a measurement uncertainty of 4 times better than the uncertainty of the meter
- specialized in Coriolis mass flow technology
- willing to adjust to the customer's conditions and specific requirements

And most importantly, service must come with a smile!