PROVING CORIOLIS METERS
Class # 4130

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Introduction

Coriolis meters are in use throughout the hydrocarbon industry for the measurement of fluids including crude oil, products such as fuel oil, gasoline, and diesel, and light hydrocarbons such as natural gas liquids, propane, etc. When used for custody transfer, it is most often required by contract between the buyer and seller that the meter be proven in the field on the fluid that is being measured and at the conditions under which it will be operating. This paper will utilize the American Petroleum Institute's Manual of Petroleum Measurement Standards (MPMS) as the reference for industry practices for field proving methods and calculations.

Coriolis meters can measure volume, mass and density. If the meter is used to measure volume and the pulse output represents volume, the meter should be proven as a volume meter. MPMS Chapter 4, "Proving Systems", contains information specific to volumetric proving. If the meter is used to measure mass and the pulse output represents mass, the meter should be proven as a mass meter. Currently Chapter 4 does not contain information relative to proving on a mass basis; however MPMS Chapter 5.6, "Measurement of Liquid Hydrocarbons by Coriolis Meter," does provide guidelines for mass proving. If the density output is used for custody transfer flow calculations, the density measurement can be proven using MPMS Chapter 14.6, "Continuous Density Measurement" and a pycnometer or using MPMS Chapter 9, "Density Determination" and a hydrometer. The temperature output of a Coriolis meter is obtained from an internal RTD which is not inserted into the fluid and thus does not meet MPMS Chapter 7, "Temperature Determination" requirements and should not be used for custody transfer calculations.

This paper will attempt to combine information from these standards with field experience to provide an overview of what to expect when proving a Coriolis meter and what to look for if the proving results are not satisfactory.

Coriolis Meter Signal Processing

Coriolis meters are electronic, require power and some associated device that interprets the signals from the meter and provides useable pulse, analog or serial outputs. Whether in a separate housing or located on the meter, there is a signal processing unit or transmitter that is programmed with the meter's calibration coefficients determined by the manufacturer for each individual sensor. If these coefficients are not entered correctly, the meter factor may be significantly larger or smaller than 1.0.

The processor is programmed to output a pulse in the required units of measurement, volume or mass. The volume pulse is a gross volume pulse and not temperature compensated. The number of pulses per unit is user selectable. Chapter 4 indicates that a minimum of 10000 pulses should be accumulated during a proving run or that double chronometry must be used to count fractions of a pulse. The maximum limit on the pulse output from a Coriolis meter is determined by the maximum frequency output of the transmitter and the maximum frequency input of the prover counter, both typically 10K HZ. Since the frequency output will increase with flow rate, make sure that the limit will not be reached at the maximum flow rate of the meter. This pulse setup is synonymous with selecting a K-factor. The prover counter and other tertiary devices would be programmed with this value as pulses per unit from the Coriolis meter.

The speed at which the meter's pulse responds to flow changes is determined by the processing speed and software filtering and dampening. Some transmitters allow the user to control the update rate and damping of the output. For the purpose of proving with pipe provers, the speed should be maximized because the time between detector switches on a prover can be extremely short, a few seconds or less. The speed of response to a flow rate change required from the meter for proving is greater for smaller volume provers and for provers with shorter pre-runs. Since master meter proving can be done with much longer batch times, this issue of speed of response is not critical.

To summarize, the transmitter should be programmed correctly with the sensor's calibration coefficients, an appropriate K-factor selected, and the response time of the pulse output set as fast as possible. It is a best practice not to put any factors developed from proving into the Coriolis meter software and to keep these factors set to 1.0. With this setup, all meter factors are tracked and applied by a flow computer or SCADA package which can keep the audit trail required for custody transfer.

General Requirements for Proving

The general requirements for proving do not differ between Coriolis meters and other types of meters. Flow conditions should be stable in order to have a successful proving. Temperature, pressure, fluid composition and flow rate should remain relatively constant during proving. Some factors affecting flow rate stability include adequate pre-run length for the prover and types of pumps or valves in the system. Systems with positive displacement pumps are often difficult for proving meters because of the flow fluctuations created by the pumps. Automatic control valves can also create fluid pulsation that affects the proving results. Gathering systems that are on automatic control often have flow conditions that can change without warning. Flow velocities that exceed 60 feet per second may create some noise on the flow signal that affects the proving results. Since density changes with fluid composition, temperature and pressure, the flowing density output from the Coriolis meter and the flow rate can be monitored during proving to watch for excessive flow condition changes.

In addition to stability, other issues that have an affect on proving include proper valve seating, reliable detector switches, and condition of the sphere. Normally the prover itself is not considered suspect when a proving is not successful. If difficulties are encountered with multiple meters and not just a single meter, then it may be time to check out the prover. If a prover is manually operated, taking time to allow for conditions to stabilize between the meter and the prover and for valves to seat before the ball is launched can help to obtain successful provings.

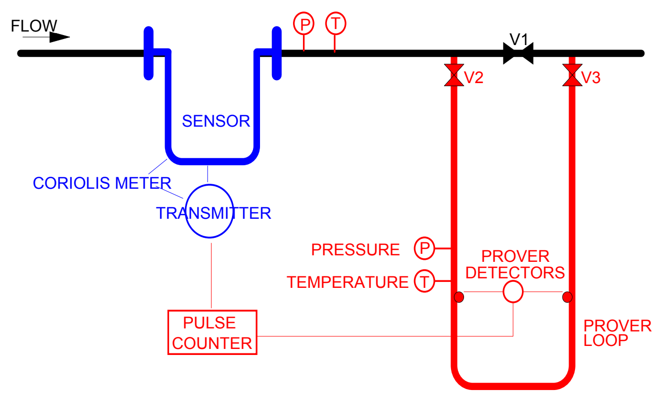
Proving software can provide for control of a number of these issues. Proving software can monitor deviations between meter and prover, stability of temperature before proving, flow stability between runs, and can make the determination that a prove has been successful.

If the meter is utilized for bi-directional metering, MPMS Chapter 5.6 indicates the meter should be proven in both directions.

Volume Proving

When a Coriolis meter is used for custody transfer based on its volume output, there is no difference in the requirements for proving from a turbine or positive displacement meter. The same calculations are made to correct for temperature and pressure differences between the prover and the meter and to correct the prover calibrated volume to observed temperature and pressure. These calculations require accurate measurement of temperature and pressure at the meter and at the prover along with the flowing density of the fluid.

Below is a typical schematic for a volumetric proving system:



Mass Proving

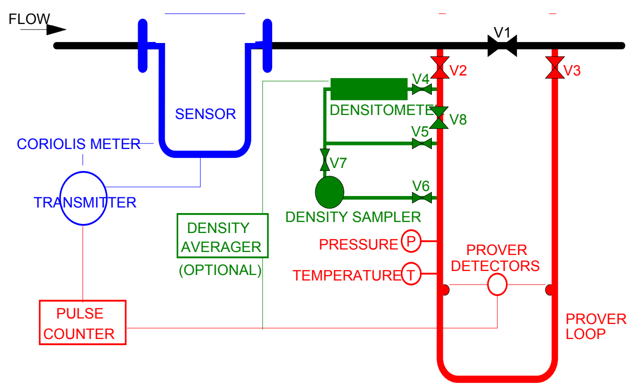
If a volume prover is to be used to prove a Coriolis meter configured for mass measurement, the prover mass must be determined. Since,

$$\text{Mass} = \text{Volume}_f \text{ X Density}_f$$

the prover mass can be determined by measuring density at the prover and multiplying the density by the prover volume. The prover's calibrated volume is corrected for temperature and pressure just the same as in a volumetric proving. In order for this equation to be valid, the density needs to be measured at the same temperature and pressure as the prover. For this reason, it is recommended that a densitometer be installed in close proximity to the prover and be well insulated. The density measurement used for mass proving should be proved as a separate measurement and the density meter factor applied prior to proving the Coriolis meter on mass.

The addition of density measurement in the proving methodology for mass makes proving more complex. For example, if density is only sampled once during a proving run and the fluid density actually varies between runs, non-repeatability of the proving runs will result. It is not the meter that is not repeating it is the prover mass that is not repeating. Knowing that density varies with temperature, pressure, it is clear that variations in either of these characteristics will cause an issue with mass proving repeatability.

Below is a typical schematic for mass proving with the densitometer located at the prover:



If the Coriolis meter's density output is used to calculate prover mass, it is critical to understand again the relationship of flowing density with temperature, and pressure changes. If the meter's density is used without any corrections for temperature and pressure, you are making the assumption that the meter temperature and pressure are the same as the prover temperature and pressure. If using the density output of the Coriolis meter the following calculation can be made to arrive at the density of the fluid at the conditions of the prover:

$$\rho_p = \rho_m * (CTL_p * CPL_p) / (CTL_m * CPL_m)$$

where,

ρ_p = density at the prover

ρ_m = density at the meter

CTL_p = correction for temperature of the liquid at the prover

CPL_p = correction for pressure of the liquid at the prover

CTL_m = correction for temperature of the liquid at the meter

CPL_m = correction for pressure of the liquid at the meter

If the fluid composition remains constant or if the fluid is a purity product, density at the prover can be calculated from temperature and pressure measurement at the prover.

One other issue to consider with mass proving has to do with the pressure surge that normally occurs when a piston or ball launches in the process of the operation of the prover. This momentary surge in pressure increases the density of the fluid, therefore, time should be allowed between the launch of the piston and the reading or calculation of the density to allow the density and pressure to return to normal. This can be done with a longer pre-run or a time delay in the proving software.

Evaluation of Proving Data

MPMS Chapter 4, Chapter 12 and Chapter 13 discuss issues related to the acceptability of proving data. There are two main topics for acceptability which are repeatability of the results between proving runs and deviation of the meter factor between provings.

A single proving must incorporate three proving runs at a minimum. There is no limit on the maximum number allowable. MPMS Chapter 12 indicates that the runs which are chosen to be evaluated do not have to be consecutive. It also indicates that runs may be averaged together and that the averaged results of sets of runs may be evaluated.

The required repeatability of results between runs is discussed in MPMS Chapter 4 and Chapter 13. Proving data is like any other statistical data, the more data you have, the greater the possibility that there will be some outliers in the data. Proving data with five different answers must have the answers agree within plus or minus 0.05% to meet the required random uncertainty for a valid proving. Proving data with ten different answers must have the answers agree within plus or minus 0.12% to meet the same required uncertainty for a valid proving.

There are two types of data which can be reviewed for repeatability between proving runs. If the number of pulses accumulated by the prover counter between runs is evaluated, this is referred to as pulse or average data repeatability. With mechanical meters, pulse repeatability is seen to reflect the condition of such things as mechanical gears, bearing wear, blade imperfections, couplings, adjustors, counters, mechanical temperature-correction devices, and other accessories. The repeatability of the pulse output from a Coriolis meter can be affected by such things as flow rate changes, density changes, electrical noise or flow noise caused by high velocity. If a meter factor is developed for each proving run and the meter factor is reviewed for repeatability, this method is called the average factor method. This method would analyze the repeatability of all aspects of the proving and is recommended for mass proving with a pipe prover because it would include repeatability of the density measured between proving runs.

The deviation of a new meter factor from one previously obtained by another proving is referred to as reproducibility. Reproducibility defines the meter's performance and/or a change in the prover, the densitometer at the prover in the case of mass proving, the isolating valves, proving conditions, or the proving procedure. Keep in mind, that a change in the densitometer correction factor from one proving to the next will have a direct affect on reproducibility of the mass meter factor from proving to proving. If you are operating on the low end of a meter's linearity curve, you should expect a greater meter factor deviation or difference in accuracy from a flow rate which falls in the normal linear range of the meter. Historically a deviation in meter factor of 0.25% between provings is considered suspect and a point at which the flow meter, valves or the prover should be evaluated.

Troubleshooting

The effort to troubleshoot the meter itself is not difficult due to the available diagnostic tools often found in the transmitter software. The first thing to acknowledge is if anything has changed since the last successful proving. A review of the software program should be made if it is possible a change was made. A look at the pickup coil voltages and drive gain can define a problem with the internal measurements of the meter. The manufacturer can advise on the typical readings for the coils. The temperature measurement made by the internal RTD on the sensor should be checked. A sensor with a failed RTD will not prove successfully.

Cavitation at the meter will result in erratic measurements. The internal drive gain reading will be excessively high if cavitation is occurring. Pressure drop across the system including the prover should be evaluated to look for this problem. Increasing the back pressure on the system may help achieve a successful prove.

A change in pipe stress on the meter may affect the meter zero and thus change the meter factor. Changes in pipe stress occur if the meter has been installed without good flange alignment or if changes in piping near the meter have occurred. The zero can be checked by blocking the meter in and verifying that the zero has not changed. Small flow fluctuations around zero are normal. The actual process of zeroing the meter through the transmitter should not be performed without the ability to run another proving. Re-zeroing at every proving is not recommended as a stable meter factor is an indicator of a stable zero.

Since the measurement of density is used to arrive at a volume measurement by a Coriolis meter, a shift in a volume meter factor may reflect a change in the measured density. Corrosion, erosion, or build-up on the inside of the meter will change the volume meter factor. These issues will also affect a mass proving if the density from the Coriolis meter is being used to calculate the prover mass. There may be diagnostic routines that compare the meter's internal readings to the original readings prior to installation thus confirming the meter's health.

If a thorough examination of the Coriolis meter shows no problems, then valves, proving procedures and the prover would be next in line for evaluation.

It is often helpful to open up the criteria set in the proving software for aborting the prove. For example, if you have it set up to abort a prove after five runs that do not repeat within 0.05%, increase the number of runs and repeatability requirements to allow a proving report to be generated. This can provide more insight into the measurements for review of the total situation.

Density Proving

It is not necessary to prove the density measurement unless the density output is being used for custody transfer calculations. If the Coriolis meter is set up for volume measurement, this does not mean that the density measurement must be proven separately. A volume meter factor corrects the Coriolis meter's volume output which includes the meter's ability to measure both mass and density. This is why you would not develop a meter factor on volume and apply it to a mass measurement. The volume meter factor would be further away from 1.0 because it is correcting for the density error in addition to the mass error.

The density output from a Coriolis meter is proven exactly like any other vibrating element densitometer. The two ways to verify a density measurement are the use of a hydrometer per MPMS Chapter 9 or the use of a pycnometer per MPMS Chapter 14.6. API is in the process of combining these chapters into one single document because continuous density measurement is becoming more common in the industry. Both methods for density proving require proper sampling techniques to allow for the measurement of a representative sample. Capturing a sample of the fluid at the same temperature and pressure as the meter is the key to determining a valid density factor. For hydrometers, the possible problems are the need for a pressurized sample container and the ability to pull a representative sample from the flowing pipeline. Errors in reading the hydrometer can be minimized by providing a good environment including a level surface, good light, and a place protected from the weather. The use of a pycnometer allows for better capture of a sample at the flowing conditions. Laboratory quality weight scales are necessary along with a thorough cleaning of the pycnometer after each use.

Fluid Compressibility and Prover Considerations

Stability of temperature and pressure during proving becomes more critical as the fluid's relative density gets lighter. Crude oil is easier to prove because its density does not change as dramatically with temperature and pressure changes as does propane as an example. Changes in fluid composition also changes relative density and can affect repeatability of a proving.

Pipe provers have a defined time between detector switches at any single flow rate. Larger pipe provers have more time between switches than smaller volume provers. More time for a proving run provides a longer time to accumulate pulses and thus more data to analyze for repeatability. More time for a proving run also reduces the effect of any time delay on the pulse output of the meter which will minimize any error in the meter factor. The recommended size of a pipe prover is based on the flow rate which determines the time between detector switches and the required time for the Coriolis meter to change its pulse output when a flow rate change occurs. For example, if a meter can respond in less than 100 milliseconds to a flow rate change, you would probably like to see approximately 0.5 seconds between detector switches. It would take a larger prover and longer time between detector switches if the response time to a change was 1 second. Master meters do not have a run time defined by detector switches therefore run times are totally flexible.

Conclusion

Coriolis meters can very accurately measure volume, mass and density and this can be confirmed by utilizing recognized field proving techniques. Knowledge of fluid characteristics, good measurement practices, and a real understanding of the practice of field proving are the basis for a successful prove.

Direct mass measurement from a single device can provide better mass flow accuracy than indirect methods as there is no slipstream required for density measurement and there are not two meters to maintain and prove. However, mass proving with a pipe prover requires density measurement and all the knowledge associated with how to arrive at indirect mass from the volume of the prover and density measurement at prover conditions.

Coriolis meters measure volume and measure density. The density output can be used to calculate inferred mass or net volume, to detect an interface or to monitor quality. The measurement of the full flow stream overcomes errors associated with installing a densitometer in a slip-stream. The volume proving does not differ from other flow meters nor does the methodology for proving its density output.

No moving parts are a key advantage for Coriolis meters, not in only providing a sustained accuracy over time, but eliminating spare parts inventory and high maintenance costs. With no moving parts comes the associated requirement that signal processors produce the pulse for proving. With software comes programming and controlling the desired meter response but also real-time information for pipeline control, alarm capabilities and meter diagnostics.