

## Optimal Mass Flow Meter Using Virtual Technology

K. Sheela Sobana Rani<sup>1</sup>, R. Gokilapritha<sup>2</sup> and K. Lakshmi<sup>3</sup>

<sup>1,2,3</sup> Sasurie Academy of Engineering, Coimbatore-641 653

**Abstract.** Today's flow meter market is influenced by a number of forces. End-users are looking for increased accuracy and reliability in the flow meters they purchase. Growth in the energy markets, especially the oil & gas industry, has led to increasing demand for instruments to measure both oil and Natural gas. The run-up in the per-barrel price of crude oil means that end-users are willing to pay more to measure it. It also increases the importance of accuracy in measurement. An open loop testing System specialized for CMF is designed based on Virtual Instrument (VI) technology.

**Keywords:** Coriolis, mass flow meter.

### 1. Introduction

Coriolis mass flow meters provide a direct mass flow measurement and are easy to size based on process requirements. The principle of operation is the Coriolis effect (or) conservation of angular momentum due to the Coriolis acceleration of a fluid stream. The measuring principle is based on the controlled generation of Coriolis forces. These forces were always present when both translational (straight line) and rotational (revolving) movement occur simultaneously.

$$\vec{F}_c = 2 \times \Delta m (\vec{\omega} \times \vec{v})$$

$$F_c = \text{Coriolis force}$$

$$\Delta m = \text{mass of moving body}$$

$$\omega = \text{angular velocity}$$

$$v = \text{radial velocity in rotating or oscillating system}$$

The amplitude of the Coriolis force depends on the moving mass  $\Delta m$ , its velocity  $v$  in the system and therefore its mass flow. A Coriolis meter is usually one or more pipes with longitudinally or axially displaced sections that are excited to vibrate at resonant frequency. It can be used with liquids and gases. When the fluid within the displaced section is at rest, both the upstream and downstream portion of the displaced section will vibrate in phase with each other. A mass flow meter, also known as an inertial flow meter or a coriolis flow meter, is a device that measures mass flow rate of a fluid traveling through a tube. The mass flow rate is the mass of the fluid traveling past a fixed point per unit time. The mass flow meter does not measure the volume per unit time (e.g., cubic meters per second) passing through the device; it measures the mass per unit time (e.g., kilograms per second) flowing through the device. Volumetric Flow rate is the mass flow rate divided by the fluid density. If the density is constant, then the relationship is simple. If the fluid has varying density, then the relationship is not simple. The density of the fluid may change with temperature, pressure, or composition. For ex. the fluid may also be a combination of phases such as a fluid with entrained bubbles. In a typical mass flow meter the fluid is contained in a smooth tube, with no moving parts that would need to be cleaned and maintained, and that would impede the flow. The controller was realized as a virtual instrument and programmed in the Lab VIEW environment which was also used for performing the theoretical simulations.

## 1.1. Coriolis flow meter operation

The Coriolis Mass Flow meter uses an oscillation instead of a constant angular velocity. One or two parallel measuring tubes, with fluid flowing through them, are oscillated in antiphase, much like a tuning fork. The Coriolis forces produced at the measuring tubes cause a phase shift in the tube oscillation. When there is zero flow, i.e., with the fluid standing still, both phases are equal (1 : no phase difference)

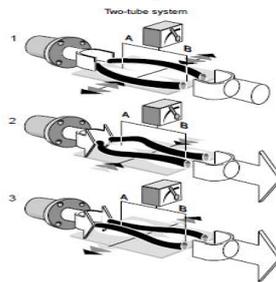


Fig.1 Coriolis Flow meter Operation

when there is mass flow, the tube oscillation is decelerated at the inlet (2) and accelerated at the outlet (3). As the mass flow rate increases, the phase difference also increases (A-B). The oscillations of the measuring tubes are determined using electrodynamic sensors at the inlet and outlet. The measurement principle operates independent of temperature, pressure, viscosity, conductivity or flow profile.

## 2. Density Measurement

The measuring tubes are continuously excited at their resonant frequency. As the mass and therefore the density of the oscillating system changes (measuring tubes and fluid), the vibrating frequency is readjusted. The resonant frequency is thus a function of the density of the fluid and enables the processor to calculate density. This density information can be provided as an output signal.

## 3. Temperature Measurement

The temperature of the measuring tubes is determined in order to calculate the compensation factor due to temperature effects. This signal corresponds to the process temperature and is also available as output. The applications for the Coriolis mass flow meter are numerous. Some users are familiar with the ability to measure mass flow rate in liquids or gas at higher temperatures and higher pressure but one important unique strength of the Coriolis mass flow meter is its ability to report density directly. Unlike most inferential flow meters which depend on some external density sensor and outside calculations, the Coriolis mass meter is directly measuring density. Due to its popularity the Coriolis mass flow meter is also custody transfer approved and used in numerous hydrocarbon flow measurement applications as a part of a billing system. This is because of the recognized high accuracy and repeatability. These are two basic Coriolis meter configurations Bent tube and straight tube. In this we are using bent tube is more common. Gas companies find the meters appealing because they have no moving parts to wear out, have relatively low maintenance requirements, can meter bi-directional flows and usually provide measurement accuracy comparable to competing metering technologies, or better. A unique characteristic of Coriolis meters is that they measure mass flow rate, while most other flow meters measure volumetric flow rate. Although typically unnecessary, the conversion from mass to volumetric flow rate (and vice versa) is relatively straightforward if the operating conditions (e.g., temperature, pressure, etc.) and gas properties are known. The conversion to standard flow rate requires only knowledge of the gas density at base conditions. The principal advantage of this bent-tube meter design is that it usually does not require a minimum length of straight pipe immediately upstream and downstream of the meter, as do others. This helps to minimize the meter installation's footprint.

## 4. CMF Open Loop Characteristic System Connection

Coriolis meter manufacturers routinely perform a water calibration (usually at a test pressure near atmospheric) at their factory before the meter is shipped to the field site. However, since the calibration test pressure and fluid density are normally much different from those at the field-metering site, there is a risk of introducing a meter bias with a factory water-flow calibration. Gas company personnel should ask the meter

manufacturer for objective test data, such as test data comparing the meter output for water flow and high-pressure gas flow.

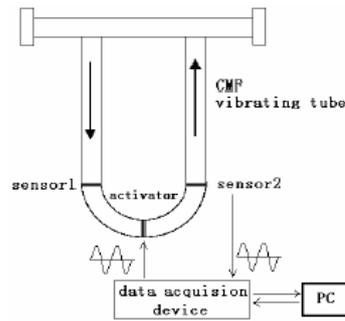


Fig. 2 CMF Open Loop Characteristic System Connection

When a wide range of flow rate is required at a particular metering site, combining ultrasonic and Coriolis meters may provide the optimum blend of range, accuracy and cost-effectiveness. Coriolis force, also known as gyroscopic force, is generally associated with a continually rotating system. Projectiles fired from a gun in the hemisphere appear to veer slightly to the right, while in the Southern Hemisphere they appear to veer to the left; a body moving on a rotating frame of a reference, such as a merry-go round, experiences a lateral force and must lean sideways in order to move forward when walking outward along the radius. During the down cycle, the tube applies an upward resisting force to the fluid or the fluid pushes the tube down. On the outlet side, the Coriolis force has the opposite direction. To simply the problem, we assume that the tube has a perfect U shape with a cross section area of  $A$ . The length and width are  $l$ ,  $d$  respectively. The opposite directions of Coriolis forces on inlet and outlet sides result in a twisting moment  $T_c$

$$T_c = Fc \times d = m \times a_c \times d = \rho A l \times 2\Omega V \times d$$

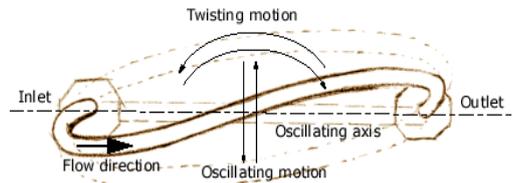


Fig. 3 Coriolis Forces on inlet and outlet sides

During the down cycle, the tube applies an upward resisting force to the fluid or the fluid pushes the tube down. On the outlet side, the Coriolis force has the opposite direction. To simply the problem, we assume that the tube has a perfect U shape with a cross section area of  $A$ . The length and width are  $l$ ,  $d$ , respectively. The opposite directions of Coriolis forces on inlet and outlet sides result in a twisting moment  $T_c$ .

## 5. Coriolis Flow Meter Verification

Coriolis flow meters contain no moving parts and typically last for 10 or more years. They are also unique among flow measurement devices in that the mass flow measurement is unaffected by the process fluids; that is, the flow calibration factor (FCF) is unchanged over the life of the flow meter. However in many applications, such as custody transfer where the flow meter is used essentially as a cash register or the pharmaceutical industry where processes need to be tracked rigorously, a method of verifying the accuracy of the flow meter is highly desirable. Micro Motion's original electronics were of course analog, being developed in the 1980s. Their diagnostic capabilities were extremely limited. Micro Motion introduced digital signal processing into their attached electronics in 2002. DSP allowed us to expand our diagnostic capabilities. When developing the next generation DSP-based electronics, an embedded self diagnostic was a key requirement. CMF flow tube must be vibrating at its natural frequency stably during work. Discussing the infinitesimal element of the vibrating tube, it can be regarded as a single freedom damping system. Here,  $k$ ,  $m$ ,  $c$ ,  $F(t)$  are the equivalent stiffness, equivalent mass, equivalent damping and equivalent force separately.

The oscillator's forced vibrating kinetic equation is represent inertia force, damping force and elastic force of vibrating system separately. So the normalized frequency characteristic function is as below.

$$m\ddot{x} + c\dot{x} + kx = F(t)$$

Where,  $mx$ ,  $cx$ ,  $kx$  represent inertia force, damping force and elastic force of vibrating system separately.

$\xi = \frac{c}{2\sqrt{km}}$  is the equivalent subsidence ratio of system. The normalized amplitude-frequency characteristic

$A(\omega)$  and phase-frequency characteristics of system are as follows.

$$A(\omega) = \frac{1/k}{\sqrt{(1-p^2)^2 + (2\xi P)^2}}$$

$$P = \frac{\omega}{\omega_n} \times \text{When } P=1 \times \omega = \omega_n$$

$$A(\omega_n) = \frac{1/k}{2\xi} \quad \Phi(\omega_n) = -90^\circ$$

The state when the amplitude gain of system achieves its maximum value is thought to be resonant state, the vibrating frequency then is defined as system natural frequency. The relationship between resonant frequency and natural frequency is

$$\omega_r = \omega_n \sqrt{1-2\xi^2}$$

The peak of resonant amplitude gain is

$$A(\omega_r) = \frac{1/k}{2\xi\sqrt{1-\xi^2}}$$

Formula shows that vibrating system's resonant frequency  $\omega_r$  and equivalent subsidence ratio  $\xi$  have something to do with the natural frequency

$$\omega_1 = \omega_n \sqrt{1-2\xi^2 - 2\xi\sqrt{1-\xi^2}} \quad \omega_2 = \omega_n \sqrt{1-2\xi^2 + 2\xi\sqrt{1-\xi^2}} \quad \frac{\omega_r}{\omega_2 - \omega_1} = \frac{\omega_r(\omega_2 + \omega_1)}{\omega_2^2 - \omega_1^2} \approx \frac{1}{2\xi}$$

Coriolis mass flow meter (CMF) is generally regarded as a linear system when the vibration amplitude of the measuring tube is relatively small, but the spectrum of its output signals still shows existence of some multiple frequency components. Taking into consideration the nonlinear factors and external excitation, the motion equations of the CMF straight measuring tube are established by properly simplifying the boundary conditions of the measuring tube and integrating the mathematical model of the CMF sensor. In addition, the motion equations are discretized with the Galerkin method, and from the discretized results, it is discovered that the system contains a group of nonlinear factors. By using a laser vibrometer, the state of the closed loop resonant vibration of the measuring tube and the forced vibration of the standard sine signal are measured. It will be important to verify the measurement accuracy of the measuring tube with different vibration amplitudes, which evidences that nonlinear influences become more serious with the vibration amplitude rising.

## 6. Testing System's Interface

This project focuses the open-loop characteristic testing system for the field test experiment. The system can get the resonant frequency and amplitude rapidly and accurately. After the scanning the CMF's mechanical quality factor curve can be drawn in real time and Q value can be calculated accurately. Frequency resolution of the close scanning can be within the accuracy of 0.001Hz. The natural frequency, amplitude and Q value has been verified for their Accuracy and this project have been focused for Power factor.

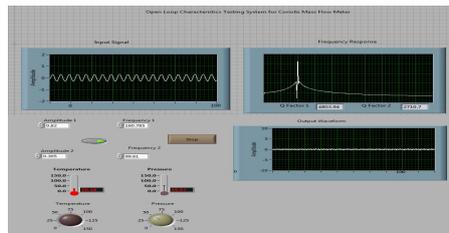


Fig. 4. Testing system's interface

## 7. Proposed System

The Coriolis Meter is designed for the measurement of Quality Factor with reference to the Amplitude and Frequency of Vibration, Pressure and temperature in the highest accuracy. The Coriolis technology is ideal for demanding fluid measurement applications – independent of whether the fluid is conductive, multi-phase or viscous. This project focuses the open-loop characteristic testing system for the field test experiment. The system can get the resonant frequency and amplitude rapidly and accurately. After the scanning the CMF's mechanical quality factor curve can be drawn in real time and Q value can be calculated accurately. Frequency resolution of the close scanning can be within the accuracy of 0.001Hz and also it has been studied for the Quality factor Characteristics. In Future the remaining characteristics like Accuracy, Flow rate with Zero Stability will be derived from this Testing system.

## 8. Conclusion

The CMF's open-loop testing system based on virtual instrument technology designed in this paper realizes rapid and accurate measurement of mechanical quality factor for resonant sensors. According to the data it can be concluded that the CMF1's natural frequency is higher, amplitude at natural frequency is greater and Q value is much more bigger than CMF2. So it's necessary to make further optimization designing structure, fixture and tube shape to raise Q value and make sure the measurement accuracy and stability. The system's frequency resolution can achieve 0.001Hz. It not only has a lot of advantages such as simple operation, commonality and so on, but also provides necessary data for CMF's performance evaluation. The open-loop characteristic data obtained from our experiment provide a basis for optimization design of CMF's structure and tube shape, and also has instructive significance to CMF's close-loop system design.

## 9. References

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