Manual of Petroleum Measurement Standards Chapter 5—Metering

Section 6—Measurement of Liquid Hydrocarbons by Coriolis Meters

FIRST EDITION, OCTOBER 2002

REAFFIRMED, NOVEMBER 2013

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AMERICAN PETROLEUM INSTITUTE

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0 Introduction

0.1 This standard is intended to describe methods to achieve custody transfer levels of accuracy when a Coriolis meter is used to measure liquid hydrocarbons.

0.2 Coriolis meters measure mass flow rate and density. It is recognized that meters other than the types described in this document are used to meter liquid hydrocarbons. This publication does not endorse or advocate the preferential use of a Coriolis meter nor does it intend to restrict the development of other types of meters. Those who use other types of meters may find sections of this publication useful.

1 Scope

1.1 This standard is applicable to custody transfer applications for liquid hydrocarbons. Topics covered are:

a. Applicable API standards used in the operation of Coriolis meters.

b. Proving and verification using both mass- and volume-based methods.

c. Installation.

d. Operation.

e. Maintenance.

1.2 The mass- and volume-based calculation procedures for proving and quantity determination are included in Appendix E.

1.3 Although the Coriolis meter is capable of simultaneously determining density, this document does not address its use as a stand-alone densitometer. See API *MPMS* Chapter 14.6 for this type of application. The measured density from the Coriolis meter is used to convert mass to volume.

2 Field of Application

The field of application of this document is any division of the petroleum industry where dynamic flow measurement of applicable fluids is desired. The use of Coriolis meters for alternate applications or fluids may be addressed within other chapters of the API *MPMS* and are not precluded by this standard.

3 Definitions

3.1 accessory equipment: Any additional electronic or mechanical computing, display, or totalization equipment used as part of the metering system.

3.2 base conditions: Defined pressure and temperature conditions used in the custody transfer measurement of fluid volume and other calculations. Base conditions may be defined by regulation or contract. In some cases, base conditions are equal to standard conditions, which within the U.S. are usually 14.696 psia and 60°F, and in other regions 101.325 kPa (absolute) and 15°C.

3.3 base density: The density of the fluid at base conditions.

3.4 calibration: The process of utilizing a reference standard to determine a coefficient which adjusts the output of the Coriolis transmitter to bring it to a value which is within the specified accuracy tolerance of the meter over a specified flow range. This process is normally conducted by the manufacturer.

3.5 cavitation: Phenomenon related to and following flashing if the pressure recovers and the vapor bubbles collapse (implode). Cavitation will cause a measurement error and can damage the sensor.

3.6 Coriolis meter: Also referred to as Coriolis mass meter or Coriolis force flowmeter. A Coriolis meter is a device which by means of the interaction between a flowing fluid and the oscillation of a tube(s), measures mass flow rate and density. The Coriolis meter consists of a sensor and a transmitter.

3.7 Coriolis meter factor, mass or volume (MF, MF_m, MF_v): A dimensionless number obtained by dividing the actual quantity of fluid passed through the meter (as determined by proving), by the quantity registered by the meter. For subsequent metering operations, the actual quantity is determined by multiplying the indicated quantity by the meter factor.

3.8 Coriolis transmitter: The electronics associated with a Coriolis meter which interprets the phase shift signal from the sensor, converts it to a meaningful mass flow rate (represented in engineering units or a scaled value), and generates a digital or analog signal representing flow rate and/or quantity. Most manufacturers also use it to drive the sensor tubes, determine fluid density, and calculate a volumetric flow rate.

3.9 flashing: A phenomenon which occurs when the line pressure falls to or below the vapor pressure of the liquid, often due to local lowering of pressure because of an increase in the liquid velocity.

3.10 flowing density: The density of the fluid at actual flowing temperature and pressure.

3.11 flow sensor: A mechanical assembly consisting of:

- **housing:** The means of providing environmental protection. This may or may not provide secondary containment.
- **measurement sensor(s):** Sensors to monitor oscillations and to detect the effect of Coriolis forces. These are also referred to as pickups or pickoffs.
- **support structure:** A means for supporting the vibrating conduit.
- **vibrating conduit:** Oscillating tube(s) or channel through which the fluid to be measured flows.
- **vibration drive system:** The means for inducing the oscillation of the vibrating tube.

3.12 K-factor: Pulses per unit quantity (volume or mass); a coefficient, entered in the accessory equipment by a user, which relates a frequency (mass or volume) input from the Coriolis transmitter to a flow rate.

3.13 manufacturer density calibration factor: A numerical factor which may or may not be used to address density sensitivity of each individual Coriolis meter sensor. It is unique to each sensor and derived during sensor calibration. When programmed into the transmitter, the density calibration factor(s) helps ensure that the meter performs to its stated specifications.

Note: The Manufacturer Density Calibration Factor should not be confused with Density Meter Factor (*DMF*).

3.14 manufacturer flow calibration factor: A numerical factor which may or may not be used to address flow sensitivity of each individual Coriolis meter sensor. It is unique to each sensor and derived during sensor calibration. When programmed into the Coriolis transmitter, the flow calibration factor(s) helps ensure that the meter performs to its stated specifications.

Note: The Manufacturer Flow Calibration Factor should not be confused with K-Factor or Meter Factor *(MF)*.

3.15 meter assembly: The Coriolis sensor and the Coriolis transmitter used for the measurement of fluid.

3.16 pressure loss (pressure drop): The difference between upstream and downstream pressures due to the frictional and inertial losses associated with fluid motion in the entrance, exit, and internal passages of the flow meter or other specified systems and equipment.

3.17 primary element: See flow sensor.

3.18 proving: The process of comparing the indicated quantity which passes through a meter under test, at operating conditions, to a reference of known quantity in order to establish a meter factor. This process is normally conducted in the field.

3.19 Pulse Scaling Factor: Abbreviated *PSF*, pulses per unit mass or volume; a coefficient entered in the Coriolis meter transmitter by the manufacturer or a user which defines the relationship between a pulse output and a quantity. A similar K-factor entered into the accessory equipment is used to translate the pulses back into a quantity. The *PSF* may be entered directly or derived from operator entries such as flow rate and frequency.

3.20 zeroing: A procedure that eliminates observed zero offset. The stored zero value is used by the Coriolis transmitter to calculate flow rate.

Note: The zeroing operation should not be confused with resetting the totalizer.

3.21 zero offset, observed: The difference between the observed zero value and the stored zero value.

3.22 zero stability: The deviation from a zero indication by the meter over an appreciable time when no physical flow is occurring and no output inhibiting is applied.

Note: This is a systematic uncertainty, which can be present over the working range of the meter.

3.23 zero value, observed: A measurement output indicating the average mass flow rate under zero flow conditions with no output inhibiting (i.e., no low flow cutoff and bi-directional flow) applied.

3.24 zero value, offset limit: The maximum allowable observed zero offset in relation to the stored zero value used to determine when to rezero the flowmeter; generally established by the user.

3.25 zero value, stored: The correction value stored in the transmitter which cancels out the flow rate observed at no flow conditions during zeroing of the flowmeter.

4 Referenced Publications

The current editions of the following standards, codes, and specifications are cited in this document, or provide additional information pertinent to Coriolis meter operation or calibration:

API *Manual of Petroleum Measurement Standards*

Chapter 1		"Vocabulary"
Chapter 4		"Proving Systems"
Chapter 5	Section 1	"General Consideration for Measurement by Meters"
Chapter 5	Section 5	"Fidelity and Security of Flow Measurement Pulsed-Data Transmission Systems"
Chapter 7		"Temperature Determination"
Chapter 8	Section 1	"Manual Sampling of Petroleum and Petroleum Products"
Chapter 8	Section 2	"Automatic Sampling of Petroleum and Petroleum Products"
Chapter 8	Section 3	"Mixing and Handling of Liquid Samples of Petroleum and Petroleum Products"
Chapter 9		"Density Determination"
Chapter 11		"Physical Properties Data"
Chapter 12	Section 2	"Calculation of Petroleum Quantities Using Dynamic Measurement Methods and Volume Correction Factors"
Chapter 13		"Statistical Aspects of Measuring and Sampling"
Chapter 14	Section 6	"Continuous Density Measurement"
Chapter 20	Section 1	"Allocation Measurement"
Chapter 21	Section 2	"Electronic Liquid Volume Measurement Using Positive Displacement and Turbine Meters"

ANSI/ASME[1]

MFC-9M-1989	"Measurement of Liquid Flow in Closed Conduits by Weighing Method"
MFC-11M-1989	"Measurement of Liquid Flow by Means of Coriolis Mass Flowmeters"

5 Abbreviations

Abbreviations used within the document are listed below:

ω = angular velocity of the oscillating tube of a Coriolis meter

ΔF_c = transverse Coriolis force associated with length Δx

ρ = fluid density

ρ_b = fluid density at base conditions

ρ_{fm} = fluid density at flowing conditions at the Coriolis meter

ρ_{fp} = fluid density at flowing conditions at the prover

δm = particle of mass contained in the Coriolis meter

Δp = pressure drop through the flowmeter at the maximum operating flow rate (psi)

Δx = a finite element of the length of the oscillating tube of a Coriolis meter

A = cross-sectional area of the oscillating tube interior of a Coriolis meter

a_r = radial acceleration (centripetal)

a_t = transverse acceleration (Coriolis)

CPL_m = correction for pressure effect on fluid at the Coriolis meter

CPL_p = correction for pressure effect on fluid at the prover

CPS_p = correction for pressure effect on steel at the prover

CTL_m = correction for thermal expansion of fluid at the Coriolis meter

CTL_p = correction for thermal expansion of fluid at the prover

CTS_p = correction for thermal expansion of steel at the prover

Err_0 = zero error (%)

f = tube frequency, measured to determine fluid density

F_c = Coriolis force, the product of transverse acceleration and the particle mass

IM_m = indicated Coriolis meter mass

IV_m = indicated Coriolis meter volume

KF_m = K-factor in units of pulses per unit mass

KF_v = K-factor in units of pulses per unit volume

MF_m = meter factor when the Coriolis meter is configured to indicate mass

MF_v = meter factor when the Coriolis meter is configured to indicate volume

$MPMS$ = API Manual of Petroleum Measurement Standards

[1]ASME International, 3 Park Avenue, New York, New York 10016-5990

P = fixed point around which a tube of a Coriolis meter oscillates

p_e = equilibrium vapor pressure of fluid at the operating temperature (psia)

P_b = minimum back pressure (psig)

P_m = fluid pressure at the Coriolis meter

P_p = fluid pressure at the prover

PSF = Pulse Scaling Factor

q_0 = observed Coriolis meter flow rate with no flow

q_f = typical flow rate during normal operation

q_m = mass flow rate

t = time period

T_m = fluid temperature at the Coriolis meter

T_p = fluid temperature at the prover

v = fluid velocity in a tube of a Coriolis meter

6 System Description

A Coriolis meter consists of a sensor and a transmitter. A typical Coriolis sensor has one or two tubes through which the fluid flows. The tube or tubes are made to vibrate at their natural or harmonic frequencies by means of an electromagnetic driving mechanism. The flowing fluid generates a Coriolis force that is directly proportional to the mass flow rate of the fluid. The magnitude of the Coriolis force can be detected and converted to a mass flow rate. Refer to Appendix A for Principle of Operation. The Coriolis transmitter powers the sensor, processes the output from the sensor in response to mass flow, and generates signals for accessory equipment representative of that flow rate.

A Coriolis meter may also be configured to indicate volumetric flow rate. In this case, the frequency of the oscillating tube or tubes is measured and used to determine the density of the fluid. The density is determined in a similar manner as other types of vibrating tube density meters and is independent of the mass flow rate determination. Refer to Appendix B. The volumetric flow rate may be determined by dividing the mass flow rate by the measured density at flowing conditions. Throughout this document, both mass and volume measurements are referred to. Proving methods will vary depending upon the configuration of the Coriolis meter.

6.1 FLOW SENSOR CONSIDERATIONS

Select flow sensors to measure parameters safely and accurately over the performance range needed. The flow sensor directly measures mass flow rate and density. All other parameters are inferred from these two measurements. It should be noted that the Coriolis meter has a mass-based output signal and will avoid solution-mixing errors associated with volumetric measurement of multicomponent streams with molecules of various sizes. Consider the effect of the following issues on the flow sensor to ensure it meets all requirements.

6.1.1 Sensor Tube Configuration

6.1.1.1 Each manufacturer produces Coriolis meters with different sensor designs and each will have different tubing configurations. Tubing configuration will influence:

a. The pressure drop across the meter.
b. Susceptibility to erosion, flashing, and cavitation.
c. Minimum and maximum flow rates.
d. Accuracy of the measurement.
e. Susceptibility to coating and clogging.

6.1.1.2 Flow sensors often restrict the cross-sectional flow area resulting in higher fluid velocity and pressure drop than experienced in the associated piping. The pressure drop for a particular installation will depend on the tube configuration along with the viscosity and density of the fluid and the desired flow rate. Consider the amount of pressure drop required by the flow sensor with respect to total pressure drop allowed in the system. Consult the flow sensor manufacturer for appropriate methods to calculate velocity and pressure drop through the sensor to assess the potential for erosion.

6.1.1.3 High fluid velocities, when coupled with abrasive particles in the stream, may cause erosion and sensor failure. Select the flow sensor to provide required accuracy within the allowable system pressure drop constraints while avoiding erosion.

6.1.1.4 To help mitigate the hazards associated with a tube failure, additional or optional equipment provided by the meter manufacturer or the user may need to be considered such as:

a. Flow sensor housings, constructed as a pressure-containing vessel, designed to contain fluid under pressure to a specified pressure limit.
b. Burst disks, pressure relief valves and drains, or vents on the housing, to relieve pressure inside the housing and allow fluids released due to a tube fracture to be directed away from the flow sensor to an area less hazardous to operating/maintenance personnel.

6.1.1.5 The stream velocity and pressure drop experienced in the flow sensor could cause cavitation which will cause inaccurate measurement and may damage the sensor. Provide sufficient pressure to avoid cavitation or flashing in the vicinity of the meter (at, or immediately upstream/downstream) at all times while measuring the parameters of interest. The relatively high fluid velocities, which often occur in Coriolis meters, cause local dynamic pressure drop inside the meter that may lead to cavitation. A guideline which may be used is to maintain the pressure at the outlet of the meter above the pressure defined by Equation 1 (see 6.3.2). For some high vapor pressure products such as ethylene and high-purity ethane, this guideline may not be sufficient.

6.1.1.6 Consider the fluid characteristics and flow sensor design to provide for adequate draining, vapor elimination, and cleaning ability. On light hydrocarbon streams with high vapor pressure characteristics, flow sensors should be installed in a manner which avoids trapping any vapors. Since these liquids vaporize as pressure drops, self-draining features are not likely required. Heavier hydrocarbons may be less likely to vaporize at low pressures and therefore may require means to drain the sensor.

6.1.1.7 For streams containing materials capable of collecting in the sensor, consider the susceptibility of the tube designs to clogging, plugging, or fouling. Different tube configurations may be more or less likely to promote the accumulation of sediments or coatings within the tubes. Besides restricting flow, the accumulation of material within the tube is likely to affect the accuracy of the density signal output of the sensor.

6.1.2 Sensor Tube Material

Material selection depends on properties of the fluid such as corrosiveness and the absence or presence of abrasive or deposit-forming materials. Consider combinations of the flowing stream with possible contaminants including hydrostatic test water or air remaining after construction to address material compatibility. Materials used for all wetted parts must be compatible with the stream.

6.1.3 Accuracy

6.1.3.1 Flow sensor accuracy is a function of the mass flow rate through the sensor. Error limits are often provided by manufacturers for flow rates from 100% of the rated maximum to a small percentage of this flow rate. Like other measuring devices, uncertainty increases as flow rate approaches zero (see Figure 1). Variations in line pressure may affect sensor accuracy. Consult the manufacturer for the performance envelope describing error limits throughout the flow rate range and operating pressure range and consider these limits with respect to the system requirements. Sensitivity to pressure effects typically increases with meter size. Meter performance may tend to deteriorate as meter tube wall thickness and diameter increase.

6.1.3.2 Flow sensor accuracy and performance can also be impaired by external piping loads, vibration, and pulsation. Refer to 6.3 for further details.

6.1.3.3 If there is an observed zero offset, it will decrease measurement accuracy primarily in the lower flow rate range of the meter.

6.1.3.4 Each flow sensor will have potentially different accuracy specifications. Each individual design will have a different sensitivity to flow rate changes, vibration, operating pressure and ambient temperature. Select a sensor that meets accuracy requirements for the installation while minimizing the effect of these influencing factors.

6.1.4 Pressure Rating

6.1.4.1 The flow sensor must have a pressure rating adequate for the service and the piping system in which it is installed. Flow sensor tubes, end connections, and external housing may have different pressure ratings, but all must meet pressure codes for the service. Consider the maximum and minimum pressure limits for the flow sensor and ensure that the operating pressures and pressures experienced during abnormal operating conditions, such as flow stoppages and maintenance, fall within these limits.

6.1.4.2 The flow sensor should be pressure tested to a sufficient margin of safety above the maximum operating pressure of the weakest component. Codes or standards (e.g., DOT part 195 subpart E sections 195.300 through 195.310 and ANSI B31.3) may specify the margin of safety. Commonly, this pressure test is performed as a hydrostatic test. The tubes and end connections are usually tested as a unit. Secondary containment structures may have to be tested separately. Consider radiographic, ultrasonic, or other supplemental testing methods depending on service requirements.

6.1.5 Electrical

6.1.5.1 Select the flow sensor, its transmitter, and accessory equipment to meet the required electrical area classification. Consider the power requirements for the flow sensor and transmitter. Design the electrical signal system to provide appropriate fidelity and security.

6.1.5.2 The flow sensor, Coriolis transmitter, and their interconnecting cables are all susceptible to Electromagnetic Interference (EMI). Since the electrical signals of the Coriolis meter are at relatively low power levels, care must be taken to avoid interference generated from nearby electrical equipment and wiring. Coriolis meters employ various materials and methods to provide shielding against EMI.

6.1.6 Documentation

The flow sensor manufacturer should provide a calibration certificate, test results, electrical area classification certification, and material test reports to properly document the flow sensor.

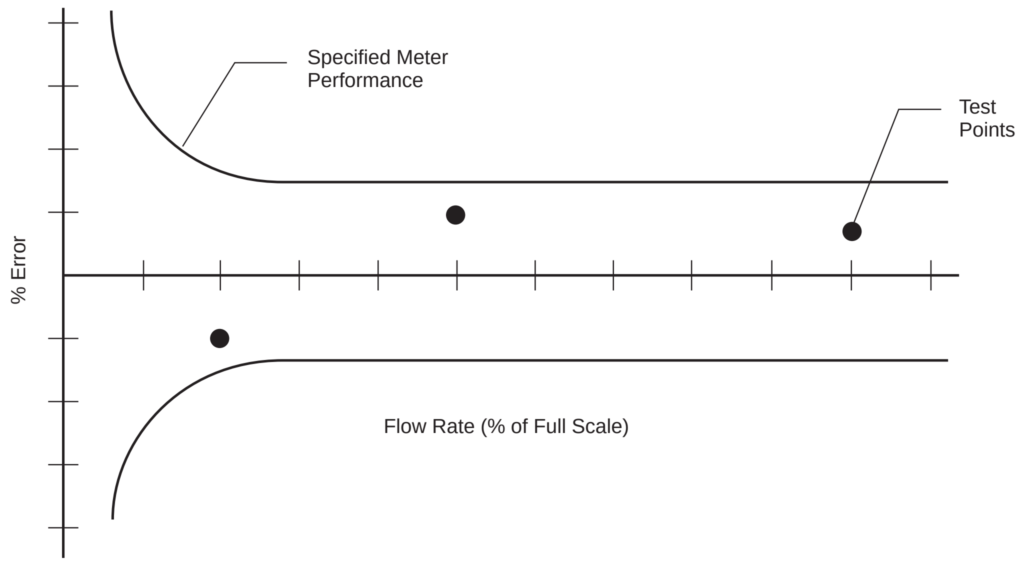


Figure 1—Typical Coriolis Meter Accuracy Specification

6.1.7 Bidirectional Flow

Some flow sensors may be capable of bidirectional flow. If bidirectional flow is required for your application, select a flow sensor that is compatible.

6.1.8 Sensor Orientation

Different manufacturers may have specific requirements regarding the orientation of the sensor in the associated piping. For different operating conditions there may be restrictions on whether the sensor tubes may be in a vertical line or oriented in a hanging, sideways, or upwards position.

6.2 CORIOLIS TRANSMITTER CONSIDERATIONS

6.2.1 Environmental

Evaluate the temperature and humidity extremes for appropriate protection. Consider weather-proofing, fungus-proofing, and corrosion.

6.2.2 Electrical

a. Power supply requirements for continuous or intermittent meter readout.
b. Certification for area classification.

6.2.3 Operability

a. Physical size of the Coriolis transmitter.
b. Means of configuring (keypad, handheld, EPROMs).
c. Display of parameters.
d. Ease of electrical connections.
e. Ease of zeroing and parameter changes.
f. Ability to totalize bidirectional flows separately.
g. Alarms.

6.2.4 Input and Output Signals

a. Types of readout or indicating devices to be used and the signal processing, including its susceptibility to Radio Frequency Interference (RFI) and Electromagnetic Interference (EMI).
b. Security of readouts.
c. Security of electrical transmission system.
d. Ensure that the Coriolis meter transmitter is compatible with sensor, accessory equipment, higher-level data logging, or control systems. The transmitter should provide the necessary output signals.
e. Ensure that the transmitter can provide signals to all required accessory equipment, while simultaneously generating a pulse output for a prover counter.
f. Consistency of pulse output duty cycle during proving (some Coriolis meters output pulses in bursts).
g. Proximity requirements to sensor.
h. Availability of digital inputs to start/stop totalization.
i. Ability to drive control outputs for alarms or to signal flow reversal.
j. Allowable distances between communications components in the communications system (RS232, RS485, etc.).

6.3 SYSTEM DESIGN CONSIDERATIONS

This document describes the methods of obtaining mass and volume measurements of fluids using Coriolis meters. Those intending to apply Coriolis meters for custody transfer metering should satisfy themselves that the meter, its application, and proving facilities can reliably and consistently meet the accuracy criteria of all parties engaged in the transaction. Serious consideration should be given to the following items before applying Coriolis meters for custody transfer measurements.

6.3.1 General

a. External vibrations at specific frequencies may cause measurement errors.
b. Two-phase flow (liquid/gas) can adversely affect meter performance.
c. Coriolis meter systems should comply with all applicable codes and regulations. A schematic diagram of a typical meter installation is shown in Figure 2.

6.3.2 Piping

a. Where the flow range or pressure drop is too great for one meter, the installation of a bank of meters in parallel may be used. When more than one meter is installed in parallel, a means should be provided to balance flow through the meters and isolate the meters for proving purposes.
b. Any condition that tends to contribute to vaporization or cavitation of the liquid stream should be avoided by system design and by operating the meter within its specified flow range. Vaporization or cavitation can be minimized or eliminated by maintaining sufficient pressure in and immediately downstream of the meter. In lieu of actual test data to determine back pressure requirements, the following equation can be applied:

$$P_b = 2\Delta p + 1.25 p_e \qquad (1)$$

where

P_b = minimum back pressure (psig),

Δp = pressure drop through the flowmeter at the maximum operating flow rate (psi),

p_e = equilibrium vapor pressure of liquid at the operating temperature (psia).

Note: For some dense-phase fluids, such as ethylene and high-purity ethane, these guidelines may not be sufficient.

c. Two-phase flow (liquid/gas) can adversely affect meter performance. A Coriolis meter installation should be equipped with air/vapor eliminator equipment, as necessary, so that measurement accuracy is not degraded.
d. The effect of fluid swirl and nonuniform velocity profiles caused by upstream and downstream piping configuration on meter performance may differ from one meter design to another.
e. The Coriolis meter should be oriented in a position that will assure that the measuring tube or tubes are completely filled with fluid under all flow and static conditions, or provisions made to not measure flow during no-flow conditions if gas can accumulate in the tubes and cause false readings.
f. For volumetric measurement, thermowells should be installed near the flow sensor so that the measured temperature is representative of the fluid temperature in the Coriolis meter. Normal practice is to install the thermowell downstream of the meter.
g. A recording or indicating pressure device should be installed near the flow sensor. For volume measurement of highly compressible fluids under varying flow rates, it may be necessary to install pressure-sensing equipment both upstream and downstream of the Coriolis meter and use the average pressure in meter factor computations. These pressure measurements may also be used to compensate for pressure effects on meter performance.
h. Strainers or other protective devices may be provided upstream of the meter to remove foreign objects which may cause measurement error.
i. Provide access to the meter/transmitter for servicing and display readout. A crane or boom truck may be needed for servicing larger meters.
j. Avoid installations near sources of flow pulsation and vibration.

6.3.2.1 Stored Zero Value Verification

a. Valves to stop flow through the Coriolis meter to allow zeroing are required. It is preferable to have shut-off valves located both upstream and downstream of the meter to block it in during zeroing. As a minimum, a block-and-bleed valve located downstream of the meter is required.
b. Stored zero value verification is required as part of the normal operating procedure for the meter.

6.3.2.2 Density Verification

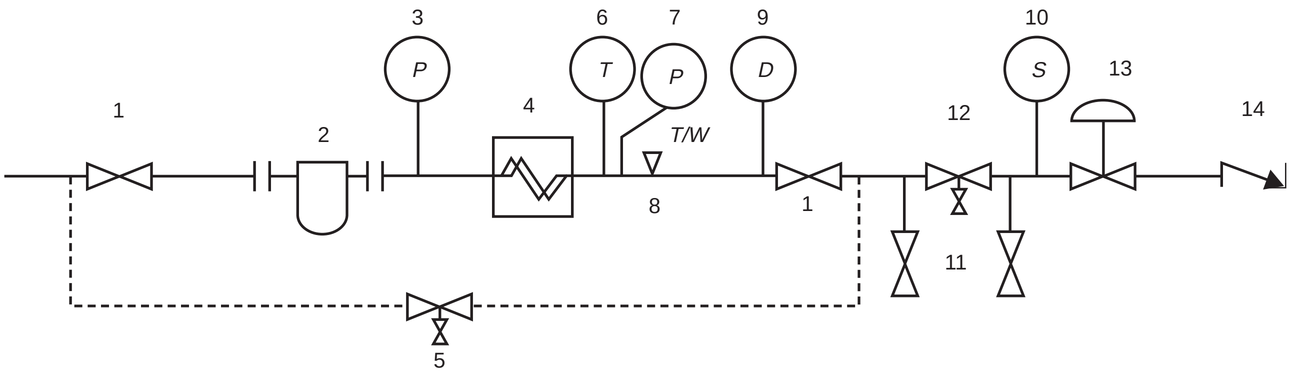
Accurate determination of the line density is critical to successful proving of a Coriolis meter when the prover and the Coriolis meter do not measure in the same units (mass or volume). Consider the:

- Ability to sample product for hydrometer/lab tests.
- Ability to attach pycnometer or master densitometer.

6.3.3 Valves

Valves in a meter installation which divert, control or block flow during metering or proving shall be capable of smooth opening and closing. The critical valves shall provide a leak-proof shutoff with a method of checking for leakage, such as a block and bleed. See Figure 2.

a. All valves that could affect measurement shall be designed so they will not admit air when subjected to hydraulic hammering or vacuum conditions.
b. For controlling intermittent flow, valves shall be of the fast-acting, shock-minimizing type so as to avoid damaging



1. Block valve
2. Strainer/air eliminator (optional)
3. Pressure indicating device (optional)
4. Coriolis meter
5. Meter bypass (optional) with block and bleed valve or blind
6. Temperature indicating device
7. Pressure indicating device
8. Test thermowell (optional)
9. Density measurement/verification point
10. Manual sample point or autosampler (optional) with probe
11. Proving connection, block valves
12. Block and bleed isolation valve for proving/zeroing
13. Control valve (as required)
14. Check valve (as required)

Note: All sections of line that may be blocked in must have provisions for pressure relief.

Figure 2—Typical Schematic for Coriolis Meter Installation

the equipment and/or adversely affecting the accuracy of measurement.

Automatic devices such as a flow-limiting control valve or restricting orifice, if required to prevent flows in excess of the maximum rate of the meter, shall be installed downstream of the meter. The device shall be selected or adjusted so that sufficient backpressure will be maintained to avoid cavitation or vaporization.

Special considerations should be given to bidirectional installations to minimize the effect of flow-limiting devices on the meter's performance.

c. The Coriolis meter shall be protected from pressure surges as well as from excessive pressures caused by thermal expansion of the fluid when the installation is not operating. A relief valve, if used, should not be installed between the prover and the Coriolis meter.

6.3.4 Proving Facilities

Facilities must be provided for proving the meter under conditions as close to normal operating conditions as practical.

Stability of temperature, pressure, flow rate, and product composition is typically necessary to achieve acceptable proving repeatability.

a. Metering systems should be provided with either manual or automatic means to permit proving the meter under conditions of flow rate, pressure, temperature, and fluid characteristics that exist during the normal operation of the meter.

b. Connections for proving shall be installed so air or vapor is not trapped in the piping between the meter and the prover. Adequate bleed-off connections should be provided (see API *MPMS* Chapter 4.8). Minimizing the distance between the meter and prover can alleviate problems in obtaining accurate meter proving results. It is recommended that the flow sensor be located upstream of the proving connection.

Consider the location and distance between the proving connections and the Coriolis transmitter for meter proving. Unlike other meter types, where the pulse generation for meter proving is located at the primary element, the Coriolis meter's pulse generation for meter proving is located at the Coriolis transmitter. If the transmitter is not located near the proving facility, then a remote termination junction box should be provided near the proving facility to provide access to the Coriolis meter pulse generation for interfacing the electronic counter on the prover.

An independent verification of agreement between the prover counter and the Coriolis transmitter and/or accessory equipment shall be made at the time of proving.

6.3.5 Mounting

a. Proper mounting of the Coriolis sensor is required. Follow the manufacturer's preferred recommendations. Consideration should be given to the support of the sensor, the alignment of the inlet and outlet flanges with the sensor, and the orientation of the sensor (vertical or horizontal, upward or downward).

b. Mount the Coriolis transmitter such that it may be easily accessed to attach communications equipment, to view displays, and to use keypads. Unlike turbine and positive displacement meters, the prover signal is not from the sensor (meter) but rather from the Coriolis transmitter. Locating the transmitter as close as practical to the prover tap location will facilitate connecting the prover to the meter.

c. Piping should be anchored to avoid transferring any stresses from the piping to the flow sensor. Piping vibration and fluid pulsation may affect the ability of the flow sensor to accurately measure stream parameters as the external vibration or pulsation approaches the resonant frequency of the sensor. Consult the manufacturer for vibration or pulsation frequencies to be avoided. Pulsation dampeners may be required in some situations.

d. Meter performance, specifically observed zero offset, will be adversely affected by axial bending and torsional stresses from pressure, weight, and thermal effects; these stresses and associated loads can be minimized by utilizing properly aligned pipe work and well-designed supports. A spool piece, equal in length to the Coriolis meter, should be used in place of the meter to align pipework during the construction phase.

e. Precautions should be taken to ensure that external vibration at the operating frequency of the flow sensor or one of its harmonics are isolated and do not become detrimental to the meter's performance.

6.3.6 Orientation

Solids settlement, plugging, coating, or trapped gas can affect the meter performance. Allowable sensor orientations will depend on the application and the geometry of the oscillating tube(s) and should be recommended by the manufacturer.

6.3.7 Multiple Meters in Close Proximity

In some applications it may be necessary to install multiple flow sensors in close proximity, either in parallel or series. In this case, the vibrations generated by each sensor could interfere with each other, thereby causing erroneous measurement. This is called crosstalk. Vibration isolation or dampening can be achieved by altering piping, isolation valves, and/or supports. Some manufacturers may also be able to alter the drive frequency of their sensors, thereby reducing the possibility of mechanical crosstalk between adjacent meters.

6.3.8 System Set-up

A factory calibration for mass rate is usually performed gravimetrically (against a weigh tank). A typical factory calibration is described in Appendix B.

Correction and calibration factors that may affect the mass, volume, density, or flow rate determined by the Coriolis meter are depicted in Figure 3. See Section 3 for more information on the individual factors.

6.3.9 Choosing a Pulse Scaling Factor

Care must be taken when selecting a pulse scaling factor (*PSF*) to ensure that the following two conditions are satisfied:

a. *When the Coriolis meter is flowing at maximum specified flow rate*—The pulse frequency output by the Coriolis transmitter must not exceed 90% of the maximum input frequency of the accessory equipment receiving the pulse signal.

b. *When the Coriolis meter is flowing at minimum specified flow rate*—The pulse frequency output by the Coriolis transmitter should be high enough to produce sufficient pulses per unit time to provide the appropriate flow rate and quantity resolution needed for the application.

7 Safety

A Coriolis meter is subject to safety considerations for both mechanical and electrical aspects of the sensor and the Coriolis transmitter. Installation of the Coriolis meter should comply with applicable electrical standards and practices with regard to the area classification of the equipment, location of any component of the Coriolis meter within a hazardous area, and suggested maintenance practices to reduce electrical hazards.

7.1 TUBE FAILURE

7.1.1 During operation, one of the main safety concerns is the possibility of a tube fracture occurring. If this occurs, there are two main safety issues:

a. The pressure within the flow sensor housing may exceed the design limits, possibly causing the housing to rupture.

b. Fluids that are toxic, corrosive, flammable, or volatile may be hazardous to operating/maintenance personnel and/or the environment.

7.1.2 To help mitigate the hazards associated with a tube failure, additional or optional equipment provided by the meter manufacturer or the user may need to be considered such as:

a. Flow sensor housings constructed as a pressure-containing vessel, designed to contain fluid under pressure to a specified pressure limit.

b. Burst disks, pressure relief valves and drains, or vents on the housing, to relieve pressure inside the housing and allow fluids released due to a tube fracture to be directed away from the flow sensor to an area less hazardous to operating/maintenance personnel.

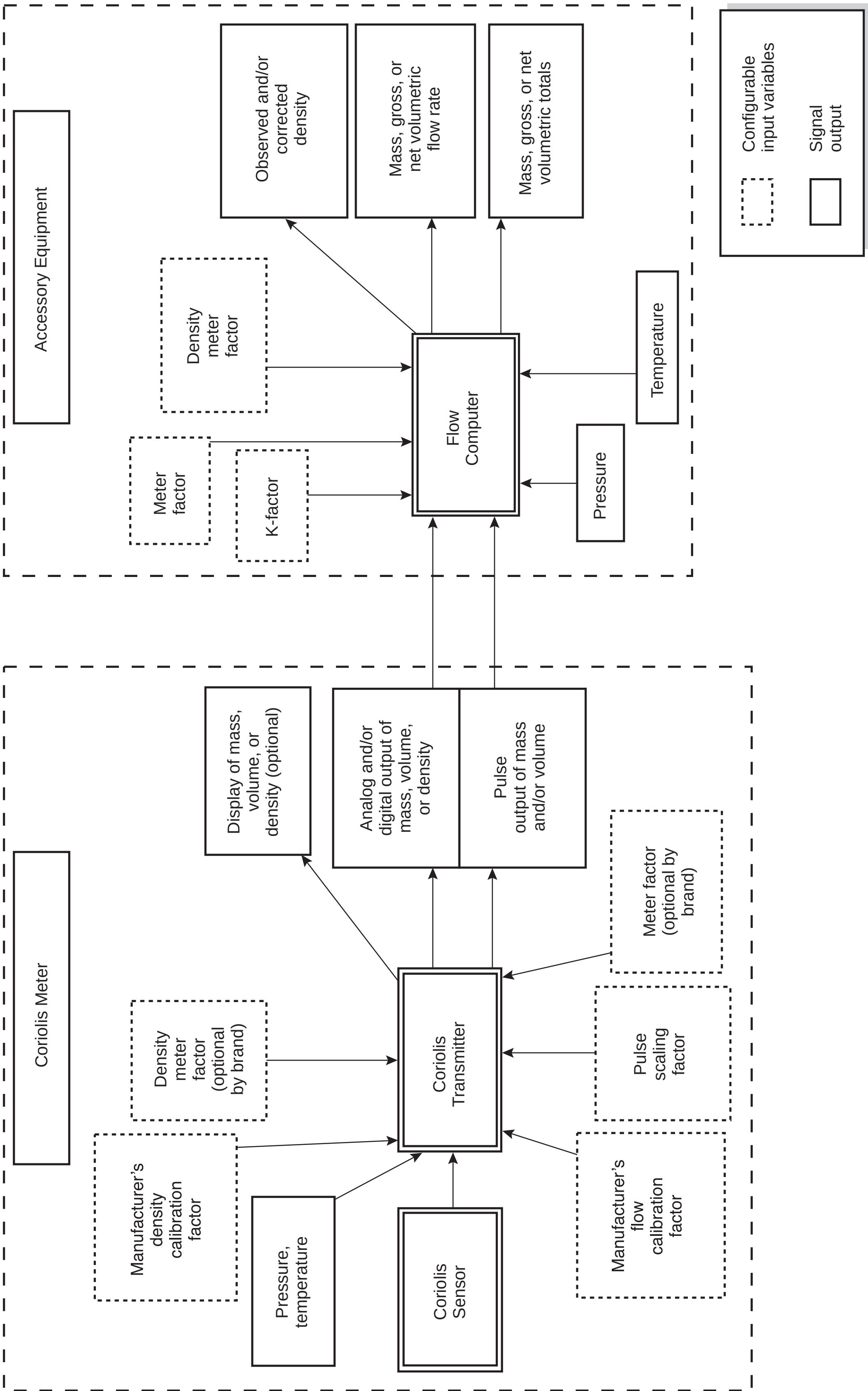


Figure 3—Factors Affecting Coriolis Meter Outputs

8 Operations/Performance

8.1 START-UP OF METERING SYSTEMS

8.1.1 Initial Fill

8.1.1.1 To avoid damage to the Coriolis meter, a spool piece should be installed in place of the meter each time new piping or fluids are introduced into the piping system that may contain deleterious materials from construction or maintenance activities.

8.1.1.2 During initial fill, cavitation, flashing, and fluid hammer caused by two-phase flow may cause damage to the sensor and should be avoided. Also, care must be taken to avoid damage to the Coriolis meter from shock loading caused by rapid opening or closing of valves.

8.1.2 Meter Zeroing

8.1.2.1 Even though the stream is not flowing, the flowmeter may indicate small fluctuating amounts of flow caused by the phase shift between the sensor pickoffs. The source of this non-zero phase shift signal may be mechanical noise, fluctuations within the Coriolis transmitter, or a combination of the two.

8.1.2.2 As part of the normal startup procedure for a Coriolis meter, a procedure is followed which establishes the stored zero value under non-flowing conditions. This process is typically called "zeroing" the flowmeter. Improper zeroing will result in measurement error. In order to zero the Coriolis meter, there must be no flow through the flow sensor. The sensor must be filled with the liquid to be measured at typical operating conditions. A typical zeroing procedure is as follows:

a. Open bypass valve if so equipped.
b. Stop flow through the sensor by closing the downstream double block-and-bleed valve and ensure seal integrity.
c. Close upstream valve if provided.

CAUTION: Blocking in the system can result in elevated pressures if the temperature rises.

d. Follow the zeroing procedure as specified by the manufacturer.

8.1.2.3 Errors arising from a shift in the observed zero offset from its initial value of zero after the completion of zeroing can be difficult to characterize or predict. The main sources of this error component are changes in stresses on the tube, usually caused by variations in temperature, pressure or density, or changes in the mounting conditions as a result of poor installation practices. Drift in electronic components in the transmitter can also result in this type of error. The error associated with a shift from the stored zero value of the meter is a constant offset in flow rate. Thus, this constant offset will result in a percent error that increases as the mass flow rate decreases. This error component can be minimized by rezeroing the meter when conditions change that could result in deleterious stresses being introduced into the flow sensor. In order to establish the need for rezeroing, the recommendations in 8.3 should be followed.

8.2 EFFECTS OF FLUID PROPERTIES, OPERATING AND INSTALLATION CONDITIONS ON CORIOLIS METER PERFORMANCE

Coriolis meters are related by the physical principle of the Coriolis effect, upon which they all depend (see Appendix A). However, the implementation of the Coriolis effect to achieve flow measurement is accomplished through many different tube configurations and electronic processing techniques. The resulting dissimilarities can be significant and will play a role in determining the specific features, as well as the performance level, of a given Coriolis meter.

In general, Coriolis meter accuracy is affected by conditions that change the flexibility of the oscillating tube and/or changes from the stored zero value. Fluid properties, operating conditions, and installation conditions can all affect Coriolis meter accuracy, as explained below.

8.2.1 Fluid Properties

a. Density—Changes in the fluid density may result in a shift in the zero value, which may affect meter accuracy. A significant change in fluid density, as determined by testing, may require rezeroing and reproving of the meter.
b. Viscosity—There is no data to show that changes in fluid viscosity affect meter accuracy directly. However, high viscosity fluids may affect the meter operation because of increased pressure drop. This may result in a need to operate at a lower percentage of maximum rated flow.

8.2.2 Operating Conditions

8.2.2.1 Flow rate variations—Flow rate can affect the density measurement because flow rate affects the frequency of vibration. If the measured density is not compensated for flow rate, volumetric flow measurement will be affected by flow rate.

8.2.2.2 Fluid temperature—Changes in fluid temperature affect the elasticity of the oscillating tube(s), stresses on piping near the meter, and fluid density, which may change the meter's flow rate indication at zero flow. The effect of temperature is systematic and can be characterized and compensated for to minimize its influence on the accuracy of the Coriolis meter. The size of this effect depends on meter design, piping design, and amount of temperature change.

8.2.2.3 Fluid pressure—Significant changes in pressure can affect the vibrational characteristics of the sensing tubes. The effect on meter calibration should be quantified by testing. Pressure sensitivity tends to increase with sensor size.

8.2.2.4 Multiple-phase flow streams (liquid/gas/solids)—Gas or air in a liquid stream is detrimental to accurate measurement and should be minimized or eliminated.

8.2.2.5 Flashing and/or cavitation within the flow sensor—Sufficient backpressure must be maintained on the meter to prevent flashing or cavitation in the meter (see 6.3.2). Tube geometries and sensor designs may create a low pressure area within the sensor which is lower than the outlet pressure. The manufacturer should be consulted when operating conditions are close to the vapor pressure of the liquid.

8.2.2.6 Coatings or deposits within the flow sensor—Heavy or nonuniform coating can cause a shift in flow calibration. Calibration is also affected if the density of the coating is significantly different than the density of the flowing fluid.

8.2.2.7 Erosion of the flow sensor—Abrasive solids can reduce the sensor tube thickness, which in severe cases can lead to calibration shifts and tube failure.

8.2.2.8 Corrosion of the flow sensor—Tube material compatibility with the fluid is essential for reliable service.

8.2.3 Effect of Fluid Properties

To achieve the level of accuracy required for custody transfer measurement, a Coriolis meter should be proved on a similar fluid and under similar operating and installation conditions as encountered in normal operations. If there are changes in the fluid properties or operating conditions, or there is an alteration to the flow sensor installation, a change in meter factor may result. Therefore, the Coriolis meter should be proved under the new conditions as soon as practical.

8.2.4 Installation Conditions

a. Vibration—Although Coriolis meters are designed to withstand vibration in pipeline installations, vibration near the frequency of the sensor (or one of its harmonics) can seriously affect the accuracy of the meter. The sensor should be installed as far as possible from vibration sources such as pumps, compressors, and motors. The manufacturer can advise on vibration mitigation methods.

b. Multiple flow sensor vibration interference (crosstalk)—Sensors of the same size and model operate at similar frequencies and can transmit vibrational energy to adjacent meters. This can cause measurement errors (see 6.3.7).

c. Pulsating flow—Hydraulic pulsation near the operating frequency of the sensor (or one of its harmonics) can also affect the accuracy of the meter. If this condition exists, pulsation dampeners may be helpful.

d. Mechanical stress—The sensor is susceptible to axial, radial, and torsional stresses caused by the piping installation (see 6.3.5).

e. Nonuniform velocity profile or swirl—Testing on several meter designs has indicated that nonuniform velocity profile, including swirl, has little or no effect on meter performance. This may not hold true for all meter designs.

f. Electromagnetic and radio frequency interference—Strong magnetic fields could affect the electromagnetic signals from the sensor. The meter sensor and electronics must not be installed near radio frequency or electromagnetic interference sources such as variable frequency motors, transformers, radio transmitters, large switchgear, or high voltage cables. The cable that connects the sensor and transmitter must not be installed near high voltage power cables or sources of EMI and RFI noise.

g. Voltage regulation—Install power line conditioning if the power to the electronics is not clean.

8.3 CONSIDERATIONS FOR CHANGING THE STORED ZERO VALUE IN THE FLOWMETER (REZEROING)

Periodic verification of the stored zero value is necessary to ensure that it is within limits defined by one or more of the following:

a. Manufacturer's recommendation.
b. Performance testing and monitoring.
c. Custody transfer agreements.

Rezeroing is necessary when the observed zero value is outside the specified zero offset limits. Since the meter should be proved after rezeroing, needless rezeroing should be avoided in order to minimize potential errors associated with meter factor reproducibility.

The stored zero value is determined by the Coriolis transmitter during the zeroing of the Coriolis meter. The stored zero value is used by the Coriolis transmitter in the calculation of the mass or gross volume flow rate from the meter. The observed zero offset is affected by:

a. Flow sensor installation conditions (e.g., upstream piping configuration, vibration, pulsation).
b. Pipeline stress (e.g., as induced by ambient temperature changes or maintenance on adjacent equipment).
c. Fluid temperature.
d. Fluid pressure.
e. Fluid density.
f. Ambient temperature at the Coriolis transmitter.
g. Change of Coriolis transmitter or the sensor.

The need for rezeroing the Coriolis meter will depend on the operating flow rate of the system.When the observed zero offset is very small, it has minimal effect on meter accuracy at the maximum rated flow rate of the meter. The influence of the zero offset becomes more significant at lower flow rates as illustrated by the Coriolis meter accuracy specification shown in Figure 1. In general, the error associated with the zero can be determined from the following equation:

$$Err_0 = \frac{q_0}{q_f} \times 100 \qquad (2)$$

where

Err_0 = zero error (%),

q_0 = observed zero value,

q_f = flow rate during normal operation.

8.3.1 The observed zero value will not normally be constant. Small variations are expected and a properly zeroed meter will fluctuate between positive and negative flow rates within the specified zero stability for the meter. Some manufacturers of Coriolis transmitters can display the mean zero value based on a configurable or predefined time period and may also provide a measure of the variability of that zero value.

8.3.2 The verification of the stored zero value requires that flow through the meter be stopped and then the indicated flow rate under this condition be monitored.

8.3.3 If a threshold is set in the Coriolis meter to suppress the indication below a certain value (low flow cut-off), then this value should be set to zero. Some Coriolis meter transmitters allow the user to view the actual flow rate independently of the low flow cut-off setting.

8.3.4 Verification of the stored zero value should be performed on a scheduled basis for a new or existing meter installation to determine rezeroing requirements. A log and possibly a graph should be maintained of all meter factors and zero adjustments (observed zero values – as found and as left) so that trending of Coriolis meter performance can be conducted.

8.4 MAINTENANCE

8.4.1 Flow Sensor

8.4.1.1 Repair of the flow sensor by other than the manufacturer or a certified repair facility is not recommended. The physical characteristics of the meter tube assembly can be altered or other damage can result from unauthorized repair, making the flow sensor unusable.

8.4.1.2 Following factory repair or replacement of the flow sensor, the new calibration factor for the repaired or replacement flow sensor should be entered into the Coriolis transmitter to match the sensor's unique characteristics. The calibration factor will be provided by the manufacturer. The Coriolis meter shall be rezeroed when returned to operation. A proving shall be accomplished as soon as practical after reinstallation of a repaired or replacement flow sensor.

8.4.1.3 An internal coating buildup on the sensor may have an adverse effect on density measurement, in which case the volume measurement will be affected. An internal coating buildup may also cause an observed zero offset. If this occurs, it may be necessary to clean the tubes, rezero the meter, and reprove the meter to establish a new meter factor. An indication of a possible internal coating condition can be an error in density measurement and/or an increase in drive power.

8.4.2 Coriolis Transmitter Repair or Replacement

Replacement of individual electronic components should only be done with assistance of the manufacturer. Replacement of circuit boards or the transmitter in total may affect the Coriolis meter's calibration. Users should ensure that the correct calibration and scaling factors are entered into the Coriolis transmitter. The Coriolis meter shall be rezeroed when returned to operation. A proving should be accomplished as soon as practical after any repair or replacement.

9 Proving

Field (in-situ) meter proving provides a means of establishing the meter factor for the Coriolis meter under actual operating conditions. There are various methods of applying the meter factor to indicate the actual quantity measured through the meter. The adjustment from indicated to actual quantity can be made by varying the meter factor or K-factor. These factors can reside in either the Coriolis transmitter or accessory equipment or be applied manually (see Figure 3). The preferred method is to apply a meter factor in the accessory equipment because of its audit trail capability. It is important that the method selected be used consistently.

Note: A Coriolis meter is calibrated by the manufacturer to determine one or more calibration factors that are entered into the Coriolis transmitter. These factors, although adjustable, should remain unchanged. Any factor changed that can affect the quantities measured by the meter must be retained in the audit trail. (See Section 10.) In applications where the flow rate varies during normal operation, it may be desirable to determine meter factors over a range of flow rates. The various meter factors can then be used to linearize the output from the Coriolis meter at varying flow rates. If the meter is used to measure bidirectional flow, a meter factor should be developed for each direction.

In addition to the initial proving of a Coriolis meter when installed in the field, periodic provings are necessary to confirm or reestablish the performance accuracy of the Coriolis meter. Meter provings should be performed if any of the following events occur:

a. Anytime the meter is rezeroed.

b. When the flow sensor installation or mounting conditions are modified.

c. When the Coriolis meter density measurement is calibrated, if the Coriolis meter is configured to indicate volume.
d. When the meter assembly is repaired.
e. When any of the assembly components have been replaced.
f. If a change in the fluid temperature, pressure, or density occurs beyond user-defined limits as determined from field experience.
g. When a flow rate change occurs that will cause a shift in the meter factor in excess of predetermined tolerance limits. The meter factor shift due to flow rate shall be determined from field proving experience.
h. At the request of parties involved in custody transfer.
i. On a schedule based on throughput, elapsed time, or contract.
j. Anytime the accuracy of a meter is in question.
k. When a change in the direction of flow through the meter occurs, if a meter factor has not been determined for the new direction.

The following sections detail proving methods, proving considerations, meter factor calculation, application of the proving results, and frequency of proving. Appendix E summarizes the key information presented in 9.1.

9.1 PROVING CONSIDERATIONS

9.1.1 Conditions

Proving conditions should be as close to the actual metering conditions as practical. Occasionally there may be exceptions to this requirement; however, the essential purpose of proving is to confirm the meter assembly performance at normal operating conditions.

The conditions under which a meter is proven are:

a. Stable product composition.
b. Stable product temperature and pressure.
c. Stable flow rate.
d. System valves and seals have been checked to ensure there is no leakage.
e. Trial runs have been conducted to evacuate any air/gas from the system.

Requirements for stability of temperature, pressure, and product composition will vary, depending on the proving method being employed and the properties of the fluid being measured.

If the Coriolis meter is configured to indicate mass and is being proven against a gravimetric tank prover, then the stability of the fluid properties is less critical because there is no need for a density determination.

If the Coriolis meter is configured to indicate mass and is being proven against a volumetric standard (volumetric tank prover, conventional pipe prover, small volume prover, or volumetric master meter), it is essential that the density remain stable. Stabilizing the density minimizes variations in density between the prover, meter and the density determination used in the calculation. Since the measured flowing density will be used to convert the prover volume to a mass or the Coriolis meter mass to a volume, any difference in the density and the true flowing density during the proving will result in errors in the calculations. This in turn will result in an error in the meter factor. Therefore, to minimize errors, it is extremely important that the density remains stable during the proving. As an alternative, the proving system may incorporate an online densitometer, calibrated at regular intervals. This density reference is particularly useful in eliminating errors, if the density varies during a proving.

The need for stable fluid density also applies to a Coriolis meter configured to indicate volume being proven against a gravimetric tank prover.

If there are density variations during the proving, it is likely that additional proving runs will be required to obtain an acceptable meter factor. The data should be reviewed for outliers. Any outlying points should be scrutinized to determine if they were caused by density variations during the proving. These points may not be valid and may result in an incorrect meter factor if used in the average. Good proving practices and good judgement will be required when trying to compare mass measurements versus volume measurements.

To determine fluid properties:

a. Pressure and temperature measurement devices should be installed as close to the prover and/or flow sensor as practical, so the measured temperature and pressure are representative of the fluid temperature and pressure in the prover and/or flow sensor.
b. If the density is calculated based on temperature and pressure, additional pressure and temperature measurements upstream and downstream of the Coriolis meter flow sensor may be required to determine the average density in the flow sensor.
c. Density measurement devices, if used, should be installed as close to the prover and/or flow sensor as practical, so that the measured density is representative of the fluid density in the prover and/or flow sensor.

9.1.2 Meter Proving Data

9.1.2.1 Density

When discussing density measurement it is important to distinguish between base density and flowing density, and when each is applied.

Base density, ρ_b, is the density of the fluid at the base conditions of temperature and pressure.

The base density is needed to determine the required correction factors for temperature and pressure, when both the prover and the Coriolis meter are configured to indicate volume.

Flowing density, ρ_f, is the density of the fluid at actual flowing temperature and pressure.

Accurate determination of the flowing density, ρ_f, is critical to successfully prove a Coriolis meter whenever the proving device and the Coriolis meter do not measure in the same flow units: one measures mass, the other measures volume. Variations in density and errors in the determination of density are the greatest source of error when performing volumetric versus mass proving. Proving a Coriolis meter on a mass-to-mass or a volume-to-volume basis will reduce the uncertainty caused by errors in density determination.

Determination of a Coriolis meter density factor is not needed if the Coriolis meter is configured to measure volume and is being proved against a volumetric prover. For this case, the Coriolis meter factor will include the combined errors for the mass flow measurement and the density measurement. The purpose of determining a density factor would be to identify what portion of the meter factor can be attributed to each component: the mass flow and the density measurement. Even in this case, care must be taken to ensure that the density used for calculating the correction factors (*CTL*, *CPL*) is accurate. In addition, in some cases an inaccurate density may result in worsened linearity of the output volume flow rate signal.

When required, means to determine density of the flowing fluid during proving shall be incorporated in the metering system or in the prover. If the density measurement is being used to convert a volume to a mass or a mass to a volume then the accuracy of the meter factor determination will be a reflection of the accuracy and precision of the density measurement. As an illustration: if the density measurement error is 2.0 kg/m^3, then the meter factor determination will be offset by 0.2% (based on a density of 1000.0 kg/m^3). The density measurement accuracy will depend upon the requirements of the particular application.

The following methods are available to determine the fluid density:

a. Hydrometer—Refer to API *MPMS* Chapters 8 and 9.

b. On-line density from either a Coriolis meter or a separate density meter, which has been verified against an accepted density reference. Refer to API *MPMS* Chapter 14.6.

c. Sample run on a laboratory density meter. Sampling practices should be performed in accordance with API *MPMS* Chapter 8.

d. Sample, composition analysis, and calculated density. This is limited to light or pure hydrocarbons whose composition and physical properties are well known.

e. Pycnometer—Use of the pycnometer should follow API *MPMS* Chapter 14.6. The use of a pycnometer may not be practical for every liquid hydrocarbon application.

f. Equation of state if fluid composition is consistent.

9.1.2.2 Temperature and Pressure

The temperature and pressure measurements should be precise enough to allow accurate determination of the applicable correction factors for both the prover and the fluid. The requirements for temperature and pressure measurement precision will vary depending on which correction factors are being applied in the determination of the meter factor. For determination of corrections for the thermal expansion of the liquid CTL_p or CTL_m, the required temperature measurement precision will be determined based on the thermal expansion properties of the liquid. For determination of corrections for the pressure effect of the liquid CPL_p or CPL_m, the required pressure measurement precision will be determined based on the compressibility of the liquid. Experience with the specific liquid will be necessary to establish requirements for temperature and pressure measurement precision. Refer to API *MPMS* Chapter 7 for information on temperature determination.

9.1.3 Number of Runs for a Proving

The required number of test runs for each proving varies depending on:

a. Type of proving method being employed.

b. Coriolis meter type and size.

c. Operating flow rate and quantity of fluid accumulated during each proving run.

Experience with the meter/proving system will ultimately establish the number of runs required. Typical examples of the number of runs performed for each proving method are given in Table 1.

Refer to API *MPMS* Chapters 12.2.3 and 13.1 for more details regarding the number of runs required to achieve the same uncertainty as five runs at 0.05% repeatability.

The number of runs required to achieve the desired tolerance for meter factor uncertainty should be defined and agreed to by all contractual parties. Once established, the same procedure should be followed consistently in order to better track the performance of the meter. These requirements should not differ from other custody transfer meters for similar applications.

9.1.4 Repeatability

The repeatability is used as an indication of whether the proving results are valid.

There are two general methods of calculating the repeatability: one associated with the Average Data Method and the other associated with the Average Meter Factor Method as described in API *MPMS* Chapter 12.2.3.

The Average Meter Factor Method is recommended for determining repeatability because it reduces the influence of changing fluid density and/or prover volume from the repeatability calculations. There can still be other sources of non-

Table 1—Typical Number of Proving Runs

Proving Method	Number of Runs
Conventional Pipe Prover	5 consecutive runs*
Small Volume Prover	2 – 5 runs of multiple passes each
Tank Prover	2 consecutive runs
Master Meter	2 consecutive runs

*Run defined as round trip for bidirectional prover

repeatability. If a density measurement device is used or density is determined from tables or equations, the repeatability will reflect the repeatability of the density determination along with the repeatability of the Coriolis meter.

Note: Some Coriolis meters may produce a nonuniform or burst pulse output which can exhibit poor repeatability when proved. See Chapter 4 for details.

9.1.5 Reproducibility

Reproducibility is defined as the ability of a meter and prover system to reproduce results over a long period of time in service where the range of variation of pressure, temperature, flow rate, and physical properties of the metered fluid is negligibly small. The expected reproducibility is generally determined from experience with each individual proving system. A change in the meter factor greater than the user-defined limits should be considered suspect and every effort should be made to ensure that the Coriolis meter and proving system are functioning properly. Statistical control charting of meter factors will be valuable in analyzing the reproducibility of Coriolis meters and determining the required frequency of proving.

If the Coriolis sensor, transmitter, or Manufacturer Calibration Factors have changed since the last prove, especially if the Calibration Factors are not consistent with those provided by the manufacturer for the sensor in use, a large unexpected variation in meter factor may occur. In this case, a careful review of the sensor serial number, the Calibration Factors supplied by the manufacturer for that sensor, and the Calibration Factors actually contained in the Coriolis transmitter should be performed.

9.1.6 Scheduled Frequency of Proving

Frequency of proving is primarily a function of regulatory and contractual requirements. Some contracts allow adjustment of the frequency of proving.

9.1.7 Proving Methods

The methodologies used to prove a Coriolis meter are direct mass, inferred mass, and volumetric. These methodologies differ significantly in the way they determine the reference quantity of fluid (prover quantity) for a proving. The reference quantity should match the engineering units of the meter's output.

9.1.7.1 Direct Mass Proving

In a direct mass proving, the mass of fluid in the prover (reference quantity) is physically measured. The mass measured by the prover is then compared to the mass measured by the meter to generate a meter factor.

The common methods used are:

a. Gravimetric: The reference quantity of fluid is weighed on a scale and compared to a meter's indication of mass. This method is not covered in any API *MPMS* standard.

Reference: Appendix C, Figure C-3; Appendix E, Table E-1, Equation A; and Appendix E.1.1, Equation E-3.

b. Mass Master Meter: The reference quantity of fluid is obtained from a mass master meter and compared to a meter's indication of mass. This method is not covered in any API *MPMS* standard.

Reference: Appendix C, Figure C-6; Appendix E, Table E-1, Equation A; and Appendix E.1.1, Equation E-3.

9.1.7.2 Inferred Mass Proving

In an inferred mass proving, the mass of the fluid in the prover (reference quantity) is calculated rather than physically measured as in 9.1.7.1. The mass is calculated by multiplying the volume and density of the reference fluid together. The inferred mass is then compared to the meter's indicated mass to generate a meter factor. The accuracy of this method is equally dependent upon the accuracy of both the volume and the density measurements.

The volumetric proving methods in 9.1.7.3 should be used to determine the reference volume in an inferred mass proving.

The selection of a method to determine a reference density (density at the prover) is critical to a successful and accurate prove. Section 9.1.2.1 lists several methods to determine density. These methods should be closely reviewed as to their accuracy and ability to measure the density under the conditions (pressure and temperature) present at the prover. If the density varies during a prove, it must be averaged for each prover run or pass (averaged between the prover switches). The sampling frequency and the density averaging method also influences the overall accuracy of this method.

For inferred mass proving, the preferred method for determining the fluid density at the prover is to use an on-line density meter. The density meter must be installed, operated, and calibrated per API *MPMS* Chapter 14.6. The resulting output of this meter should be averaged during each prover run or pass.

Reference: Appendix C, Figures C-1, C-2, C-4, C-5; Appendix E, Table E-1, Equation B-1; and Appendix E.1.2, Equation E-4.

9.1.7.3 Volumetric Proving

In a volumetric proving, the volume of fluid in the prover (reference quantity) is determined by the methods listed below. The prover volume is then compared to the meter's indicated volume to generate a meter factor.

a. Conventional Pipe Prover

Reference: Appendix D, Figure D-1; Appendix E, Table E-1, Equation C; and Appendix E.1.3, Equation E-5.

b. Small Volume Prover

Reference: Appendix D, Figure D-2; Appendix E, Table E-1, Equation C; and Appendix E.1.3, Equation E-5.

c. Volumetric Master Meter Prover

Reference: Appendix D, Figure D-5; Appendix E, Table E-1, Equation C; and Appendix E.1.3, Equation E-5.

d. Volumetric Tank Prover

Reference: Appendix D, Figure D-4; Appendix E, Table E-1, Equation C; and Appendix E.1.3, Equation E-5.

e. Gravimetric Tank Prover

Reference: Appendix D, Figure D-3; Appendix E, Table E-1, Equation D; and Appendix E.1.4, Equation E-6. This method is not covered in any API *MPMS* standard.

f. Mass Master Meter Prover

Reference: Appendix D, Figure D-6; Appendix E, Table E-1, Equation D; and Appendix E.1.4, Equation E-6. This method is not covered in any API *MPMS* standard.

9.1.7.4 Laboratory Versus In-situ Proving

Questions often arise concerning the differences between proving or calibrating a meter in the laboratory (bench) versus in-situ (field). These two proving locations can produce different results in a meter and cannot necessarily be interchanged without producing some measurement error.

A bench prove is usually performed under ideal conditions and on a stable fluid (water). This minimizes the effects of outside influences on the meter's accuracy.

An in-situ proving verifies the meter's accuracy under operating conditions. Operating conditions can affect a meter's accuracy and repeatability. An in-situ proving compensates or corrects for those influences. Conditions that might affect the in-situ meter proving are:

a. Mechanical stress on the meter.
b. Flow variations.
c. Piping configurations.
d. Fluid pressure and extreme temperatures.
e. Ambient temperature changes.
f. Fluid type and composition.

9.1.7.4.1 Zeroing Meters for Laboratory Proving

It is impractical to duplicate the mechanical stresses of a field installation in a lab or bench proving. As this change will affect the meter's zero, it is necessary to minimize the change in calibration by zeroing the meter twice: prior to performing the bench prove once it is installed in the proving apparatus and again after the meter is installed back at its field location.

9.1.8 Manufacturer Calibration Factors

As described in Section 6, Manufacturer Calibration Factors are entered into the Coriolis transmitter which are unique to each particular sensor. If the sensor, transmitter, or calibration factors have been changed since the last prove, a shift in meter factor may occur. To ensure that no unexplained meter factor shift can occur, it is advisable that the operator confirms that there has been no change in the Manufacturer Calibration Factors since the last prove. These values should be documented as part of each proving report.

9.1.9 Correcting Coriolis Meter Indication

The result of a meter proving will be a new or reaffirmed meter factor. It is possible to revise the K-factor but this method is not preferred. The meter factor (*MF*) may be entered in accessory equipment, for some manufacturer's equipment, in the Coriolis transmitter, or applied manually to the quantity indicated.

If the K-factor is revised, the preferred method of correction is to change the K-factor in the accessory equipment.

Unlike turbine or positive displacement meters, Coriolis sensors do not, by the nature of their operation, generate a raw pulse output representing either mass or volume. The Coriolis transmitter performs internal calculations to determine a flow rate and an appropriate frequency to represent that flow rate. The exact relationship between frequency and flow rate is configurable by the user. Put in other terms, the Coriolis transmitter outputs a pulse each time a user-configured mass or volume of fluid passes through the meter. A

Pulse Scaling Factor (relating pulses to quantity) or other variables from which a *PSF* may be calculated are entered into the Coriolis transmitter, usually in such a manner that the output has a convenient relationship such as 1000 pulses/barrel.

When the preferred method of correction is used, and the meter factor is varied after a prove, the K-factor in the accessory equipment will match the Pulse Scaling Factor entered in the Coriolis transmitter.

When the K-factor is revised, the meter factor must be set to one (in both the Coriolis transmitter and the accessory equipment) and the Pulse Scaling Factor in the Coriolis transmitter must remain as it was during the prove. Only the K-factor in the accessory equipment is changed.

10 Auditing and Reporting Requirements

An electronic liquid measurement system (ELM) shall be capable of establishing an audit trail by compiling and retaining sufficient information for the purpose of verifying custody transfer quantities. Since the accuracy of an ELM system is also affected by the calibration provided by a prover, an audit trail is also necessary for the prover. The audit trail shall include Quantity Transaction Records, Configuration Logs, Event Logs, Alarm Logs, corrected Quantity Transaction Records, and field test records. **Audit trail information may be retained in paper or electronic format.** Refer to API *MPMS* Chapter 21.2, "Electronic Liquid Measurement" for guidance and definitions.

Audit trail requirements apply only to data which will affect the custody transfer quantity. Off-site systems often perform diverse functions other than those described within the standard. These other functions are not a part of this standard. Only data associated with measurement is to be included under auditing and reporting requirements.

The following subsections define the purpose of each record type, the required data contained therein, and the minimum retention time for that information so that the integrity of custody transfer quantities calculated by the flow computation device may be verified.

The primary reason for retaining historical data is to provide support for the current and prior quantities reported on the measurement and quantity statements for a given accounting cycle. In the event of a meter system failure or data corruption, it may be possible to use recent historical meter data to estimate quantities and/or corrections to corrupted data. Where such estimated values are used for a custody transfer, it is essential that the original and historical data be retained so that all interested parties can verify the validity of the estimated data. The method or methods of determining estimates of corrected values is beyond the scope of this standard.

10.1 CONFIGURATION LOG

See API *MPMS* Chapter 21.2, "Electronic Liquid Measurement" for the general contents of the Configuration Log. In addition, the Pulse Scaling Factor, Manufacturer's Density Calibration Factor(s), and the Manufacturer's Flow Calibration Factor(s) must be included along with documentation relating the Manufacturer's Factors to a specific flow sensor (such as by serial number).

10.2 QUANTITY TRANSACTION RECORD (QTR)

See API *MPMS* Chapter 21.2, "Electronic Liquid Measurement" for the general contents of the Quantity Transaction Record. There are no special requirements for Coriolis meters.

10.3 EVENT LOG

See API *MPMS* Chapter 21.2, "Electronic Liquid Measurement" for the general contents of the Event Log. In addition, the zeroing of the Coriolis meter must be recorded, including the date and time the meter was zeroed, along with the as-found and as-left observed zero value in engineering units. Recording some measure of zero stability is also useful.

10.4 ALARM AND ERROR LOG

There are no special requirements for the Alarm and Error Logs for Coriolis meters other than those specified in API *MPMS* Chapter 21.2, "Electronic Liquid Measurement."

APPENDIX A—PRINCIPLE OF OPERATION

Coriolis meters operate on the principle that inertia forces are generated whenever a particle in a rotating body moves relative to the body in a direction toward or away from the center of rotation. This principle is shown in Figure A-1.

A particle of mass δm slides with constant velocity v in a tube T that is rotating with angular velocity ω about a fixed point P. The particle acquires two components of acceleration:

a. A radial acceleration a_r (centripetal) equal to $\omega^2 r$ and directed towards P.
b. A transverse acceleration a_t (Coriolis) equal to $2\omega v$ at right angles to a_r and in the direction shown in Figure A-1.

To impart the Coriolis acceleration a_t to the particle, a force of magnitude $2\omega v \delta m$ is required in the direction of a_t. This comes from the oscillating tube. The reaction of this force back on the oscillating tube is the Coriolis Force $F_c = 2\omega v \delta m$.

From the illustration it can be seen that when a fluid of density ρ flows at constant velocity v along an oscillating tube rotating as in Figure A-1, any length Δx of the oscillating tube experiences a transverse Coriolis force of magnitude $\Delta F_c = 2\omega v \rho A \Delta x$, where A is the cross-sectional area of the oscillating tube interior. Since the mass flow rate q_m can be expressed as:

$$\dot{m} = \frac{dm}{dt} = q_m = \rho A V \qquad \text{(A-1)}$$

We then have that

$$\Delta F_C = 2\omega q_m \Delta x \qquad \text{(A-2)}$$

Hence we see that (direct or indirect) measurement of the Coriolis force exerted by the flowing fluid on a rotating tube can provide a measure of the mass flow rate. This is the basic principle of the Coriolis meter.

If the vibrating tube(s) of a Coriolis meter is (are) viewed in a polar coordinate system, it (they) exhibit(s) angular velocities in the range $-\omega \le 0 \le \omega$ in a continuously varying sinusoidal fashion. With flow through the tube, a Coriolis force that also varies sinusoidally is generated. The tube is anchored at or near the points of flow entry and exit and is vibrated in such a way that the maximum amplitude of vibration is at the midpoint between the two anchored points. As a result, the Coriolis forces generated on the upstream and downstream halves of the tube are of equal magnitude but opposite direction. These opposing forces impart a bending moment on the tube that is superimposed on the vibration induced by the Coriolis meter's drive system.

The bending moment causes the vibrating tube to distort asymmetrically. The magnitude of the distortion is directly proportional to the mass flow rate of the flowing fluid. Coriolis meter manufacturers use various proprietary techniques to monitor the magnitude of the distortion and process the measured signals into appropriate analog and/or digital outputs.

In simple terms, the fundamental measurement of a Coriolis meter is a respective offset in position of the upstream portion of the oscillating tube to the downstream portion of the tube. This measurement is accomplished with position or velocity measurement sensors upstream and downstream of the driving mechanism. As mass flow rate through the oscillating tube increases, the relative offset in position from the upstream portion of the tube to the downstream portion increases.

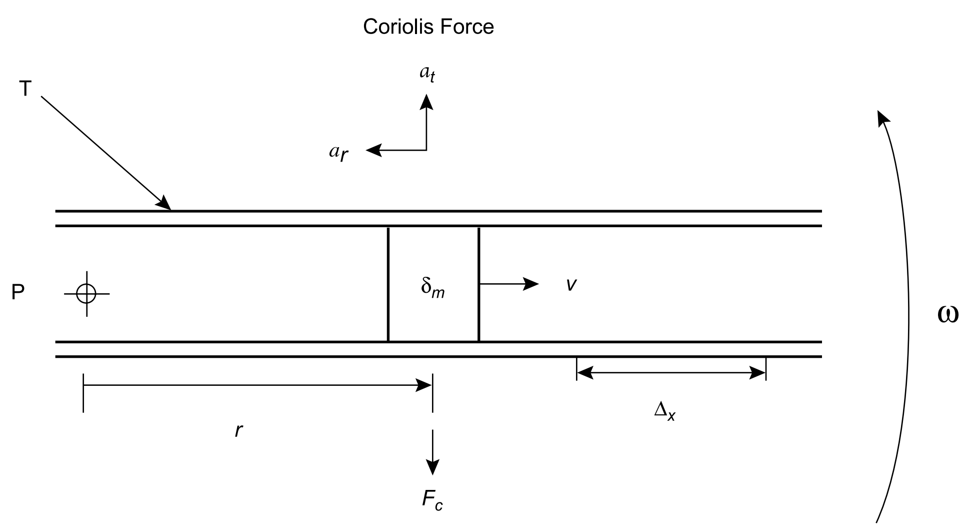


Figure A-1—Coriolis Force Illustration

APPENDIX B—FACTORY CALIBRATION

During factory calibration, the output of a Coriolis meter under test is compared with a standard of higher accuracy to establish an initial calibration factor. Coriolis meters are typically factory calibrated on gravimetric flow stands that are traceable to a national standard. The test liquid, commonly water, flows through the Coriolis meter and is collected in a tank on a weigh scale (see Figure B-1). The mass readout from the Coriolis meter is compared to the weigh scale mass indication, corrected for buoyancy effect. A repeatable calibration factor(s), within the meter's accuracy tolerance, is established. The calibration factor(s) converts the Coriolis meter output to a flow rate in desired engineering units.

A separate calibration is performed on the density measurement of the Coriolis meter. Density of the fluid contained within the vibrating tubes is inversely proportional to the Tube Frequency of the sensor assembly. This relationship is represented by the following equation.

$$\rho \propto \frac{1}{f^2} \tag{B-1}$$

where

ρ = Flowing Density,

f = Tube Frequency, resonant frequency of the Coriolis sensor assembly.

Factory calibration of densitometers involves measurement of the tube frequency from the Coriolis meter and the density value of the calibration fluid while the Coriolis meter is full of fluid, either in a static or flowing state. Most densitometers are calibrated with two or more fluids (generally air and water) whose density values are well defined and relatively stable. Density values for the fluid(s) can be determined either by using equations of state or calculations from laboratory data or by incorporating a transfer standard to determine the density of the fluid during calibration.

For convenience, and to establish traceability to acceptable standards, the test fluids may be referenced to base conditions of temperature and pressure using equations outlined in API *MPMS* Chapter 14.6. All the factory parameters should be measured with instruments traceable to NIST or other internationally recognized standards organizations.

The factory calibration produces the coefficients that define the density per time period squared relationship for each densitometer. This equation is then linearly interpolated or extrapolated by the Coriolis transmitter to determine fluid density in the field.

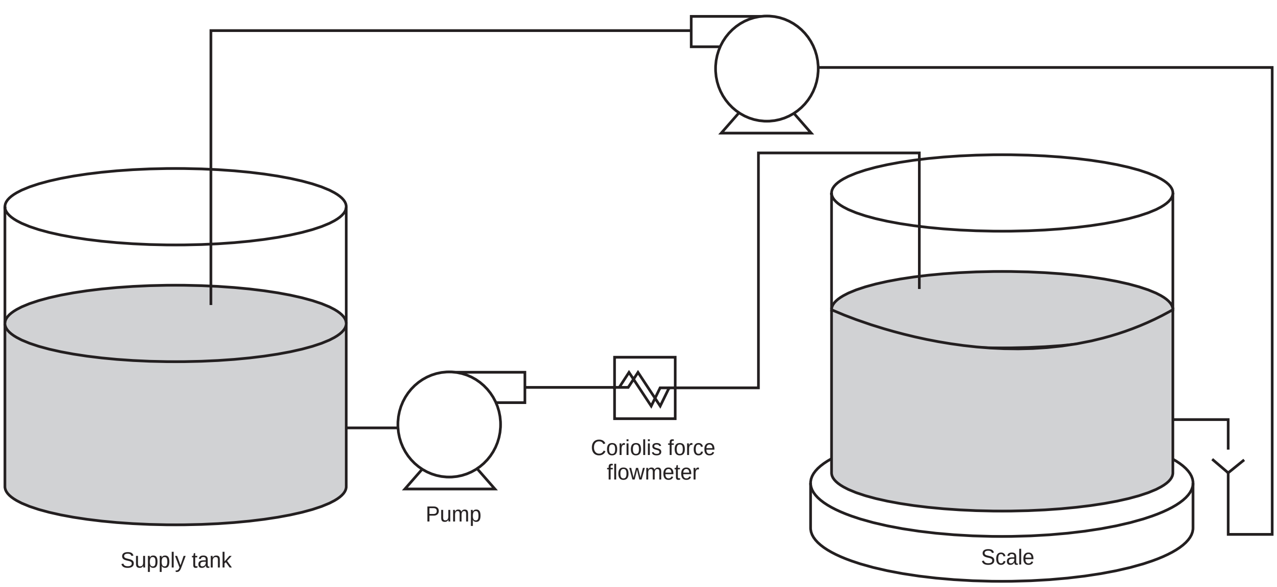


Figure B-1—Calibration System Schematic

APPENDIX C—PROVING FORMS FOR METERS WITH MASS OUTPUTS

As described in Section 9, a Coriolis meter can be proved with conventional pipe or small volume provers, gravimetric or volumetric tank provers, and master meters. A Coriolis meter can be configured to indicate either mass or volume. The proving calculations will differ for mass and volume configurations. The different proving methods for meters configured to indicate mass are detailed in the following proving forms. Proving forms for meters configured to indicate volume are given in Appendix D.

It should be understood that the prover forms shown in this appendix are intended to serve as examples to illustrate the sequence of calculations. In order to minimize confusion in the calculations, only one set of measurement units are presented in these example forms. Individuals who will be performing provings on Coriolis meters are encouraged to develop their own proving forms to include other types of information as appropriate. Table C-1 below provides additional conversion factors for use in the development of appropriate prover forms for a variety of measurement units.

Table C-1—Density Conversion Factors

Coriolis Meter Mass Measurement Units	Prover Volume Measurement Units	Density Measurement Units (note)	Density Conversion Factor
lb	Gallons	kg/m^3	$lb/gal = 0.008345406 \times kg/m^3$
lb	Barrels	kg/m^3	$lb/bbl = 0.3505071 \times kg/m^3$
lb	Cubic feet	kg/m^3	$lb/ft^3 = 0.06242797 \times kg/m^3$
kg	Cubic meters	g/cc	$kg/m^3 = 1000 \times g/cc$
kg	Cubic meters	kg/m^3	$kg/m^3 = 1.00 \times kg/m^3$
kg	Liters	kg/m^3	$kg/liter = 0.001 \times kg/m^3$

Note: Where the Relative Density (Specific Gravity) is relative to water at 60°F and 14.696 psia, density (g/cc) = SG $\times$ 0.999014. Where the Relative Density (Specific Gravity) is relative to water at 15°C and 101.325 kPa, density (g/cc) = SG $\times$ 0.999098, or density (kg/m^3) = SG $\times$ 999.098.

Table C-2—Buoyancy Correction Factors
(Not applicable to closed, pressurized vessels)

Density (Kg/m^3)	Correction Factor
2000	1.0005
1900	1.0005
1800	1.0005
1700	1.0006
1600	1.0007
1500	1.0007
1400	1.0007
1300	1.0008
1200	1.0009
1100	1.0009
1000	1.0011
900	1.0012
800	1.0014
700	1.0016
600	1.0019
500	1.0023

PROVER INFORMATION

CERTIFICATION DATE: ____________ (YY/MM/DD) PROVER COMPANY ____________

BASE PROVER VOLUME ____________ (BARRELS) PROVER UNIT SERIAL NO. ____________

METER INFORMATION

SERIAL NO. ____________ MANUFACTURER ____________

METER ID ____________ MODEL ____________

LOCATION ____________

MANUFACTURER FLOW CALIBRATION FACTOR(S) ____________

PULSE SCALING FACTOR ____________ (PULSES/lb) *KF* (In Associated Equipment) ____________ (PULSES/lb)

PROCESS CONDITIONS

FLOW RATE ____________ (lb/MIN) ____________ (bbl/HR) FLUID TYPE ____________

DENSITY SOURCE ____________ (DEVICE/LOCATION)

PROVE INFORMATION

PREVIOUS METER FACTOR ____________ (DATE OF PROVE YY/MM/DD) ____________ (FACTOR)

RUN NUMBER	**1**	**2**	**3**	**4**	**5**
TOTAL METER PULSES					
PROVER DENSITY (kg/m^3)					
PROVER TEMPERATURE (°F)					
CTS_p					
PROVER PRESSURE (psig)					
CPS_p					
PROVER VOLUME (Bbl) = (Base Prover Volume * CTS_p * CPS_p)					
PROVER MASS (lb) = (Prover Volume * Prover Density * 0.3505071)					
CORIOLIS METER MASS (lb) = (Pulses/Mass K-Factor)					
METER FACTOR = (Prover Mass/Coriolis Meter Mass)					

AVERAGE METER FACTOR ☐ LOCATION OF ENTRY (of Meter Factor) ____________ TRANSMITTER/CALC. DEVICE

PERCENT REPEATABILITY ____________ ((MAX – MIN)/MIN) * 100 ZERO VERIFIED? ________ YES/NO ________ AS FOUND ________ AS LEFT

PROVER ____________ (SIGN) ____________ (DATE) WITNESS ____________ (SIGN) ____________ (DATE)

Figure C-1—Proving Calculations
Conventional Pipe Prover—Coriolis Meter Mass

PROVER INFORMATION

CERTIFICATION DATE: ____________ (YY/MM/DD) PROVER COMPANY ____________

BASE PROVER VOLUME ____________ (BARRELS) PROVER UNIT SERIAL NO. ____________

METER INFORMATION

SERIAL NO. ____________ MANUFACTURER ____________

METER ID ____________ MODEL ____________

LOCATION ____________

MANUFACTURER FLOW CALIBRATION FACTOR(S) ____________

PULSE SCALING FACTOR ____________ (PULSES/lb) *KF* (In Associated Equipment) ____________ (PULSES/lb)

PROCESS CONDITIONS

FLOW RATE ____________ (lb/MIN) ____________ (bbl/HR) FLUID TYPE ____________

DENSITY SOURCE ____________ (DEVICE/LOCATION)

PROVE INFORMATION

PREVIOUS METER FACTOR ____________ (DATE OF PROVE YY/MM/DD) ____________ (FACTOR)

NUMBER OF PASSES/RUN ____________

RUN NUMBER	**1**	**2**	**3**	**4**	**5**
AVERAGE INTERPOLATED PULSES (Meter)					
AVERAGE PROVER DENSITY (kg/m^3)					
AVERAGE PROVER TEMPERATURE (°F)					
CTS_p					
AVERAGE PROVER PRESSURE (psig)					
CPS_p					
PROVER VOLUME (Bbl) = (Base Prover Volume * CTS_p * CPS_p)					
PROVER MASS (lb) = (Prover Volume * Prover Density * 0.3505071)					
CORIOLIS METER MASS (lb) = (Pulses/Mass K-Factor)					
METER FACTOR = (Prover Mass/Coriolis Meter Mass)					

AVERAGE METER FACTOR ____________ LOCATION OF ENTRY (of Meter Factor) ____________ TRANSMITTER/CALC. DEVICE

PERCENT REPEATABILITY ____________ ((MAX – MIN)/MIN) * 100 ZERO VERIFIED? ________ YES/NO ________ AS FOUND ________ AS LEFT

PROVER ____________ (SIGN) ____________ (DATE) WITNESS ____________ (SIGN) ____________ (DATE)

Figure C-2—Proving Calculations
Small Volume Prover—Coriolis Meter Mass

PROVER INFORMATION

CERTIFICATION DATE: ______________ (YY/MM/DD) PROVER COMPANY ______________

WEIGH SCALE RESOLUTION ______________ (LBS.) PROVER UNIT SERIAL NO. ______________

TARGET TEST QUANTITY ______________ (LBS.)

METER INFORMATION

SERIAL NO. ______________ MANUFACTURER ______________

METER ID ______________ MODEL ______________

LOCATION ______________

MANUFACTURER FLOW CALIBRATION FACTOR(S) ______________

PULSE SCALING FACTOR ______________ (PULSES/lb) *KF* (In Associated Equipment) ______________ (PULSES/lb)

PROCESS CONDITIONS

FLOW RATE ______________ (lb/MIN) ______________ (bbl/HR) FLUID TYPE ______________

DENSITY SOURCE ______________ (DEVICE/LOCATION)

PROVE INFORMATION

PREVIOUS METER FACTOR ______________ (DATE OF PROVE YY/MM/DD) ______________ (FACTOR)

RUN NUMBER	**1**	**2**	**3**	**4**	**5**
WEIGH SCALE TOTAL (lb)					
TOTAL METER PULSES					
PROVER FILL TIME (sec)					
PROVER DENSITY (kg/m^3)					
BUOYANCY FACTOR (Table C-2)					
CORRECTED SCALE MASS (lb) = (Scale Total * Buoyancy Factor)					
METER MASS (lb) = (Pulses/Mass K-Factor or Visual Totalizer Display)					
METER FACTOR = (Corrected Scale Mass/Meter Mass)					

AVERAGE METER FACTOR ☐ LOCATION OF ENTRY (of Meter Factor) ______________ TRANSMITTER/CALC. DEVICE

PERCENT REPEATABILITY ______________ ((MAX – MIN)/MIN) * 100 ZERO VERIFIED? ______ YES/NO ______ AS FOUND ______ AS LEFT

PROVER ______________ (SIGN) ______________ (DATE) WITNESS ______________ (SIGN) ______________ (DATE)

Figure C-3—Proving Calculations
Gravimetric Tank Prover—Coriolis Meter Mass

PROVER INFORMATION

CERTIFICATION DATE: ____________ (YY/MM/DD) PROVER COMPANY ____________

PROVER RESOLUTION ____________ (BARRELS) PROVER UNIT SERIAL NO. ____________

BASE PROVER VOLUME ____________ (BARRELS)

METER INFORMATION

SERIAL NO. ____________ MANUFACTURER ____________

METER ID ____________ MODEL ____________

LOCATION ____________

MANUFACTURER FLOW CALIBRATION FACTOR(S) ____________

PULSE SCALING FACTOR ____________ (PULSES/lb) *KF* (In Associated Equipment) ____________ (PULSES/lb)

PROCESS CONDITIONS

FLOW RATE ____________ (lb/MIN) ____________ (bbl/HR) FLUID TYPE ____________

DENSITY SOURCE ____________ (DEVICE/LOCATION)

PROVE INFORMATION

PREVIOUS METER FACTOR ____________ (DATE OF PROVE YY/MM/DD) ____________ (FACTOR)

RUN NUMBER	**1**	**2**	**3**	**4**	**5**
TOTAL METER PULSES					
PROVER FILL TIME (sec)					
PROVER DENSITY (kg/m^3)					
PROVER TEMPERATURE (°F)					
CTS_p					
PROVER PRESSURE (psig)					
CPS_p					
PROVER VOLUME (Bbl) = (Base Prover Volume * CTS_p * CPS_p)					
PROVER MASS (lb) = (Prover Volume * Prover Density * 0.3505071)					
METER MASS (lb) = (Pulses/Mass K-Factor or Visual Totalizer Display)					
METER FACTOR = (Prover Mass/Meter Mass)					

AVERAGE METER FACTOR ☐ LOCATION OF ENTRY (of Meter Factor) ____________ TRANSMITTER/CALC. DEVICE

PERCENT REPEATABILITY ____________ [(MAX – MIN)/MIN] * 100 ZERO VERIFIED? ______ YES/NO ______ AS FOUND ______ AS LEFT

PROVER ____________ (SIGN) ____________ (DATE) WITNESS ____________ (SIGN) ____________ (DATE)

Figure C-4—Proving Calculations
Volumetric Tank Prover—Coriolis Meter Mass

PROVER INFORMATION

CERTIFICATION DATE: ____________ (YY/MM/DD) PROVER COMPANY ____________

MASTER METER K-FACTOR ____________ (PULSES/lb) MANUFACTURER ____________

SERIAL NO. ____________ MODEL ____________

METER INFORMATION

SERIAL NO. ____________ MANUFACTURER ____________

METER ID ____________ MODEL ____________

LOCATION ____________

MANUFACTURER FLOW CALIBRATION FACTOR(S) ____________

PULSE SCALING FACTOR ____________ (PULSES/lb) *KF* (In Associated Equipment) ____________ (PULSES/lb)

PROCESS CONDITIONS

FLOW RATE ____________ (lb/MIN) ____________ (bbl/HR) FLUID TYPE ____________

DENSITY OBTAINED BY ____________ (DEVICE/LOCATION)

PROVE INFORMATION

PREVIOUS METER FACTOR ____________ (DATE OF PROVE YY/MM/DD) ____________ (FACTOR)

RUN NUMBER	**1**	**2**	**3**	**4**	**5**
TOTAL MASTER METER PULSES					
TOTAL METER PULSES					
DENSITY AT MASTER METER (kg/m^3) (at flowing conditions)					
TEST TIME (sec)					
MASTER METER VOLUME (Bbl) = (Master Meter Pulses/Master K-Factor)					
MASTER METER MASS (lb) = (Master Volume * Master Density * 0.3505071)					
CORIOLIS METER MASS (lb) = (Pulses/Mass K-Factor)					
METER FACTOR = (Prover Mass/Meter Mass)					

AVERAGE METER FACTOR ____________ LOCATION OF ENTRY (of Meter Factor) ____________ TRANSMITTER/CALC. DEVICE

PERCENT REPEATABILITY ____________ [(MAX – MIN)/MIN] * 100 ZERO VERIFIED? ______ YES/NO ______ AS FOUND ______ AS LEFT

PROVER ____________ (SIGN) ____________ (DATE) WITNESS ____________ (SIGN) ____________ (DATE)

Figure C-5—Proving Calculations
Volumetric Master Meter—Coriolis Meter Mass

PROVER INFORMATION

CERTIFICATION DATE: ____________ (YY/MM/DD) PROVER COMPANY ____________

MASTER METER K-FACTOR ____________ (PULSES/lb) MANUFACTURER ____________

SERIAL NO. ____________ MODEL ____________

METER INFORMATION

SERIAL NO. ____________ MANUFACTURER ____________

METER ID ____________ MODEL ____________

LOCATION ____________

MANUFACTURER FLOW CALIBRATION FACTOR(S) ____________

PULSE SCALING FACTOR ____________ (PULSES/lb) *KF* (In Associated Equipment) ____________ (PULSES/lb)

PROCESS CONDITIONS

FLOW RATE ____________ (lb/MIN) ____________ (bbl/HR) FLUID TYPE ____________

DENSITY SOURCE ____________ (DEVICE/LOCATION)

PROVE INFORMATION

PREVIOUS METER FACTOR ____________ (DATE OF PROVE YY/MM/DD) ____________ (FACTOR)

RUN NUMBER	**1**	**2**	**3**	**4**	**5**
TOTAL MASTER METER PULSES					
TOTAL METER PULSES					
TEST TIME (sec)					
MASTER METER DENSITY (kg/m^3)					
MASTER METER MASS (lb) = (Pulses/Mass K-Factor or Visual Totalizer Display)					
METER MASS (lb) = (Pulses/Mass K-Factor or Visual Totalizer Display)					
METER FACTOR = (Master Meter Mass/Meter Mass)					

AVERAGE METER FACTOR [ ] LOCATION OF ENTRY (of Meter Factor) ____________ TRANSMITTER/CALC. DEVICE

PERCENT REPEATABILITY ____________ [(MAX – MIN)/MIN] * 100 ZERO VERIFIED? ______ YES/NO ______ AS FOUND ______ AS LEFT

PROVER ____________ (SIGN) ____________ (DATE) WITNESS ____________ (SIGN) ____________ (DATE)

Figure C-6—Proving Calculations
Mass Master Meter—Coriolis Meter Mass

APPENDIX D—PROVING FORMS FOR METERS WITH VOLUME OUTPUTS

This Appendix provides examples of proving forms for Coriolis meters configured to output volumes.

PROVER INFORMATION

CERTIFICATION DATE: ____________ (YY/MM/DD) PROVER COMPANY ____________

BASE PROVER VOLUME ____________ (BARRELS) PROVER UNIT SERIAL NO. ____________

METER INFORMATION

SERIAL NO. ____________ MANUFACTURER ____________

METER ID ____________ MODEL ____________

LOCATION ____________

MANUFACTURER FLOW CALIBRATION FACTOR(S) ____________

PULSE SCALING FACTOR ____________ (PULSES/bbl) *KF* (In Associated Equipment) ____________ (PULSES/bbl)

PROCESS CONDITIONS

FLOW RATE ____________ (lb/MIN) ____________ (bbl/HR) DENSITY CORR. FACTOR ____________

DENSITY SOURCE ____________ (DEVICE/LOCATION) DENSITY ____________ (kg/m^3 @ 60°F) FLUID TYPE ____________

PROVE INFORMATION

PREVIOUS METER FACTOR ____________ (DATE OF PROVE YY/MM/DD) ____________ (FACTOR)

RUN NUMBER	**1**	**2**	**3**	**4**	**5**
TOTAL METER PULSES					
PROVER TEMPERATURE (°F)					
CTS_p					
CTL_p					
PROVER PRESSURE (psig)					
CPS_p					
CPL_p					
METER TEMPERATURE (°F)					
CTL_m					
METER PRESSURE (psig)					
CPL_m					
PROVER VOLUME (Bbl) = [(BaseVol * CTS_p * CPS_p) * CTL_p * CPL_p]					
CORIOLIS METER VOLUME (Bbl) = [(Pulses/Vol. K-Factor) * CTL_m * CPL_m]					
METER FACTOR = (Prover Volume/Coriolis Meter Volume)					

AVERAGE METER FACTOR ☐ LOCATION OF ENTRY (of Meter Factor) ____________ TRANSMITTER/CALC. DEVICE

PERCENT REPEATABILITY ____________ [(MAX – MIN)/MIN] * 100 ZERO VERIFIED? ________ YES/NO ________ AS FOUND ________ AS LEFT

PROVER ____________ (SIGN) ____________ (DATE) WITNESS ____________ (SIGN) ____________ (DATE)

Figure D-1—Proving Calculations
Conventional Pipe Prover—Coriolis Meter Volume

PROVER INFORMATION

CERTIFICATION DATE: ____________ (YY/MM/DD)   PROVER COMPANY ____________

BASE PROVER VOLUME ____________ (BARRELS)   PROVER UNIT SERIAL NO. ____________

METER INFORMATION

SERIAL NO. ____________   MANUFACTURER ____________

METER ID ____________   MODEL ____________

LOCATION ____________

MANUFACTURER FLOW CALIBRATION FACTOR(S) ____________

PULSE SCALING FACTOR ____________ (PULSES/bbl)   *KF* (In Associated Equipment) ____________ (PULSES/bbl)

PROCESS CONDITIONS

FLOW RATE ____________ (lb/MIN) ____________ (bbl/HR)   DENSITY CORR. FACTOR ____________

DENSITY SOURCE ____________ (DEVICE/LOCATION)   DENSITY ____________ (kg/m^3 @ 60°F)   FLUID TYPE ____________

PROVE INFORMATION

PREVIOUS METER FACTOR ____________ (DATE OF PROVE YY/MM/DD) ____________ (FACTOR)

NUMBER OF PASSES/RUN ____	**1**	**2**	**3**	**4**	**5**
AVERAGE INTERPOLATED PULSES (Meter)					
AVG. PROVER TEMPERATURE (°F)					
CTS_p					
CTL_p					
AVERAGE PROVER PRESSURE (psig)					
CPS_p					
CPL_p					
AVERAGE METER TEMPERATURE (°F)					
CTL_m					
AVERAGE METER PRESSURE (psig)					
CPL_m					
PROVER VOLUME (Bbl) = [(BaseVol * CTS_p * CPS_p) * CTL_p * CPL_p]					
METER VOLUME (Bbl) = [(Pulses/Vol. K-Factor) * CTL_m * CPL_m]					
METER FACTOR = (Prover Volume/Meter Volume)					

AVERAGE METER FACTOR ☐   LOCATION OF ENTRY (of Meter Factor) ____________ TRANSMITTER/CALC. DEVICE

PERCENT REPEATABILITY ____________ [(MAX – MIN)/MIN] * 100   ZERO VERIFIED? ______ YES/NO ______ AS FOUND ______ AS LEFT

PROVER ____________ (SIGN) ____________ (DATE)   WITNESS ____________ (SIGN) ____________ (DATE)

Figure D-2—Proving Calculations
Small Volume Prover—Coriolis Meter Volume

PROVER INFORMATION

CERTIFICATION DATE ______ (YY/MM/DD) PROVER COMPANY ______

WEIGH SCALE RESOLUTION ______ (LBS.) PROVER UNIT SERIAL NO. ______

TARGET TEST QUANTITY ______ (LBS.)

METER INFORMATION

SERIAL NO. ______ MANUFACTURER ______ MODEL ______

METER ID ______ LOCATION ______

MANUFACTURER FLOW CALIBRATION FACTOR(S) ______

PULSE SCALING FACTOR ______ (PULSES/bbl) *KF* (In Associated Equipment) ______ (PULSES/bbl)

PROCESS CONDITIONS

FLOW RATE ______ (lb/MIN) ______ (bbl/HR) DENSITY CORR. FACTOR ______

DENSITY SOURCE ______ (DEVICE/LOCATION) DENSITY ______ (kg/m^3 @ 60°F) FLUID TYPE ______

PROVE INFORMATION

PREVIOUS METER FACTOR ______ (DATE OF PROVE YY/MM/DD) ______ (FACTOR)

RUN NUMBER	1	2	3	4	5
WEIGH SCALE TOTAL (lb)					
SCALE OBSERVED DENSITY (kg/m^3)					
TOTAL METER PULSES					
PROVER FILL TIME (sec)					
PROVER TEMPERATURE (°F)					
CTL_p					
PROVER PRESSURE (psig)					
CPL_p					
METER TEMPERATURE (°F)					
CTL_m					
METER PRESSURE (psig)					
CPL_m					
SCALE MASS (lb) = (Scale Tot. * Buoyancy Factor)					
PROVER VOLUME (Bbl) = [(Scale Mass/0.3505071*Obs. Den.) * CTL_P * CPL_P]					
METER VOLUME (Bbl) = [(Meter Pulses/Vol. K-Factor) * CTL_m * CPL_m]					
METER FACTOR = (Master Meter Volume/Meter Volume)					

AVERAGE METER FACTOR LOCATION OF ENTRY (of Meter Factor) ______ TRANSMITTER/CALC. DEVICE

PERCENT REPEATABILITY ______ [(MAX – MIN)/MIN] * 100 ZERO VERIFIED? ______ YES/NO ______ AS FOUND ______ AS LEFT

PROVER ______ (SIGN) ______ (DATE) WITNESS ______ (SIGN) ______ (DATE)

Figure D-3—Proving Calculations
Gravimetric Tank Prover—Coriolis Meter Volume

PROVER INFORMATION

CERTIFICATION DATE: ____________ (YY/MM/DD) PROVER COMPANY ____________

PROVER RESOLUTION ____________ (BARRELS) SERIAL NUMBER ____________ BASE PROVER VOLUME ____________ (BARRELS)

METER INFORMATION

SERIAL NO. ____________ MANUFACTURER ____________ MODEL ____________

METER ID ____________ LOCATION ____________

MANUFACTURER FLOW CALIBRATION FACTOR(S) ____________

PULSE SCALING FACTOR ____________ (PULSES/bbl) *KF* (In Associated Equipment) ____________ (PULSES/bbl)

PROCESS CONDITIONS

FLOW RATE ____________ (lb/MIN) ____________ (bbl/HR) DENSITY CORR. FACTOR ____________

DENSITY SOURCE ____________ (DEVICE/LOCATION) DENSITY ____________ (kg/m^3 @ 60°F) FLUID TYPE ____________

PROVE INFORMATION

PREVIOUS METER FACTOR ____________ (DATE OF PROVE YY/MM/DD) ____________ (FACTOR)

RUN NUMBER	1	2	3	4	5
TOTAL METER PULSES					
PROVER FILL TIME (sec)					
PROVER TEMPERATURE (°F)					
CTS_p					
CTL_p					
PROVER PRESSURE (psig)					
CPS_p					
CPL_p					
METER TEMPERATURE (°F)					
CTL_m					
METER PRESSURE (psig)					
CPL_m					
PROVER VOLUME (Bbl) = [(BaseVol * CTS_p * CPS_p) * CTL_p * CPL_p]					
CORIOLIS METER VOLUME (Bbl) = [(Pulses/Vol. K-Factor) * CTL_m * CPL_m or Visual Totalizer Display * CTL_m * CPL_m]					
METER FACTOR = (Prover Volume/Coriolis Meter Volume)					

AVERAGE METER FACTOR ☐ LOCATION OF ENTRY (of Meter Factor) ____________ TRANSMITTER/CALC. DEVICE

PERCENT REPEATABILITY ____________ [(MAX – MIN)/MIN] * 100 ZERO VERIFIED? ______ YES/NO ______ AS FOUND ______ AS LEFT

PROVER ____________ (SIGN) ____________ (DATE) WITNESS ____________ (SIGN) ____________ (DATE)

Figure D-4—Proving Calculations
Volumetric Tank Prover—Coriolis Meter Volume

PROVER INFORMATION

CERTIFICATION DATE: ____________ (YY/MM/DD) PROVER COMPANY ____________

MASTER METER K-FACTOR ____________ (PULSES/bbl) MANUFACTURER ____________

SERIAL NO. ____________ MODEL ____________

METER INFORMATION

SERIAL NO. ____________ MANUFACTURER ____________ MODEL ____________

METER ID ____________ LOCATION ____________

MANUFACTURER FLOW CALIBRATION FACTOR(S) ____________

PULSE SCALING FACTOR ____________ (PULSES/bbl) *KF* (In Associated Equipment) ____________ (PULSES/bbl)

PROCESS CONDITIONS

FLOW RATE ____________ (lb/MIN) ____________ (bbl/HR) DENSITY CORR. FACTOR ____________

DENSITY SOURCE ____________ (DEVICE/LOCATION) DENSITY ____________ (kg/m^3 @ 60°F) FLUID TYPE ____________

PROVE INFORMATION

PREVIOUS METER FACTOR ____________ (DATE OF PROVE YY/MM/DD) ____________ (FACTOR)

RUN NUMBER	**1**	**2**	**3**	**4**	**5**
TOTAL MASTER METER PULSES					
TOTAL METER PULSES					
TEST TIME (sec)					
MASTER METER TEMPERATURE (°F)					
CTL_p					
MASTER METER PRESSURE (psig)					
CPL_p					
METER TEMPERATURE (°F)					
CTL_m					
METER PRESSURE (psig)					
CPL_m					
MASTER METER VOLUME (Bbl) = [(Master Pulses/K-Factor) * CTL_p * CPL_p]					
METER VOLUME (Bbl) = [(Meter Pulses/Vol. K-Factor) * CTL_m * CPL_m]					
METER FACTOR = (Master Meter Volume/Meter Volume)					

AVERAGE METER FACTOR ____________ LOCATION OF ENTRY (of Meter Factor) ____________ TRANSMITTER/CALC. DEVICE

PERCENT REPEATABILITY ____________ ZERO VERIFIED? ______ YES/NO ______ AS FOUND ______ AS LEFT

PROVER ____________ (SIGN) ____________ (DATE) WITNESS ____________ (SIGN) ____________ (DATE)

Figure D-5—Proving Calculations
Volumetric Master Meter—Coriolis Meter Volume

PROVER INFORMATION

CERTIFICATION DATE: ____________ (YY/MM/DD) PROVER COMPANY ____________

MASTER METER K-FACTOR ____________ (PULSES/lb) MANUFACTURER ____________

SERIAL NO. ____________ MODEL ____________

METER INFORMATION

SERIAL NO. ____________ MANUFACTURER ____________ MODEL ____________

METER ID ____________ LOCATION ____________

MANUFACTURER FLOW CALIBRATION FACTOR(S) ____________

PULSE SCALING FACTOR ____________ (PULSES/bbl) *KF* (In Associated Equipment) ____________ (PULSES/bbl)

PROCESS CONDITIONS

FLOW RATE ____________ (lb/MIN) ____________ (bbl/HR) DENSITY CORR. FACTOR ____________

DENSITY SOURCE ____________ (DEVICE/LOCATION) DENSITY ____________ (kg/m^3 @ 60°F) FLUID TYPE ____________

PROVE INFORMATION

PREVIOUS METER FACTOR ____________ (DATE OF PROVE YY/MM/DD) ____________ (FACTOR)

RUN NUMBER	**1**	**2**	**3**	**4**	**5**
TOTAL MASTER METER PULSES					
MASTER FLOWING DENSITY (kg/m^3)					
TOTAL METER PULSES					
TEST TIME (sec)					
MASTER METER TEMPERATURE (°F)					
CTL_p					
MASTER METER PRESSURE (psig)					
CPL_p					
METER TEMPERATURE (°F)					
CTL_m					
METER PRESSURE (psig)					
CPL_m					
MASTER METER VOLUME (Bbl) = [(Pulses/KF) * CTL_p * CPL_p]/[FlwDens. * 0.350507]					
METER VOLUME (Bbl) = [(Meter Pulses/Vol. K-Factor) * CTL_m * CPL_m]					
METER FACTOR = (Master Meter Volume/Meter Volume)					

AVERAGE METER FACTOR ☐ LOCATION OF ENTRY (of Meter Factor) ____________ TRANSMITTER/CALC. DEVICE

PERCENT REPEATABILITY ____________ [(MAX – MIN)/MIN] * 100 ZERO VERIFIED? ________ YES/NO ________ AS FOUND ________ AS LEFT

PROVER ____________ (SIGN) ____________ (DATE) WITNESS ____________ (SIGN) ____________ (DATE)

Figure D-6—Proving Calculations
Mass Master Meter—Coriolis Meter Volume

APPENDIX E—CALCULATIONS

Table E-1—Coriolis Meter—Proving Overview

	Proving Method					
	Tank Prover		Conventional Pipe	Small Volume	Master Meter	
Proving Considerations	Gravimetric	Volumetric[2]			Volumetric	Mass
Prover Design	*MPMS* Chapter 4.4	*MPMS* Chapter 4.4	*MPMS* Chapter 4.2	*MPMS* Chapter 4.3	Varies	Varies
Proving Procedure	*MPMS* Chapter 4.8	*MPMS* Chapter 4.8	*MPMS* Chapter 4.8	*MPMS* Chapter 4.8	*MPMS* Chapter 4.5 and 4.8	*MPMS* Chapter 4.8
Process Measurements[1] Coriolis Meter-mass	A – None	B – [ρ_{fp}, T_p, P_p]	B – [ρ_{fp}, T_p, P_p]	B – [ρ_{fp}, T_p, P_p]	B – ρ_{fp}	A – None
Process Measurements[1] Coriolis Meter-volume	D – [ρ_{fp}, T_p, P_p, T_m, P_m]	C – [ρ_{fp}, T_p, P_p, T_m, P_m]	C – [ρ_{fp}, T_p, P_p, T_m, P_m]	C – [ρ_{fp}, T_p, P_p, T_m, P_m]	C – [ρ_{fp}, T_p, P_p, T_m, P_m]	C – [ρ_{fp}, T_p, P_p, T_m, P_m]
Meter Factor Calculations Coriolis Meter-mass	A	B	B	B	B $CTS_p = 1$ $CPS_p = 1$	A
Meter Factor Calculations Coriolis Meter-volume	D	C	C	C	C $CTS_p = 1$ $CPS_p = 1$	C

Notes:
[1]Where A, B, C and D referred to in the table pertain to equations below.
[2]Pressure measurement is only required for closed vessel tank provers.

A: $$MF_m = \frac{\text{Prover Mass}}{IM_m}$$

B: $$MF_m = \frac{\text{Prover Volume} \times CTS_p \times CPS_p \times \rho_{fp}}{IM_m}$$

C: $$MF_v = \frac{\text{Prover Volume} \times CTS_p \times CPS_p}{IV_m} \times \frac{CTL_p \times CPL_p}{CTL_m \times CPL_m}$$

D: $$MF_v = \frac{\text{Prover Mass}}{IV_m \times \rho_{fp}} \times \frac{CTL_p \times CPL_p}{CTL_m \times CPL_m}$$

E.1 Meter Factor Calculation

Proving forms for Coriolis meters are presented in Appendices C and D. Definitions for abbreviations used in the following equations are given in Section 5.

Proper determination of the *CTL* and *CPL* correction factors requires using the base fluid density, ρ_b. For a Coriolis meter configured to indicate mass, the indicated mass (IM_m) during the proving runs is determined from the following relationship:

$$IM_m = \frac{\text{Meter Pulses}}{KF_m} \quad \text{(E-1)}$$

For a Coriolis meter configured to indicate volume, the indicated volume (IV_m) is determined from the following relationship:

$$IV_m = \frac{\text{Meter Pulses}}{KF_v} \quad \text{(E-2)}$$

E.1.1 CORIOLIS METER MASS COMPARED TO PROVER MASS

Equation E-3 is applicable to proving a Coriolis meter configured to indicate mass versus a gravimetric tank prover.

$$MF_m = \frac{\text{Prover Mass}}{IM_m} \quad \text{(E-3)}$$

E.1.2 CORIOLIS METER MASS COMPARED TO PROVER VOLUME

Equation E-4 is applicable to a Coriolis meter configured to indicate mass versus a volumetric tank prover, conventional pipe prover, small volume prover, or volumetric master meter.

$$MF_m = \frac{\text{Prover Volume} \times CTS_p \times CPS_p \times \rho_{fp}}{IM_m} \quad \text{(E-4)}$$

E.1.3 CORIOLIS METER VOLUME COMPARED TO PROVER VOLUME

Equation E-5 is applicable to a Coriolis meter configured to indicate volume versus a volumetric tank prover, conventional pipe prover, small volume prover, or volumetric master meter.

$$MF_v = \frac{\text{Prover Volume} \times CTS_p \times CPS_p}{IV_m} \times \frac{CTL_p \times CPL_p}{CTL_m \times CPL_m} \quad \text{(E-5)}$$

E.1.4 CORIOLIS METER VOLUME COMPARED TO PROVER MASS

Equation E-6 is applicable to a Coriolis meter configured to indicate volume versus a gravimetric tank prover.

$$MF_v = \frac{\text{Prover Mass}}{IV_m \times \rho_{fp}} \times \frac{CTL_p \times CPL_p}{CTL_m \times CPL_m} \quad \text{(E-6)}$$

E.1.5 CHANGING THE METER FACTOR IN THE CORIOLIS TRANSMITTER

During proving, the pulse output signal of the Coriolis meter transmitter may have been factored by a meter factor within the transmitter electronics. If this is the case, and the meter factor within the Coriolis transmitter is to be adjusted, the new meter factor determined at the time of proving must be adjusted as follows:

$$MF_{\text{new}} = MF_{prv} \times MF_{\text{exist}} \quad \text{(E-7)}$$

where

MF_{new} = new meter factor to be used by the Coriolis transmitter,

MF_{prv} = meter factor determined by meter proving,

MF_{exist} = meter factor used by the Coriolis transmitter during the proving.

E.1.6 VARYING K-FACTOR TO CORRECT METER INDICATION

Equation E-8 is applicable to Coriolis meters when the K-Factor is varied rather than the meter factor to correct the Coriolis meter output.

$$\textit{K-Factor} = \frac{PSF}{\text{Meter Factor}} \quad \text{(E-8)}$$

E.1.7 CONVERSION OF DENSITY BETWEEN PROVER AND METER CONDITIONS

Some meter factor equations use the density determined at the prover flowing conditions. If density is determined at the Coriolis meter flowing conditions, then the following relationship can be used to convert between the two sets of operating conditions. It is always preferable to determine the density at the required location and avoid any conversion if it is possible. If the meter density is used to determine the prover density, it must be calibrated in accordance with API *MPMS* Chapter 14.6.

$$\rho_{fp} = \rho_{fm} \times \frac{CTL_p \times CPL_p}{CTL_m \times CPL_m} \quad \text{(E-9)}$$

E.2 Quantity Calculations

The meter factor, which is determined in E.1, is applied to the Coriolis meter indication to determine the actual measured quantity as shown in the following equations:

$$\text{Measured Mass} = \frac{\text{Meter Pulses}}{KF_m} \times MF_m \quad \text{(E-10)}$$

$$\text{GSV} = \frac{\text{Meter Pulses} \times CTL_m \times CPL_m}{KF_v} \times MF_m \quad \text{(E-11)}$$

Refer to API *MPMS* Ch. 12 for more information.

E.3 Meter Factor Rounding and Truncation

The discrimination levels of flow parameters and correction factors for the determination of volume and mass meter factors and for mass or volume quantities should follow those applicable guidelines found in API *MPMS* Chapters 12.2.2 and 12.2.3 except for the exceptions and additions noted below.

The rounding and calculation sequence for Equation E-5 shall follow those applicable guidelines found in API *MPMS* Chapter 12.2.3. For the remaining meter factor equations, the numerator and denominator shall be calculated separately, by serial multiplication of the correction factors, in the exact order specified, rounding at the end of the multiplication in accordance with mass discrimination Table E-2 in this document or the volume discrimination table in API *MPMS* Chapter 12.2.3.

Table E-2—Mass Discrimination Table

	lb	kg
Prover mass, meter mass (IM_m)	ABCDE.x	ABCDE.x
	ABCD.xx	ABCD.xx
	ABC.xxx	ABC.xxx
	AB.xxx	AB.xxx

Table E-3—Density Discrimination Table

	lb/US gal	kg/m^3
Prover density ρ_{fp}, meter density ρ_{fm} (where directly used in equations)	ABC.xxx AB.xxx	ABCD.xx ABC.xx
Prover density ρ_{fp}, meter density ρ_{fm} (where used to calculate correction factors)	ABC.xx AB.xx	ABCD.x ABC.x

Table E-4—Correction Factor Discrimination Table

KF_m (pulses/lb, pulses/kg)	ABCDEF.0
KF_v (pulses/US gal, pulses/bbl, pulses/m^3)	ABCDE.0 ABCD.x ABC.xx AB.xxx
MF_m	x.xxxx

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