Truck-mounted Mass Flow Metering for LPG Delivery

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Introduction

The mathematician Gustave De Coriolis first described the Coriolis Effect, which is an inertial force experienced by a moving body (or liquid) in a rotating coordinate system. A Coriolis force flowmeter measures the effect of this force acting on a fluid flowing in a vibrating tube. Generally, Coriolis meters use a pair of tubes vibrating in a sinusoidal pattern with respect to one another. The tubes, along with their accompanying drive coil and sensor coils, form the transducer for the measurement system. A flow computer, either integral to the unit or housed separately, processes raw signals from the transducer. The two form a proprietary system whose components are not interchangeable with those from another manufacturer.

Coriolis mass flow measurement devices detect the actual mass, rather than the volume, of the substance passing through the meter. Initially developed as a laboratory instrument, Coriolis meter patents date back to the early 1970s. The first viable commercial meter was introduced in 1978. Since then, the market has expanded rapidly, and mass flow is the fastest growing flowmeter technology, replacing positive displacement meters in applications in the chemical, food, and pharmaceutical sectors.

Coriolis meters exhibit greater range and accuracy than traditional positive displacement devices. They can measure fluid mass flow rates from 0.04 pounds per minute to 25,000 pounds per minute, with accuracy better than 0.1 percent and with measurement repeatability of less than 0.1 percent.

Mass is a primary measurement and remains constant. Since mass flow meters measure mass directly, the result is independent of the physical properties of the fluid such as viscosity, temperature, pressure, or density. Volume changes with temperature, and volume measurements must be corrected based on ambient conditions. For example, 362 pounds of alcohol occupy 55 gallons at 41^{O} F, but at 77^{O} F, the same mass occupies 56 gallons.

Coriolis meters exhibit metrological performance unmatched by volumetric flowmeters, with increased accuracy, improved product consistency and reduced maintenance. Precision measurement of continuous processes over long periods reduces raw material consumption and inventory shrinkage. This performance, along with the Coriolis meter’s suitability for a wide variety of fluids and applications, fueled the success of this technology. Although initially more expensive, the meters quickly earn back the investment.

Theory of Operation

A Coriolis flowmeter measures the force acting on a fluid flowing within an oscillating tube. Although it is possible to accomplish a Coriolis measurement using a continuously rotating device or an oscillating single tube, the most familiar Coriolis meter designs typically use a pair of tubes that are vibrated out of phase. The use of two tubes results in a relative displacement measurement, which helps to minimize any adverse effects of environmental vibration. A number of tube geometries are possible – helical, U-shaped, S-shaped, and others. The following example will describe the operation of a device formed from a pair of Omega-shaped tubes.

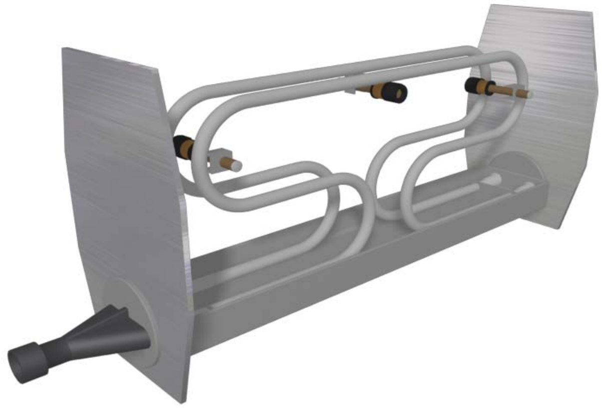

Fig. 1. Dual Omega-Tube Coriolis Meter

The tubes are vibrated in a reciprocating pattern, driven by an intrinsically safe magnet and coil assembly (a solenoid) attached to their midpoints. The solenoid drives the tubes at their resonant frequency, causing them to vibrate in and out in opposite directions. The inlet and outlet of the tube is held fixed as the tube vibrates in an arc about this axis. Two more coil and magnet assemblies, one at each end of the assembly, serve as sensors, generating a sinusoidal voltage proportional to the relative position of the two tubes. The output signals of these coils are equal in frequency and amplitude, and in phase when there is no flow through the tubes.

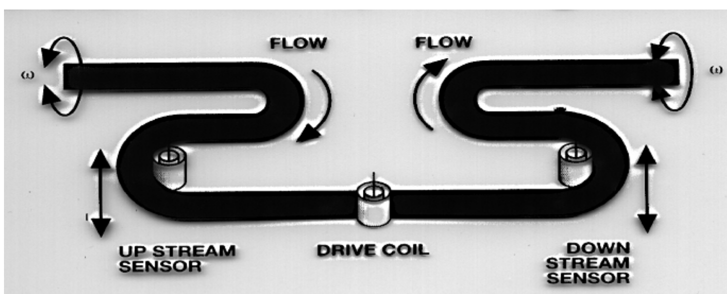

Fig. 2. Drive Coil and Sensors

When fluid flows in the moving vibrating tubes, Coriolis forces are created. When fluid flows in the tube it initially flows away from the axis as it approaches the midpoint of the tube. Once past the midpoint, the same amount of fluid returns toward the axis. At any time the mass of fluid at either end of the tube has an equal and opposite Coriolis acceleration and hence exerts an equal and opposite force F equivalent to 2mVw on the tube which tends to twist it. The difference between the positions of the two sensor coils due to the twist of the tube produces a difference in phase between the sinusoidal voltages. This phase shift is directly proportional to the mass flow rate of the fluid flowing through the tubes, and is the basis of the Coriolis flowmeter principle.

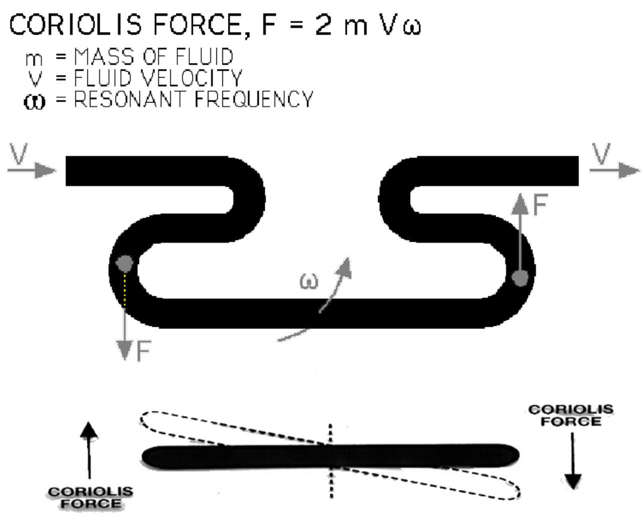

Fig. 3. Coriolis Force Calculation

Accuracy and Zeroing

Under no-flow conditions the fluid exerts zero Coriolis force on the tubes and no twist is seen. No twist means no relative positional difference between the coils and the sinusoidal voltages are in phase. Zero phase difference means zero mass flow rate. This is called the zero of the meter. However, manufacturing tolerances will introduce a slight phase difference at no-flow. This is known as the zero error or zero shift. There are also small fluctuations in the phase difference associated with installation variations and the processing of the sensor signals. The combination of these factors is known as the zero stability.

Coriolis meter accuracy is stated as percentage of mass flow rate plus or minus the zero stability. The zero shift error becomes the dominant portion of the overall accuracy at the lower end of the flow range. Alternatively, the accuracy may be stated as a percentage of rate for flow rates above some low flow threshold and as a percentage of flow range for flow rates below the threshold.

It is important to remember that the zero stability or zero shift error, is a constant error regardless of flow rate. When a new meter is put into service, it undergoes a process called "zeroing", during which this error is calculated so that it may be removed from all subsequent calculations.

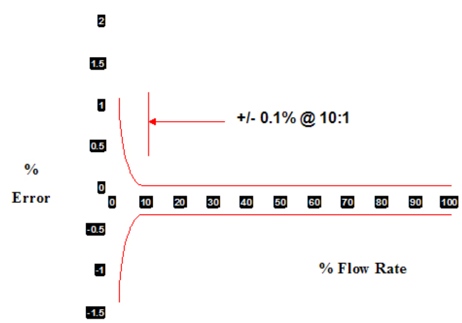

Fig. 4. Mass Flowmeter Accuracy Curve

Density and Inferred Measurements

Coriolis meters can also be used as densitometers. The tubes can be viewed as a spring and mass assembly. Once placed into motion, a spring and mass assembly will vibrate at its resonant frequency. The Coriolis meter is also vibrated at its natural "harmonic" frequency. The relationship between density and the vibration frequency and period can be quantified. As the density of the fluid inside the tubes changes, the frequency of vibration will also change. This frequency measurement is inversely proportional to the density.

$$\rho \propto 1/f_n$$

Additionally, a temperature probe is mounted on one of the flow tubes. Temperature changes the stiffness of the tube; therefore, it affects the density calculation. The flow computer compensates for this change in the tube's elasticity.

A number of other measurements can be inferred from the basic measurement of mass and density. These include volume flow rate, percent concentration of mixtures and solutions, percent solids of slurries, Brix (a measure of sugar concentration), degrees API, and degrees Baume (both related to specific gravity).

Certification, Calibration, and Proving

A new Coriolis meter is calibrated at the factory against a traceable weigh scale to establish a calibration factor for the transducer. Recalibration is not necessary on start up under field conditions; however, periodic verification or proving is advised to confirm the accuracy of the instrument during its operating life.

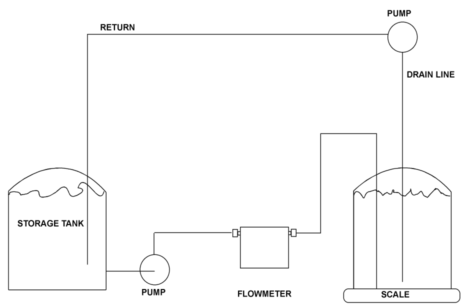

Fig. 5. Calibration Setup with Scale

There are two common proving methods -- using a mass standard or a volumetric standard. If the meter is indicating mass and is proven against a mass standard, the liquid properties during the proving run are not important to the calibration.

When proving a Coriolis meter indicating volume against a volumetric pipe prover or master meter, steady state conditions between the meter and prover are necessary to minimize variations in liquid density. A pipe prover consists of a cylinder of known volume fitted with a piston. As the collected calibration fluid displaces the piston, the meter sends pulses that represent the total volume. The meter and prover volumes can be compared and, if necessary, corrected back to a common reference condition.

As mentioned before, it is essential to maintain steady state conditions between meter and prover to minimize liquid density changes. A continuous density reading is required for the volume-to-mass conversion because changes in the physical properties of the fluid during the proving run introduce errors. Temperature, pressure and variation in entrained air content can cause density to change.

Combining instrument readings always results in a greater cumulative error and more uncertainty of the final proving result. Sufficient product should be collected to allow the resolution of the proving element to match the desired resolution of the meter calibration. API Standards are available to set out the recommended procedures for verification of Coriolis flowmeters.

Truck-Mounted Installation of Coriolis Flowmeters for Retail LPG Delivery

Although the last decade has seen rapid adoption of electronic registration devices for tank trucks in custody transfer applications, mechanical volumetric meters are still used in a majority of the new systems. In these systems, the meter's gear train is used to turn an encoder that generates the signal supplied to the electronic register. While electronic registration greatly improves the efficiency of a metering process, the system is still subject to the accuracy and maintenance constraints of the mechanical meter. In 2004, the first mass flowmeter was approved for mobile LP gas custody transfer. This fully electronic system yields reduced product losses, low maintenance, and faster deliveries.

When used on a tank truck, the meter is part of a system that includes a vapor release, differential valve, and electronic register. The system is mounted in a similar position to a traditional volumetric meter at the rear of the truck. The meter is connected in-line to the vapor release and differential valve via 2” flanges rated at 300 lbs pressure. One way of mounting a mass flowmeter on bobtails is shown in Figure 7. In this configuration, the meter is rigidly positioned for effective performance.

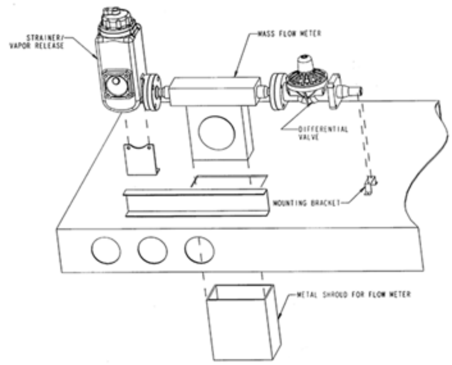

Fig. 7. Mounting Meter through Truck Deck

The advantages of accuracy, stability of calibration and lack of maintenance depend on correct installation of the meter. A specially designed bracket and flexible hoses reduce vibration and mechanical stresses. Electrical connections should be made securely and the system should be properly grounded to eliminate any electromagnetic and RF interference.

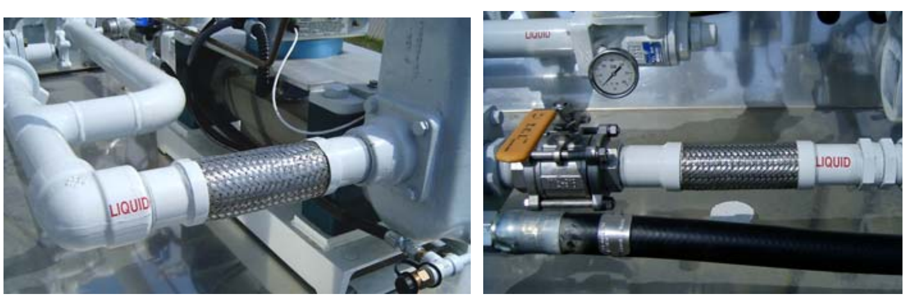

Fig. 8. Flexible Hoses used at Inlet and Outlet

Early units were mounted vertically to prevent unnecessary stress on the tubes when turned sideways, and required that a hole be cut into the deck of the truck to accommodate the height of the meter within the exiting piping profile. Newer units with improved resistance to the shock of moving over rugged terrain have now been mounted horizontally with good success and without cutting the truck deck.

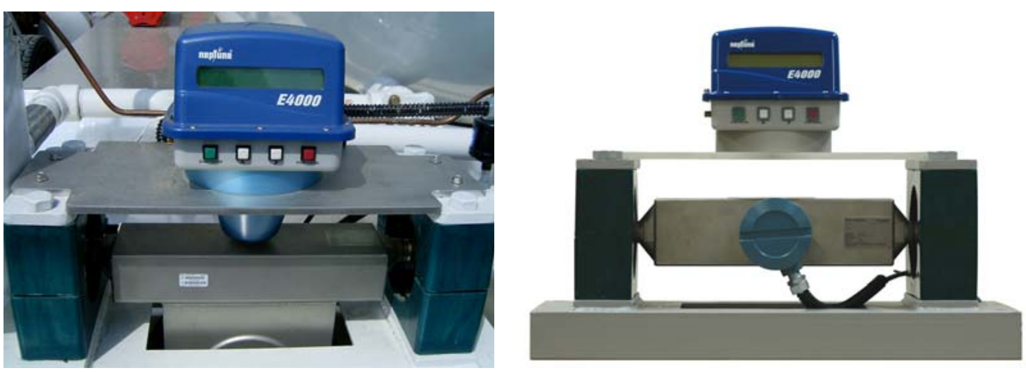

Fig. 9. Vertical and Horizontal Mounting Methods

Benefits of Coriolis Flowmeters for Mobile Delivery

Reduced Loss

Because the mass flowmeter has no moving parts to wear, its accuracy should not degrade over time. Typically, the mass flowmeter may be 0.5% more accurate than a mechanical positive displacement meter. If a retailer sells 500,000 gallons per year from one bobtail, this equates to loss reduction of 2,500 gallons. At $1 per gallon cost, the dealer recovers $2,500 per year just from gas loss reduction on one bobtail. Selling the 2500 recouped gallons at an average margin of 50 cents per gallon results in another $1250 per year in gross margin. In this case the incremental revenue may be more than $3,750.

Reduced Repair and Calibration Costs

Since there are no moving parts in the mass flow meter, there is no need to replace worn parts, saving replacement part costs and reducing down time for the drivers. Accuracy tolerances have been seen to hold over time, but if there is a need for calibration, the process is a simple change on the keypad of the electronic register, subject to local approval. There are no gears to change or multiple calibrations needed, again reducing down time.

Conclusion

Coriolis technology has proven cost effective for many applications. With better understanding of the technological constraints, we have learned how to deploy Coriolis mass flowmeters into mobile truck mounted LPG transport applications. These advances bring improved efficiency and reduced product losses to the LPG distribution and sales business.