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Using Structural Integrity Meter Verification to Verify Coriolis Flowmeters

Enhanced core processor enables a new verification method for flow meter calibration

The most common maintenance operation for a flow measurement device is to verify its calibration. For instance, an orifice measurement is checked by verifying the zero and span of the delta-pressure transmitter. Unfortunately, this is not a flow-measurement calibration; it is simply verification that one component, the delta-pressure measurement, is within tolerance.

Micro Motion Coriolis flowmeters are used widely because, among other things, their calibration is very stable over time. Even so, the calibration may need to be verified periodically, for example to meet ISO requirements. To address this customer need, Micro Motion has introduced a new feature called *structural integrity meter verification*. Structural integrity meter verification uses Micro Motion's new enhanced core processor to provide an *in situ* verification of flow and density calibrations. Structural integrity meter verification is an improvement over the orifice delta-pressure verification because structural integrity meter verification is able to verify the flow tubes as well as the electronics.

The purpose of this document is to describe the underlying technology of structural integrity meter verification and answer some frequently asked questions.

Coriolis meter calibration factors

The first step in understanding how flowmeter verification works is to review how a Coriolis flowmeter measures fluid density and mass flow.

Density measurement

The Coriolis flowmeter can be considered as a simple spring-mass system (Figure 1). The mass of the flow tube(s) plus the mass of the fluid provide the total mass of the sensor. The flow tube(s) act as the spring. The frequency of the spring-mass system is used to measure density.

A characteristic of a simple spring-mass system, and therefore a Coriolis meter, is the resonant or natural frequency of vibration. The resonant frequency is proportional to the square root of the stiffness to mass ratio, as shown in Equation 1.

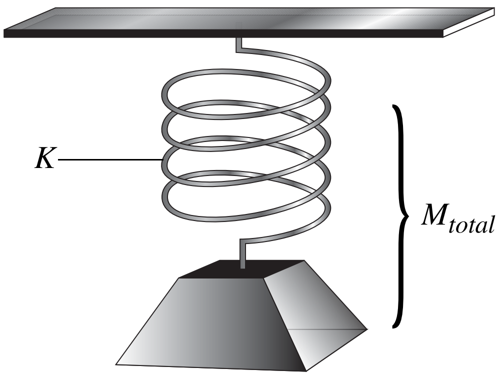

Figure 1. Spring-mass system

$$frequency \propto \sqrt{\frac{stiffness}{total\ mass}}$$

Equation 1

Since the total mass of Equation 1 is comprised of the fluid mass and the tube mass, Equation 1 can be rewritten to isolate the mass of the fluid as shown in Equation 2. Equation 2 then is the basis of the density measurement performed by all Coriolis meters. The resonant frequency of the Coriolis meter changes with fluid mass (density). Therefore, the fluid density can be determined from variations in the resonant frequency. Also note that Equation 2 introduces two other parameters, namely the

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stiffness (K) and the flow tube mass (M_t). These parameters must remain constant for the density measurement to be accurate.

$$M_f \propto \frac{K}{f^2} - M_t$$

Equation 2

Equation 2 shows how the fluid density measurement depends upon several tube properties: tube mass and tube stiffness. These tube properties are important to the verification method and will be briefly explained. Tube mass is the mass of the material used to make the flow tube. Tube stiffness (modeled previously by the spring stiffness) is a parameter that measures the displacement of the tube to an applied load. A simple equation for stiffness, K, is shown in Equation 3.

$$K = \frac{force}{displacement}$$

Equation 3

Flow measurement

Stiffness is also a key parameter in the measurement of mass flow. Figure 2 shows a simple schematic of a Coriolis meter. In this figure mass enters the single straight tube from the left and exits on the right, as can be seen by the velocity vectors (v). The flow tube is being vibrated at its resonant frequency, and in the figure the tube is shown moving upward. It can be seen in the figure that on the inlet side the mass will oppose the motion of the flow tube and exert a force on the flow tube in the down ward direction. On the outlet side the opposite is true. The flow of the fluid will enhance the motion of the flow resulting in a force in the upward direction. These two forces, which are equal in magnitude but opposite in direction, are the Coriolis forces from which the product derives its name.

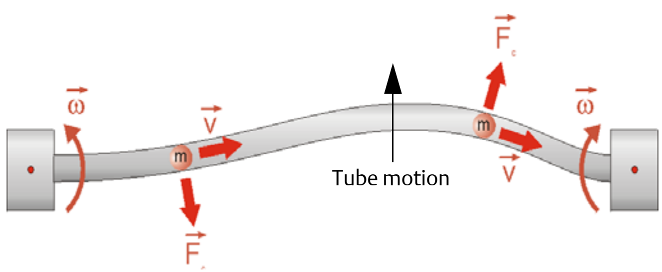

Figure 2. Coriolis "twist"

The Coriolis force imparts an additional displacement on the vibrating flow tube. It can be seen in the figure that the Coriolis force causes an additional "twisting" of the flow tube about the midpoint. The amount of twist is proportional to the Coriolis force (and therefore mass flow rate) and the stiffness of the flow tube. The accuracy of the mass flow measurement, as with the density measurement, is dependent on the flow tube stiffness remaining constant.

Determination of flow tube stiffness

Flow tube stiffness was shown to be a critical parameter in the accuracy of the flow and density measurement. This leaves two fundamental questions: how is flow tube stiffness determined, and what are the factors that can change flow tubes stiffness?

Engineering mechanics defines the stiffness of a tube in terms of the tube's dimensional and material properties. The flow tube diameter, wall thickness, and overall geometry are critical dimensional parameters. Clearly, a big diameter flow tube is stiffer than a small diameter flow tube, and for tubes of the same diameter, increasing the wall thickness will increase the stiffness. The overall profile, height, and width also affect the stiffness.

Material properties also are a factor in flow tube stiffness. Titanium tubing is stiffer than plastic tubing and steel tubing is stiffer than titanium tubing.

Flow tube diameter and wall thickness, overall height and width, and material selection are all considered carefully during the design of a new Coriolis meter. These properties, in addition to determining the stiffness of the sensor, are the key design features that determine a sensor's sensitivity to the measurement of mass flow and density.

When flowing a clean, compatible fluid, the dimensional and material properties of the flow tube do not change from the factory condition. As demonstrated previously, the flow and density calibration factors depend directly upon the tube stiffness. Thus, by monitoring the stiffness in the field it is possible to determine whether the flow or density measurement has been degraded.

Impacts to a Coriolis meter's calibration

Under normal operation, the flow tube properties are not expected to change, and, consequently, the flow and density calibration factors will remain constant. However, under some process conditions, the flow tube properties may change. Fluids that corrode or erode the flow tube will alter the wall thickness of the tube(s).

- When the tubes corrode, the overall wall thickness is reduced uniformly.
- Erosion usually affects the inlet side of the tubes differently than the outlet, resulting in a non-uniform reduction in wall thickness.

The loss of tube material, whether uniform or non-uniform, results in a decrease in tube stiffness, and both the flow and density measurements are affected. Corrosion or erosion that is not detected may ultimately rupture the flow tube.

Other types of damage can also change flow tube properties. For example, a fluid pressure above the rated pressure of the sensor may actually increase the outside diameter of the tube as well as changing the overall profile of the geometry. This type of damage will change the tube stiffness resulting in errors in flow and density measurement.

Measurement of flow tube stiffness

The dependence of density and flow calibration factors on tube stiffness has already been established. Like the density measurement, the measurement of stiffness is based on the fact that a Coriolis meter can be modeled as a simple spring-mass system (Figure 1).

Consider Figure 1, but with a time dependant force (sinusoidal) being applied to the mass. The displacement of the mass (motion of the system) is completely determined by the balance of energy. As the spring is stretched, it stores potential energy. As the mass moves, it stores kinetic energy and force is required to energize the system. The potential energy is the product of spring stiffness and displacement, and kinetic energy is the product of mass and acceleration. For sinusoidal motion, the acceleration is defined as the square of the frequency of vibration times the displacement. This energy balance can be expressed as Equation 4.

$$M \times D(t) \times f^2 - K \times D(t) = F(t)$$

Equation 4

M and *K* of Equation 4 have been previously defined as the mass and stiffness, *D(t)* is the sinusoidal displacement, and *F(t)* is the sinusoidal applied force. The first term of Equation 4 is the kinetic energy of the system (mass × acceleration). The second term is the potential energy of the system (force × displacement). The right hand side of the equation represents the energy input into the system.

Three interesting observations can be made from Equation 4. At very low frequencies, $f \approx 0$, the kinetic energy is essentially zero and the equation reduces to the definition of stiffness, defined previously as the ratio of force to displacement (Equation 3). At very high frequencies, *f* approaches infinity, the kinetic energy dominates, and Equation 4 becomes Newton's law of motion (mass × acceleration = force). The last observation to be made is that there will be a frequency at which the kinetic energy and the potential energy are equal. This frequency is called the resonant frequency and is the basis of the density measurement (Equation 1).

From Equation 4 we can now see that the motion of the spring-mass system varies with the frequency of excitation and is dependant upon the mass and the stiffness of the system. Since a Coriolis meter behaves as a simple spring-mass system, it should also be apparent that by introducing a force at multiple frequencies and monitoring displacement it should be possible to measure the stiffness of the Coriolis meter. This is indeed true and is the basis of the stiffness-based verification tool.

Figure 3 shows the displacement of a Coriolis meter to a constant force of varying frequency. The stiffness of the Coriolis meter corresponds to the displacement at zero frequency. The peak of the curve corresponds to the resonant frequency; this is the frequency at which very little force is required to maintain vibration. All that is required to generate the curve shown in Figure 3 is to introduce a force at several frequencies. From a practical standpoint, it is easiest to use a force that is close to the resonant frequency, because the force and energy required to generate motion is small, and then to estimate the stiffness at zero frequency based on this response. This is in fact the basis of the stiffness measurement and is illustrated by the test tones in Figure 3.

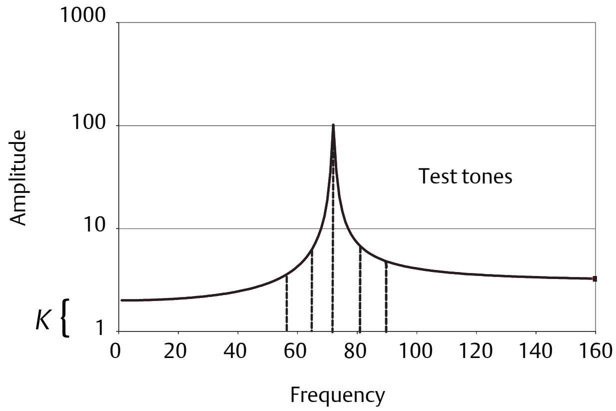

Figure 3. Frequency response function

Detecting calibration changes with the structural integrity method

It has been shown that a meter's calibration factors depend upon the stiffness of the flow tube and that the structural integrity method of meter verification measures this stiffness very accurately. How can this information detect calibration factor changes? The structural integrity method of meter verification starts during the calibration process at the Micro Motion factory. Baseline values for the structural stiffness are generated during Micro Motion's normal flow and density calibration process. This baseline value is referred to as the "factory" stiffness measurement.

Customer verifications performed in the field after the meter has been installed are compared to the baseline values to determine if the stiffness has changed from the factory values. A change in stiffness indicates that the mass flow and density measurements have been affected and that a validation procedure or recalibration procedure should be performed.

A validation procedure involves comparing the flow output of the Micro Motion meter with another flow measurement device. This secondary flow reference could be a prover, commonly used in the oil industry, or a known good master meter. Other, lower precision methods such as catch-and-weigh, are sometimes used.

Recalibration involves a primary flow standard — usually a separate lab or the Micro Motion factory.

A change in stiffness might also indicate a need to check the physical integrity of the meter. Corrosion, erosion, or damage might have occurred to cause the change in stiffness. The physical integrity of the meter can be checked with a visual inspection using a bore scope.

Meter verification confirms accurate density and flow measurement

In general, for the vast majority of applications, Coriolis flowmeters do not change over the life of the meter. Meters have been running in the field for more than 10 years meeting factory accuracy with no change in calibration. A meter verification which indicates no stiffness change confirms that the meter meets factory specifications for flow and density accuracy. In addition, when the meter verification passes, the customer can be assured that the physical integrity of the flow tubes has not been compromised.

If the sensor is damaged due to the effects of corrosion or erosion, a change in stiffness will be detected. Because there is essentially a 1:1 relationship between stiffness and the flow and density calibrations, a change in stiffness notifies the operator that the meter is in need of validation. However, it should be noted that this relationship is not exact and is dependent upon meter geometry and the type of damage (uniform or local).

Process conditions during meter verification

Very few special process conditions are necessary for structural integrity meter verification. The density of the process fluid does not matter, because the process fluid density impacts only the mass of the sensor. Stiffness is independent of mass.

Meter verification also compensates for fluid temperature. Meter verification will work over the entire specified temperature range of the flowmeter.

Flow does not need to be stopped for meter verification. In special cases at extremely high flow rates the flow noise might interfere with the meter verification procedure and a reduction in flow might be necessary.

Although flow does not have to be stopped to perform the verification, process variables are not available while the verification procedure is being performed. Process variables can be set to default or alarm values or the last value can be held for the duration of the verification.

Process stability during the measurement is important. The algorithm will check for large changes in flow rate, density, or temperature during the measurement. Rapidly changing process or ambient conditions might cause the verification to abort. The customer should then ensure that the process conditions and ambient temperature reach equilibrium before reinitiating verification.

Electronic checks during meter verification

In order to perform an accurate stiffness measurement, electronics and software need to be working correctly as well. Before the tube stiffness is checked, the meter verification procedure performs a loopback test of the electronics, where the output is switched directly into the input. So a successful verification not only ensures that the structure is unchanged, but also that the electronics are functioning correctly.

Configuration, zero, and output checks

Even though the electronics and structure may be functioning correctly, a customer may still get incorrect flow readings. If the calibration factors or meter factors are changed from the factory settings, the flow and/or density measurement might be in error. The customer should confirm that the factors in the transmitter have not been changed deliberately or inadvertently.

Incorrect re-zeroing of a meter may also result in incorrect flow measurement even if the verification passes. It is important that zeroing of Coriolis flowmeters is done properly under stable conditions. Micro Motion ELITE® Coriolis meters should not require re-zeroing except in very special circumstances.

Meter verification performed with ProLink® II version 2.5 or higher automatically checks for configuration or zero changes. The customer will be notified if a change is detected.

Output wiring and scaling are not checked by meter verification. Broken wires from the transmitter to another device will not be detected. Improper scaling of milliamp or frequency outputs may also result in measurement errors that will not be detected by meter verification. Prolink II provides other tools to check output integrity.

Customer benefits

Structural integrity meter verification delivers a simple, robust tool for verifying meter performance and provides flow meter customers with significant benefits for safety, performance, and quality checks.

Structural integrity meter verification helps eliminate process downtime, reduce equipment maintenance costs, and improve plant safety. In addition, verified meter performance results in higher-quality product with less waste and rework.

Summary

The structural integrity method of meter verification uses the basic physics of motion to ensure that Micro Motion flowmeters give accurate process measurement. When combined with the inherent reliability of Coriolis meters, this technology enables customers to maximize their return on investment by eliminating the cost and effort traditionally required to check meter performance.

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