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Field Proving by Micro Motion Coriolis Prover
Mass Master Meter Method

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Introduction

Coriolis Mass Flow Meters have been used for process optimisation for more than 20 years. Refining, petrochemical, and other process industry for use in automating and optimising production processes have adopted this technology. As companies have gained more confidence and trust in Coriolis technology it was only natural that they began to apply them in fiscal service or custody transfer metering. Coriolis inherent reliability and meter factor stability as well as multi-variable versatility (mass, density, operating volume, and temperature) have helped many users lower life cycle costs and better manage loss control.

Traditionally all LPG measurements have used volume as the basis of measurements. Mass can be a better basis for trade but, until the development of Coriolis mass flowmeters, no universally acceptable Coriolis meter based metering system was generally available. Coriolis mass flowmeters are now increasingly being introduced into custody transfer and fiscal metering duties for many different types of fluid. National regulations will require uncertainties of 0.5 or even 0.1% to meet this change in technology and philosophy. The aim of this article is to provide information to set up standardized proving method and techniques for Coriolis mass flow meters used for LPG custody transfer measurement.

A large community of Coriolis users have begun applying them not only in process but also in regulated custody transfer service of LPG and other hydrocarbons. Coriolis meters are chosen by industry to provide specific measurement solutions and are now used extensively. Their applications overlap with traditional meters and they compete well in price and performance in these areas of overlap. The following article will feature this remarkable metering technology evolution and suggest one build-in on-situ proving technique to be applied. A brief synopsis of this application will follow.

Description of LPG Integrated Metering System

Some Coriolis Meter manufacturers have promoted for many years the application "LPG custody transfer measurement", a "pay/check" scheme where two meters are placed in series with a flow computer comparing one against the other and as long as the meters agreed within a given % all was assumed to be fine.

The proposed system design uses three Coriolis flow meters in parallel for normal operation. Each meter is capable of handling 50% of the maximum flow design. Under normal operation the flow computers continuously monitor the rate and total of the individual meters and their sum, this information is retained in the flow computers and also displayed at the operator station.

Coriolis meters are initially calibrated by the manufacturer to determine calibration factors that are entered into the Coriolis transmitter. This factor should remain unchanged. This factor does not take in to account meter performance under actual operating conditions. In addition to the initial proving of a Coriolis meter when installed in the field, periodic proving are necessary to confirm or re-establish the performance accuracy of the Coriolis meter.

The subsequent sections detail proving methods, proving considerations, meter factor calculation, application of the proving results, and frequency of proving.

Integrated Calibration Verification Process

The proposed system uses the same three Coriolis meters in series for Calibration Verification. This procedure is carried out periodically. This procedure confirms the factory calibration by comparing all three meters in a series flow configuration. The audit system monitors the meters and compares them to each other. If any one-meter deviates from any other meter by greater than the allowed tolerance (e.g. 0.15% of actual mass flow rate), then the Zero Verification Procedure is and the Calibration Factor Verification is performed. If the meter continues to fail, it is replaced. This concept holds true unless all three meters were to go out of calibration by the same magnitude and direction at the same time. We do not know how to calculate this probability but consider it to be highly unlikely.

Calibration Verification should be performed if any of the following events occur:

- a) The meter is re-zeroed.
- b) When the flow sensor installation or mounting conditions are modified.
- c) When the meter assembly is repaired.
- d) When any of the assembly components have been replaced.
- e) If a change in the fluid temperature, pressure, or density occurs beyond user-defined limits as determined from field experience.
- f) 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.
- g) At the request of parties involved in custody transfer.
- h) On a scheduled meter proving date, based on throughput, elapsed time, or contract.
- i) Anytime the accuracy of a meter is in question.
- j) When a change in the direction of flow through the meter occurs, if a meter factor has not been determined for the other direction.
- k) Some manufacturers recommend this procedure be carried out every 6 months.

Meters that fail Calibration Factor Verification can be replaced with factory calibrated meters or be proven in situ by using an external prover. The failed meter, if it is replaced with a new meter, can then be returned to the manufacturer proving facility to be placed on a gravimetric proving system to verify the validity of the meter factors and if necessary reassign new factors.

Field Proving

Field meter proving (in-situ) provides a means of establishing the Meter Factor for the Coriolis meter under actual operating conditions.

Proving Methods

Three 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.

Direct Mass Proving

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

The common methods used are:

Gravimetric: The reference quantity of fluid is weighed on a scale and compared to a meter's indication of mass.

Mass Master Meter: The reference quantity of fluid is obtained from a mass master meter and compared to a meter's indication of mass.

Laboratory Versus In-Situ Proving

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

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.

Proving And Calibration Verification Considerations

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.

Number of Runs for a Proving

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

- Type of proving method being employed
- Coriolis meter type and size
- 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 number of runs performed for each proving method to obtain 0.05% repeatability is 2 to 5.

Multiple Meters in Close Proximity

One proposed LPG metering system requires installing 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 (sometimes called cross-talk). Vibration isolation or dampening can be achieved by altering piping and/or supports. Some manufacturers may also be able to alter the drive frequency of their sensors, thereby reducing cross-talk between adjacent meters.

Considerations for Re-zeroing the Flowmeter

Periodic verification of the zero value should be made to make sure that the zero value is within defined tolerance limits. The "true" zero may vary from the Coriolis transmitter's zero value with changes in:

- 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

Changes in the conditions listed above may require re-zeroing. Since the zero value is very small, it has minimal effect on meter accuracy at the maximum rated flow rate of the meter. The influence of the difference between the Coriolis transmitter zero value, and the "true" zero becomes more significant at lower flow rates as illustrated by the Coriolis meter accuracy specification shown in following equation:

$$Err_0 = \frac{q_0}{q_f} \times 100$$

(2)

Where:

Err_0 = Zero Error (%)

q_0 = Observed Coriolis meter flow rate with no flow

q_f = Typical flow rate during normal operation

Repeatability

Repeatability is used as an indication of whether the proving results are valid. This Coriolis Prover Method needs less runs as with conventional prover because the obtained repeatability after three runs (each run takes one minute) fulfils already 0.05% requirement. Therefore less data needed.

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.

Manufacturer Calibration Factors

Manufacturer Calibration Factors are entered into the Coriolis transmitter, which are unique to each particular sensor.

Correcting Coriolis Meter Indication

The result of a meter proving will be a revised Meter Factor. The meter factor (*MF*) may be entered in accessory equipment or, for some manufacturer's equipment, in the Coriolis transmitter.

Meter Factor Calculation

A proving form for Coriolis Meters Mass Master Meter proving is presented in Appendix 5.

For a Coriolis meter configured to indicate mass, the indicated mass (*IM_m*) during the proving runs is determined from the following relationship:

$$IM_m = \frac{\text{Meter pulses}}{KF_m}$$

Coriolis Meter Mass Compared to Prover Mass

This equation is applicable to proving a Coriolis meter configured to indicate mass versus a master meter.

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

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:

$$MF_{new} = MF_{prv} \times MF_{exist}$$

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

Probability all Meters Equally to Shift

All meters equally to shift in the same direction, the same magnitude and in the same time may be provoked by the following Common Causes:

- Product change
- Temperature Change
- Pressure Change
- Corrosion
- Erosion

The solution to eliminate possibility of equally shift is:

- Product change (transfer from water calibration to other product e.g.). Tests with Micro Motion Mass Meters have shown that this effect lies always within the uncertainties of the test facilities so that this effect is negligible.
- If temperature varies for more than 15 °C fine tune of temperature coefficient has to be applied.
- If pressure varies an active pressure compensation should be implemented.
- If one meter is corroded all other meters could be corroded with the same intensity. Master Meter B has to be offline during normal operation if aggressive product has to measure.
- If application is abrasive meters in parallel will erode with the same intensity. In abrasive flow Master Meter B has to be offline during normal operation. When meters are in series upstream meter will erode with higher intensity and erosion will not be common cause any more.

Probability of the event occurring other than due to a Common Cause is about as close to zero as you can get.

Conclusion

Coriolis mass flow meters have been proven to be effective instruments for optimising the custody transfer of LPG, hydrocarbons and petro-chemicals. The ability to use the same instruments to measure product quality and quantity and to perform in-site proving provides the end user with an extraordinary overall accuracy. The low maintenance cost, long-term measurement stability, and the precision accuracy of Coriolis meters offers to the user an immediate solution for optimising the profitability of their LPG custody transfer operations.

Appendixes

Appendix 1: Description of Accuracy Verification Process with Three Meters in Series

Appendix 2: Accuracy Verification Process with Three Meters in Series

Overall Scheme

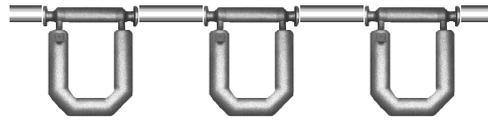
Meter Factor Verification Processes

Appendix 3: Metering System Description and Schematics

Appendix 4: Principle of Operation of a Coriolis Meters

Appendix 5: Proving Forms for Coriolis Meters Mass Master Meter Proving

Field Verification with Three Meters in Series



Meter	A	B	C	
Error	E_A	E_B	E_C	$\frac{\text{Indicated} - \text{Real}}{\text{Real}} \times 100\%$
Meterfactor	MF_A	MF_B	MF_C	$\frac{\text{Real}}{\text{Indicated}}$
Indicated Quantity	Q_A	Q_B	Q_C	
Indicated				
Number of Pulses	P_A	P_B	P_C	

(All transmitters have same configuration for pulse output, Pulse Scaling Factor PSF)

$$Q = \frac{P}{\text{PSF}}; E = \left(\frac{1}{MF} - 1\right) \times 100\%, \text{ Indicated} = \text{real}(1 + E)$$

Meterrun 1: Meter A against B gives MF_1

Meterrun 2: Meter C against B gives MF_2

$$MF_1 = \frac{Q_B}{Q_A} = \frac{\frac{P_B}{\text{PSF}}}{\frac{P_A}{\text{PSF}}} = \frac{P_B}{P_A} = \frac{\text{Real}(1 + E_B)}{\text{Real}(1 + E_A)} = \frac{\frac{1}{MF_B}}{\frac{1}{MF_A}} = \frac{MF_A}{MF_B}$$

$MF_1 = \frac{Q_B}{Q_A} = \frac{P_B}{P_A} = \frac{MF_A}{MF_B}$
--

eq. I

$MF_2 = \frac{Q_B}{Q_C} = \frac{P_B}{P_C} = \frac{MF_C}{MF_B}$
--

eq. II

Calculate Meterfactor A against C (C as reference)

$$MF_3 = \frac{Q_C}{Q_A} = \frac{P_C}{P_A} = \frac{\text{Real}(1 + E_C)}{\text{Real}(1 + E_A)} = \frac{\frac{1}{MF_C}}{\frac{1}{MF_A}} = \frac{MF_A}{MF_C} = \frac{\frac{MF_A}{MF_B}}{\frac{MF_C}{MF_B}} = \frac{MF_1}{MF_2}$$

$MF_3 = \frac{MF_1}{MF_2} = \frac{MF_A}{MF_C}$
--

eq. III

Assume only ONE meter is shifted (MF_A or MF_B or MF_C) the other two remain the same (=1.0000).

Therefore also one factor MF_1 or MF_2 or MF_3 will be 1.0000

MF_1 then MF_A and MF_B are 1.0000 \Rightarrow Meter C shifted

MF_2 then MF_C and MF_B are 1.0000 \Rightarrow Meter A shifted

MF_3 then MF_A and MF_C are 1.0000 \Rightarrow Meter B shifted

If clear which meter is shifted, e.g..

Meter A shifted, then $MF_A = MF_1$ or $MF_A = MF_3$

Meter B shifted, then $MF_B = \frac{1}{MF_1}$ or $MF_B = \frac{1}{MF_2}$

Meter C shifted, then $MF_C = MF_2$ or $MF_C = \frac{1}{MF_3}$

Examples to prove the theory

1) Meter A shifted

$$MF_A = 1.0015$$

$$MF_B = 1.0000$$

$$MF_C = 1.0000$$

1^e meterrun: $MF_1 = \frac{1.0015}{1.0000} = 1.0015$

2^e meterrun: $MF_2 = 1.0000$
 $MF_3 = \frac{MF_1}{MF_2} = 1.0015$

(Meets criteria; not B; not C; so, meter A = shifted)

$$MF_A = MF_1 \quad \text{or} \quad MF_A = MF_3$$

2) Meter B shifted

$$MF_A = 1.0000$$

$$MF_B = 1.0015$$

$$MF_C = 1.0000$$

1^e meterrun: $MF_1 = \frac{1.0000}{1.0015} = \frac{1}{1.0015} \approx 0,9985$

2^e meterrun: $MF_2 = \frac{1.0000}{1.0015} = \frac{1}{1.0015} \approx 0,9985$ So, meter B shifted

$$MF_3 = \frac{MF_1}{MF_2} = \frac{0,9985}{0,9985} = 1.0000$$

Meter B shifted

$$MF_B = \frac{1}{MF_1} = \frac{1}{0,9985} = 1.0015 \quad \text{or} \quad MF_B = \frac{1}{MF_2} = \frac{1}{0,9985} = 1.0015$$

3) Meter C shifted

$$MF_A = 1.0015$$

$$MF_B = 1.0000$$

$$MF_C = 1.0000$$

1^e meterrun:

$$MF_1 = \frac{MF_A}{MF_B} = 1.0000$$

2^e meterrun:

$$MF_2 = \frac{MF_C}{MF_B} = \frac{1.0015}{1.0000} = 1.0015$$

$$MF_3 = \frac{MF_1}{MF_2} = \frac{1}{1.0015} = 0,9985$$

Meter C shifted

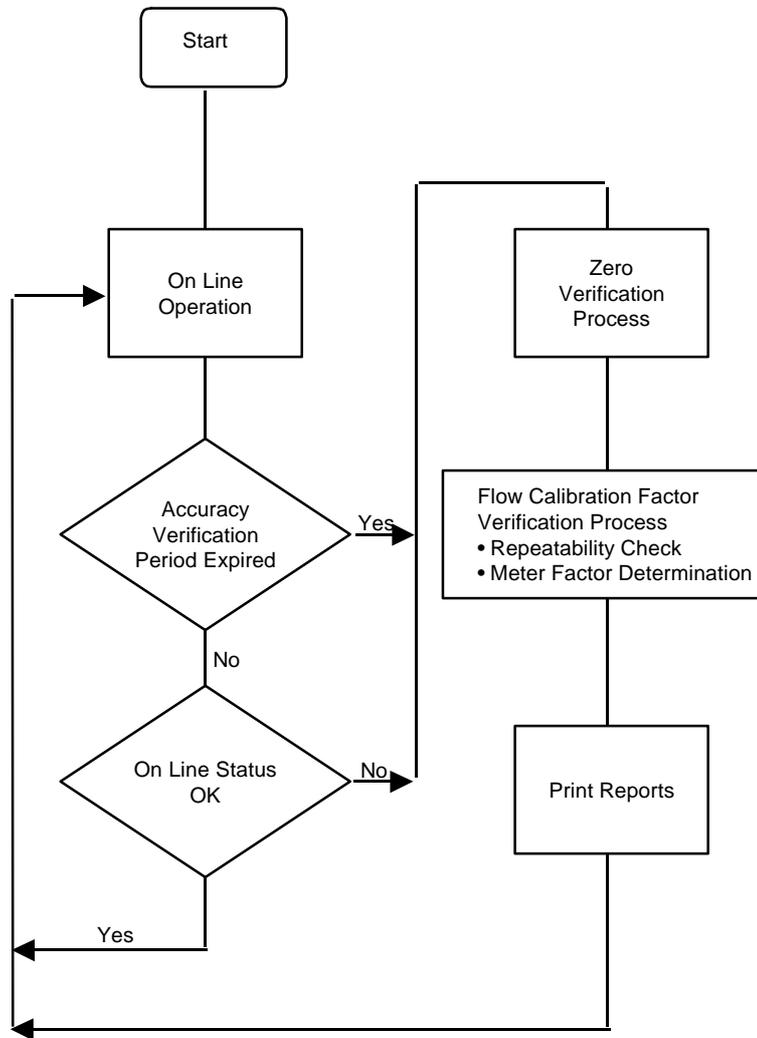
$$MF_C = MF_2 = 1.0015 \quad \text{or} \quad MF_C = \frac{1}{0,9985} = 1.0015$$

Important Note:

This method only applicable if Flow Cal Factor (FCF) within Micro Motion transmitter is adjusted in field. (Not meterfactor in Flow Computer)

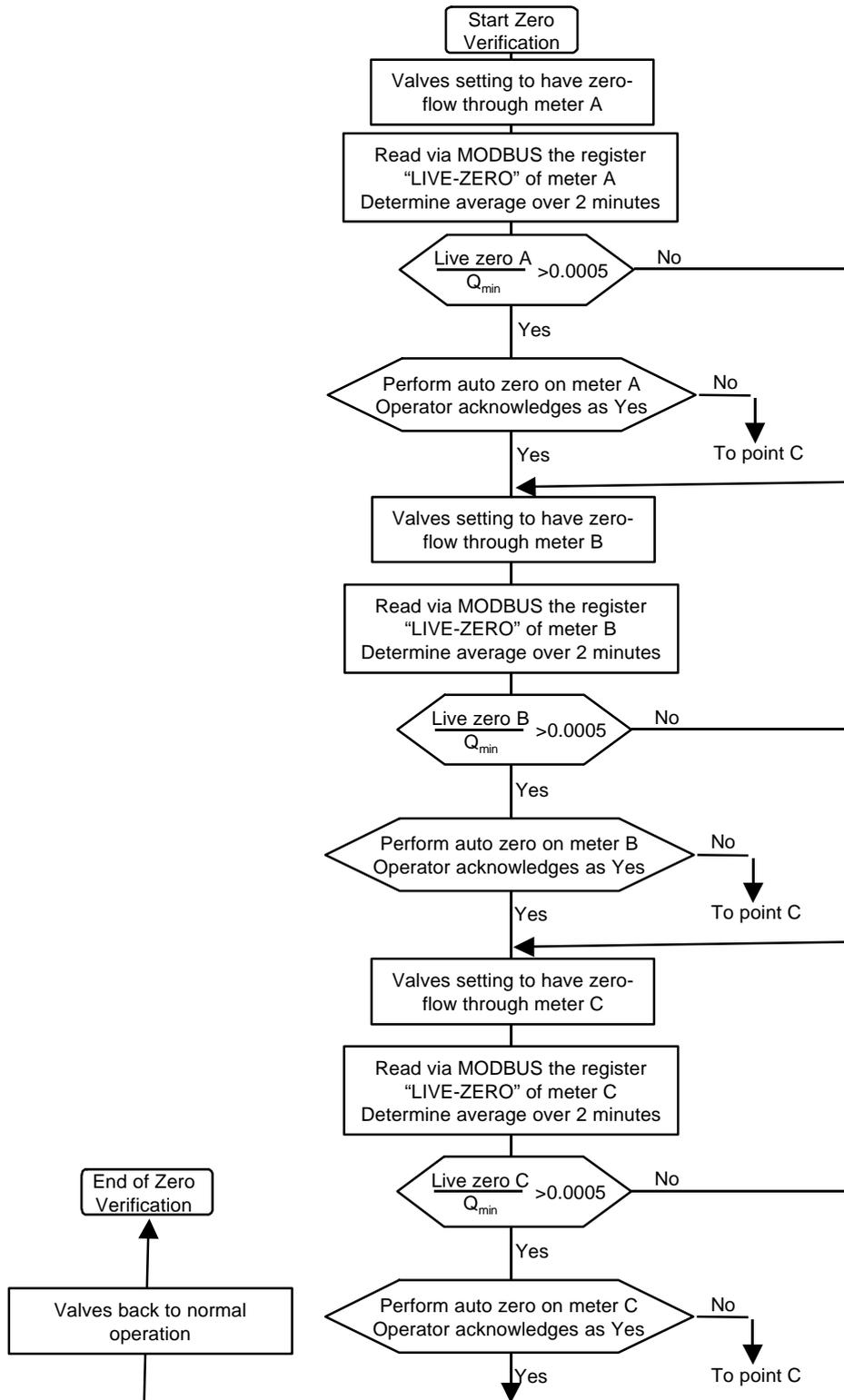
$$FCF_{NEW} = FCF_{OLD} * MF_{OUTOFVERIFICATION}$$

Accuracy Verification Process with Three Meters in Series Overall Scheme

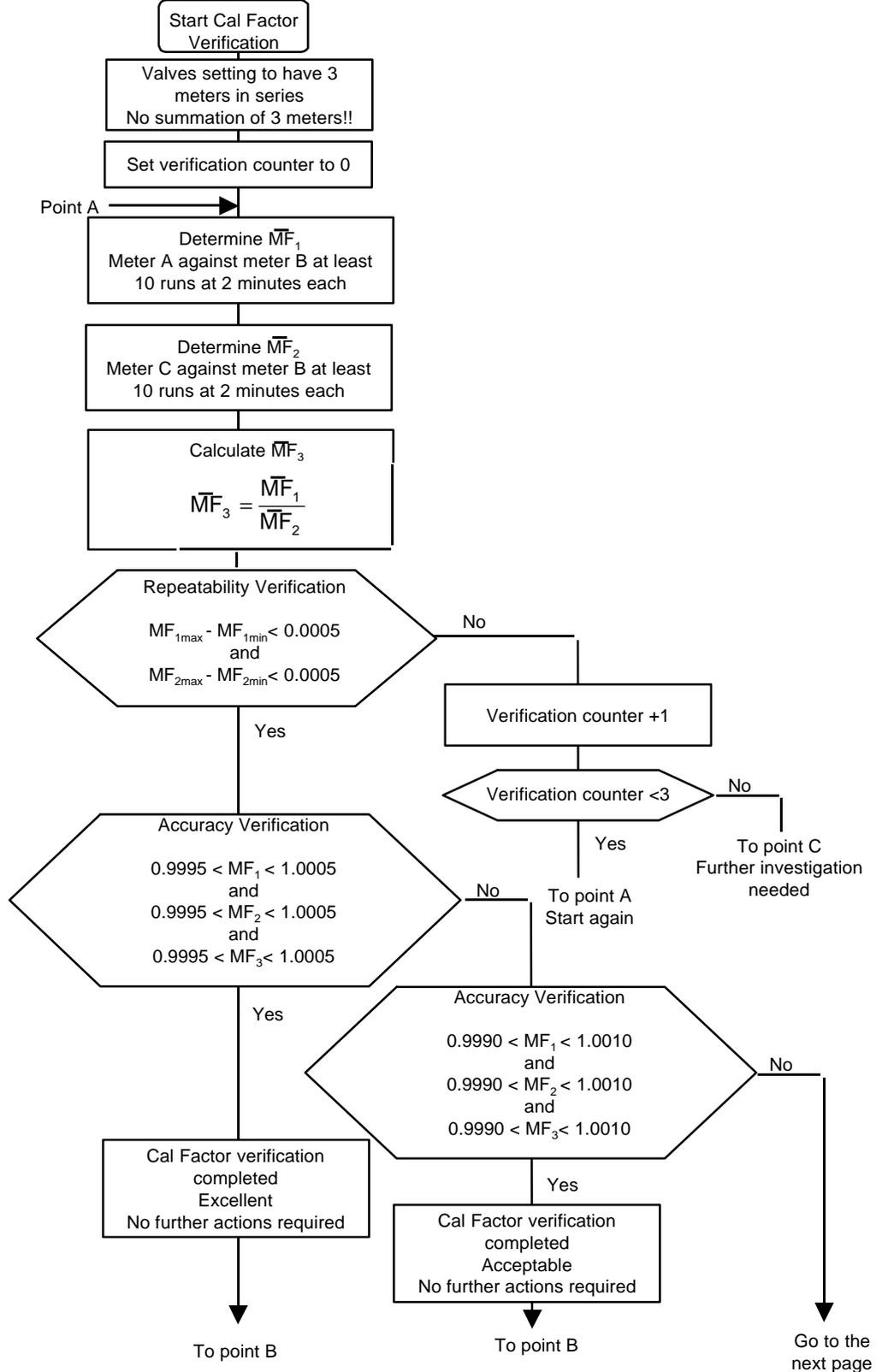


Accuracy Verification Process with Three Meters in Series

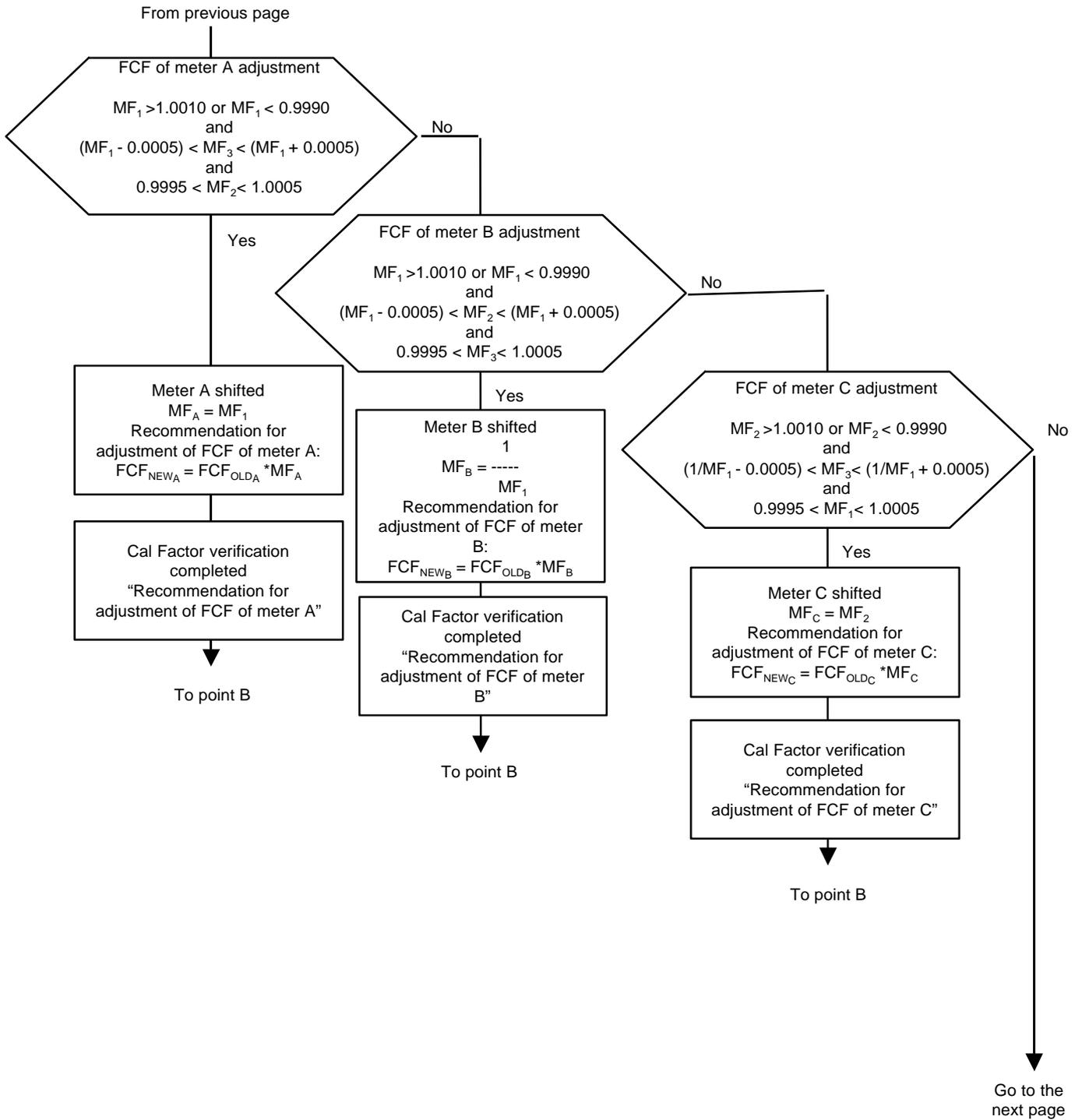
Zero Verification Process



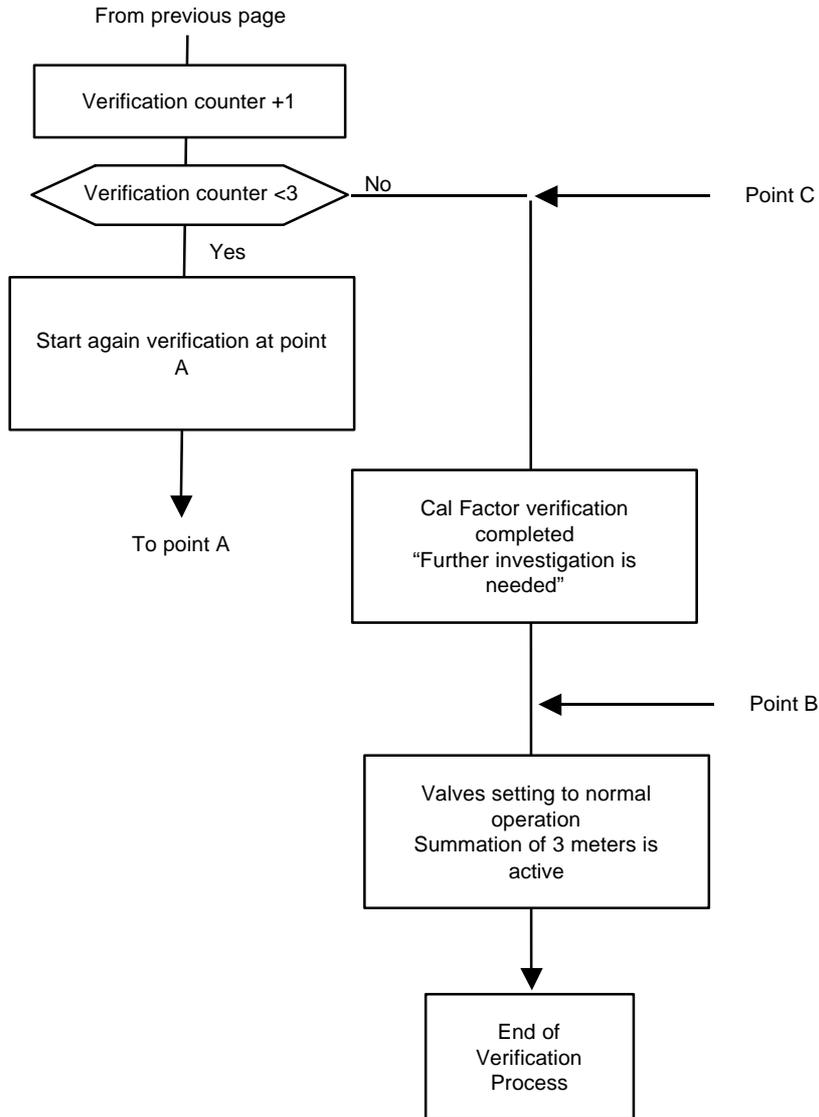
Accuracy Verification Process with Three Meters in Series Calibration Factor Verification Process



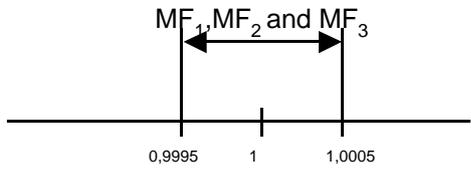
Accuracy Verification Process with Three Meters in Series Calibration Factor Verification Process



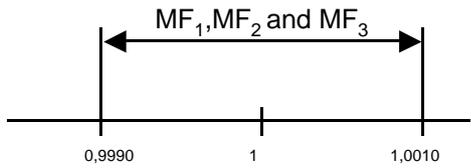
Accuracy Verification Process with Three Meters in Series Calibration Factor Verification Process



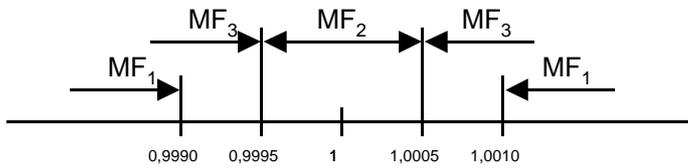
Accuracy Verification Process with Three Meters in Series Calibration Factor Verification Process



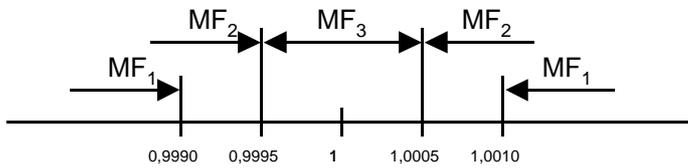
Excellent within $\pm 0,05\%$



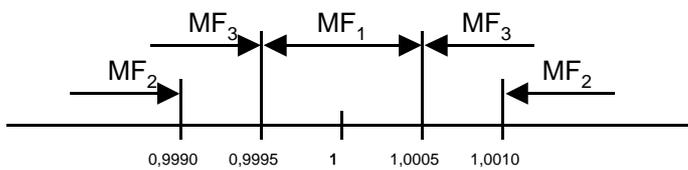
Acceptable within $\pm 0,10\%$



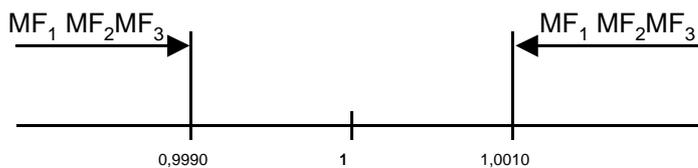
Adjust $MF_A = MF_1$



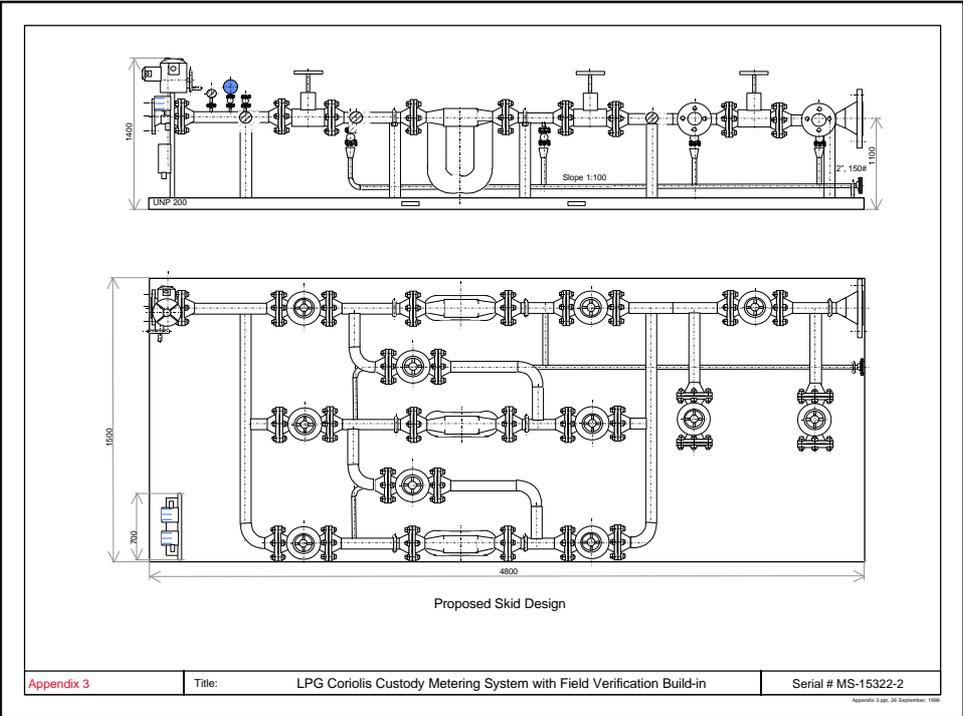
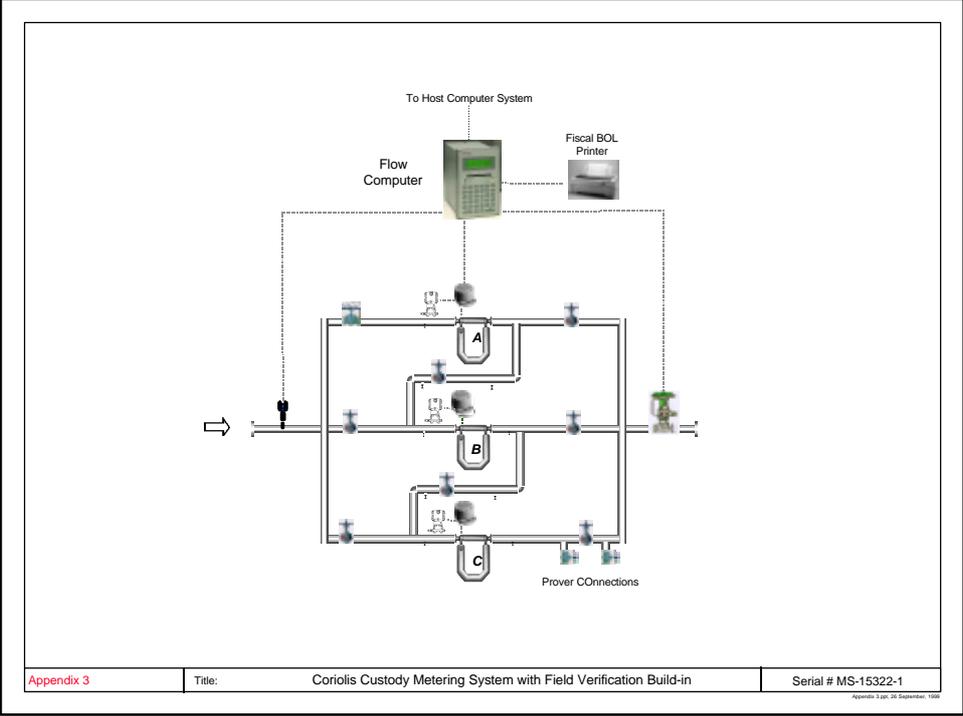
Adjust $MF_B = 1/MF_1$ or repeat calibration



Adjust $MF_C = MF_2$



Investigation Recommended



Appendix 4 - Principle of Operation of a Coriolis Meters

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 centre of rotation. This principle is shown in Figure 1.

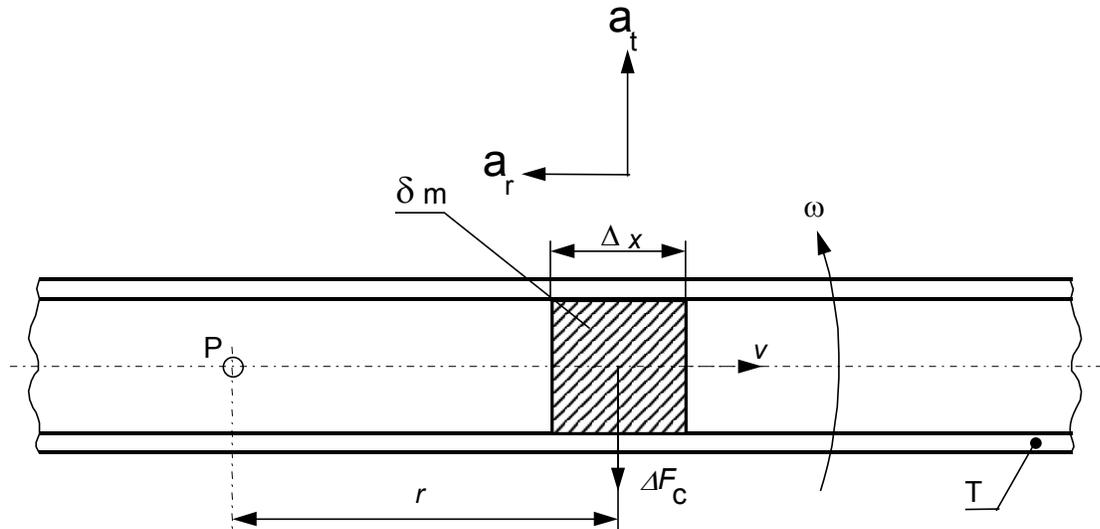


Figure 1 — Principle of operation of a Coriolis meter

A particle of mass δm slides with constant velocity v in a tube T which is rotating with angular velocity ω about a fixed point P . The particle undergoes an acceleration which can be divided into two components:

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

To impart the Coriolis acceleration a_t to the particle, a force of magnitude $2\omega \cdot v \cdot \delta m$ is required in the direction of a_t . The oscillating tube exerts this force on the particle. The particle reacts to this force with an equal force called the Coriolis force, ΔF_C , which is defined as follows:

$$\Delta F_C = 2\omega \cdot v \cdot \delta m$$

When a fluid of density ρ flows at constant velocity v along an oscillating tube rotating as shown in Figure 1, any length Δx of the oscillating tube experiences a transverse Coriolis force of magnitude $\rho F_C = 2\omega \cdot v \cdot \rho \cdot A \cdot \Delta x$ where A is the cross-sectional area of the oscillating tube interior.

Since the mass flow rate q_m can be expressed as:

$$q_m = v \cdot \rho \cdot A \quad (1)$$

The transverse Coriolis force ρF_C can therefore be expressed as follows:

$$\rho F_C = 2\omega \cdot q_m \cdot \Delta x \quad (2)$$

Hence, the (direct or indirect) measurement of the Coriolis force exerted by the flowing fluid on a rotating tube can provide a measurement of the mass flow rate.

This is the principle of operation of a Coriolis meter.

Appendix 5 — PROVING FORMS FOR METERS WITH MASS OUTPUTS

This Appendix provides example of proving form for Coriolis meters configured to output mass

MASS MASTER METER — CORIOLIS METER MASS

PROVER INFORMATION					
DATE: _____ <small>(YY/MM/DD)</small>	PROVER COMPANY _____				
MASTER METER K-FACTOR _____ <small>(PULSES / LB.)</small>	MANUFACTURER _____				
SERIAL NO. _____	MODEL _____				
METER INFORMATION					
SERIAL NO. _____	MANUFACTURER _____	MODEL _____			
METER ID _____	LOCATION _____				
MANUFACTURER FLOW CALIBRATION FACTOR(S) _____					
PULSE SCALING FACTOR _____ <small>(PULSES/BBL.)</small>	KF (In Associated Equipment) _____				_____ <small>(PULSES/BBL.)</small>
PROCESS CONDITIONS					
FLOW RATE _____ <small>(LB./MIN)</small>	_____ <small>(BBL./HR)</small>	DENSITY CORR. FACTOR _____			
DENSITY SOURCE _____ <small>(DEVICE/LOCATION)</small>	DENSITY _____ <small>(kg/m³ @ 60 °F)</small>	FLUID TYPE _____			
PROVE INFORMATION					
PREVIOUS METER FACTOR _____	_____ <small>(DATE OF PROVE YY/MM/DD)</small>			_____ <small>(FACTOR)</small>	
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.* 0.3505071]	_____	_____	_____	_____	_____
METER VOLUME (Bbl.)= [(Meter Pulses/Vol. K-Factor) * CTL _m * CPL _m]	_____	_____	_____	_____	_____
METER FACTOR= (Master Meter Volume/Meter Volume)	_____	_____	_____	_____	_____
AVERAGE METER FACTOR (for 5 runs)			LOCATION OF MF ENTRY _____		
REPEATABILITY _____ <small>((MAX-MIN)/MIN * 100, %)</small>	ZERO VERIFIED? _____		TRANSMITTER/CALC. DEVICE _____		
PROVER _____ <small>(PRINT)</small>	_____ <small>(SIGN)</small>	YES/NO _____	AS FOUND _____	AS LEFT _____	
		WITNESS _____ <small>(PRINT)</small>	_____ <small>(SIGN)</small>		