IS 15672 (2006): Flow measurement of natural gas and fluids by coriolis meters [PGD 26: Weights and Measures]

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Indian Standard

FLOW MEASUREMENT OF NATURAL GAS AND FLUIDS BY CORIOLIS METERS

ICS 75.160.30; 75.180.30

BUREAU OF INDIAN STANDARDS
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Price Group 8

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FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Weights and Measures Sectional Committee had been approved by the Production and General Engineering Division Council.

This standard is used for measuring the gas consumption at the users' end, when the gas is supplied through the pipelines.

In preparing this standard considerable assistance has been derived from following publication:

ISO 10790 : 1999 'Measurement of fluid flow in closed conduits — Guidance to the selection, installation and use of Coriolis meters (mass flow, density and volume flow measurements)'.

Annexes A, B, C, and D are for information only.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'.

CONTENTS

Indian Standard

FLOW MEASUREMENT OF NATURAL GAS AND FLUIDS BY CORIOLIS METERS

1 SCOPE

1.1 This standard provides guidance on selection, installation, calibration, performance and operation of Coriolis meters for the determination of mass flow, density, volume flow and other related parameters of fluids, synonymous for liquids and gases. For gases it specifies the determination of gas mass flow and standard volume flow (using pre-determined standard density). It also specifies appropriate considerations regarding the fluids to be measured.

1.2 The primary purpose of Coriolis meter is to measure mass flow. Some of the meters offer additional possibilities for determining the density and temperature of fluids. From the above measurements, volume flow and other related parameters may be determined. The Coriolis meter is used for fluids mixture of solids, gas in liquids and mixture of liquids.

2 TERMINOLOGY

2.1 Coriolis Meter — It is a device consisting of a flow sensor (primary device) and a transmitter (secondary device) which primarily measures the mass flow by means of interaction between a flowing fluid and the oscillation of a tube or tubes. It may also provide measurements of the density and the process the temperature of the liquid.

2.2 Flow Sensor (Primary Device) — It is a mechanical assembly consisting of an oscillating tube, drive system, measurement sensor(s), supporting structures and housing.

2.3 Oscillating Tube(s) — Tube(s) through which the fluid flows to be measured.

2.4 Drive System — It is the means for inducing the oscillation of tube(s).

2.5 Sensing Device — Sensor to detect the effect of the Coriolis force and to measure the frequency of the tube oscillations.

2.6 Supporting Structure — Support for the oscillating tube(s).

2.7 Housing — It is the environmental protection of the flow sensor.

2.8 Secondary Containment — The housing design to provide protection to the environment in the event of tube failure.

2.9 Transmitter (Secondary Device) — It is the electronic control system providing the drive and transforming the signals from the flow sensor, to give output(s) of the measured inferred parameters. It also provides corrections derived from parameters such as temperature.

2.10 Flow Rate — It is the ratio of quantity of fluid passing through the cross-section of the flow sensor and the time taken for the quantity to pass to this section.

2.11 Mass Flow Rate — It is the flow rate in which the quantity of fluid passes is expressed as mass flow rate.

2.12 Volume Flow Rate — It is the flow rate in which the quantity of fluid which passes is expressed as volume flow rate.

2.13 Accuracy of Measurement — It is the closeness of the agreement between the measurement and a true value of the measurement.

2.14 Simplicity — The mass flow meter is designed to use as a stand-alone device. It can be easily changed the configuration of the meter without the need for computers, complicated software or scripts.

2.15 Repeatability of Results of Measurements — The closeness of the agreement between the results of successive measurements of the same measurement carried out under the same conditions of measurement.

In the mass flow meter there are very few moving parts. All of the internal components are fixed in place resulting in very little physical change inside the mass flow meter. Little physical change in the flow cavity means higher rates of consistency and repeatability.

2.16 Uncertainty of Measurement — The parameter, associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurement.

2.17 Error of Measurement — The result of a measurement minus true values of the measurement.

2.18 Calibration Factor(s) — It is the numerical factor(s) unique to each sensor derived during sensor calibration which when programme into the sensors that the meter performs to its static specification.

2.19 Flow Calibration Factor(s) — It is associated with the mass flow measurement.

2.20 Density Calibration Factor(s) — It is associated with the density measurement.

2.21 Zero Offset — It is the measurement of output indicated under zero flow conditions, usually as a result of stressed being applied to the oscillating tubes by the surrounding pipe work and the process conditions. The zero offset can be reduced by means of a zero adjustment procedure.

2.22 Zero Stability — It is the magnitude of the meter output of the zero flow after the zero adjustment procedure has been completed, expressed by the manufacturer as an absolute value in mass per unit time. This value for zero stability is valid for stable conditions.

2.23 Flashing — It is the (liquids) phenomenon which occurs when the line pressure drops to, or below, the vapour pressure of the liquid. This is often due to pressure drops caused by an increase in the liquid velocity. Flashing is not applicable to gases.

2.24 Cavitation — It is the (liquid) phenomenon related to and following flashing if the pressure recovers causing the vapour bubbles to collapse (implode). Cavitation is not applicable to gases.

2.25 Dependability — The mass flow meters are being used in process like leak detection, flow monitoring and atmospheric testing.

It is the term defined that the Coriolis meter is being used in process like leak detection, flow monitoring and atmospheric testing.

2.26 Relative Humidity — It is the actual amount of water vapour contained in a gas as a percentage of the maximum water vapour contained if the gas fully saturated at metering conditions.

2.27 Choked Flow — It is the maximum flow rate for a particular geometry which can exist for the given upstream conditions. When choked flow occurs, the velocity at cross-section is equal to the local value of the speed of sound (acoustic velocity), the velocity at which small pressure disturbances propagate. Choked flow can occur either at the inlet or the outlet of a Coriolis meter.

2.28 Shock Wave — It is the discontinuity in supersonic flow across which there is a sudden rise in pressure and temperature.

2.29 Critical Nozzle — It is the venture nozzle for which the nozzle geometrical configuration and conditions of use are such that the flow rate is critical.

3 SELECTION CRITERIA FOR USE OF CORIOLIS METER

3.1 General

Coriolis meter shall be selected to measure parameters within the required range and accuracy. Consideration shall be taken to the following points when selecting a Coriolis meter:

a) *Accuracy* — The accuracy varies depending on the parameters to which it applies. Specific recommendations are mass flow, density and volume flow accuracies respectively. For the other parameters are like multi-components systems, immiscible mixture, mass fraction, volume fraction, net mass flow rate, net volume flow rate, etc.

   NOTE — Manufacturers' should specify accuracy for reference condition, if the conditions of use are significantly from those of the original calibration; the meter's performance may be affected.

b) *Installation* — The manufacturer should specify the preferred installation arrangement and state any instruction of use. The installation arrangement shall be designed to provide a maximum operating lifetime. If needed, strainers, filters, air and/or vapour eliminators or other protective devices shall be placed upstream to the meter for the removal of solids or vapours that could cause damage or provoke errors in the measurements. Coriolis meter is generally placed in the mainstream of the flow but may also be placed in a by-pass arrangement for density measurements.

c) *Installation criteria* — Consideration shall be given to the following points:

   1) space required for the Coriolis meter installation, including provision for external prover or master-meter connections, should *in-situ* calibration is required;
   2) class and type of pipe connections and materials, as well as the dimensions of the equipment to be used;
   3) hazardous area classification;
   4) climatic environmental effects on the sensor, for instance temperature, humidity, corrosive atmospheres, mechanical shock, vibration and electromagnetic field; and
   5) mounting and support requirements.

d) *Full-pipe requirement* — The primary device shall be mounted such that the oscillating tube(s) fill completely with the fluid being metered; this will prevent the measuring performance of the instrument from being impaired. The manufacturer should state the means, if any, required to purge or drain gases or liquid from the instrument.

e) *Orientation* — Plugging, coating, trapped gas, trapped condensate or settlement of solid may effect the meter's performance. The orientation of the sensor fully depend on the intended application of the meter and the geometry of the oscillating tube(s). The orientation of the Coriolis meter shall be recommended by the manufacturer.

f) *Flow conditions and straight length requirements* — The performance of a Coriolis meter is usually not affected by swirling fluid or non-uniform velocity profiles induced by up-stream or down-stream piping configurations. Although, specials straight-piping length is normally not required, good piping practices shall be observed at all times.

g) *Valves* — Valves up-stream and down-stream to a Coriolis meter, installed for the purpose of isolation and zero adjustment can be of any type, but should provide tight shut off. Control valves in series with a Coriolis meter shall be installed down-stream in order to maintain the highest possible pressure in the meter and thus reduce the chance of cavitation or flashing.

h) *Cleaning* — For certain applications (for instance hygienic services), the Coriolis meter may require *in-situ* cleaning which may be accomplished by;

   1) mechanical means (using a pig or ultrasonically);

   2) self-draining by mounting instruments in inclined or vertically upstream lines.

   3) hydro-dynamic means:

      i) sterilization (steaming-in-place, SIP); and

      ii) chemical or biological (cleaning-in-place, CIP).

   Care shall be taken to avoid cross-contamination after cleaning fluids have been used. Also chemical compatibility shall be established between the sensor wetted materials, process fluid and cleaning fluid.

j) *Hydraulic and mechanical vibrations* — The manufacturer should specify the operating frequency range of the instrument to enable assessment of possible influences of process or other external mechanically imposed frequencies. It is possible that the performance of the meter may be influenced by frequencies other than the operating frequencies. These effects may largely be addressed by appropriate mounting or clamping of the instrument.

   In environments with high mechanical vibrations or flow pulsations, consideration shall be given to the use of pulsation damping devices and/or vibration isolators and/or flexible connections.

k) *Flashing and/or cavitation* — The relatively high fluid velocities which often occur in Coriolis meters, cause local dynamic pressure drops inside the meter which may result in flashing and/or cavitation.

   Both flashing and cavitation in Coriolis meters (and immediately up-stream and/or down-stream of them), shall be avoided at all times. Flashing and cavitation may cause measurement errors and may damage the sensor.

m) *Pipe stress and torsion* — The flow sensor will be subjected to axial, bending and torsional forces during operation. Changes in these forces, resulting from variations in process temperature and/or pressure, can affect the performance of the Coriolis meter. Care shall be taken to ensure that no forces are exerted on the meter from clamping arrangements.

   Measures should also be taken to prevent excessive stresses from being exerted on the Coriolis meter by connecting pipes. Under no circumstances should the Coriolis meter be used to align the pipe work.

n) *Cross-talk between sensors* — If two or more Coriolis meters are to be mounted close together, interference through mechanical coupling may occur. This is often referred to as cross-talk. The manufacturer shall be consulted for methods of avoiding cross-talk.

4 EFFECTS DUE TO PROCESS CONDITIONS AND FLUID PROPERTIES

4.1 General

Variations in fluid properties such as density, viscosity and process conditions such as pressure and temperature, may influence the meter's performance. These effects have influences which differ depending on which parameter is of interest.

4.2 Application and Fluid Properties

In order to identify the optimum meter for a given application, it is important to establish the range of conditions to which the Coriolis meter will be subjected. These conditions should include:

a) operating flow rates and the following flow characteristics: uni-directional or bi-directional, continuous, intermittent or fluctuating;
b) range of operating densities;
c) range of operating temperatures;
d) range of operating pressures;
e) pressure on the fluid adequate to prevent cavitation and flashing;
f) permissible pressure loss;
g) range of operating viscosities;
h) properties of the metered fluids, including vapour pressure, two-phase flow and corrosiveness; and
j) effects of corrosive additives or contaminants on the meters and the quantity and size of foreign matter, including abrasive particles that may be carried in the liquid stream.

4.3 Multiphase Flow

Liquid mixtures, homogeneous mixtures of solids in liquids or homogeneous mixtures of liquids with low ratios of gas, may be measured satisfactorily in most cases. Multiphase applications involving non-homogeneous mixtures can cause additional measurement errors and in some cases can stop operation. Care shall be taken to ensure that gas bubbles or condensate droplets are not trapped in the meter.

4.4 Influence of Process Fluid

Erosion, corrosion and deposition of material on the inside of the vibrating tube(s) (sometimes referred to as coating) can initially cause measurement errors in flow and density, and in the longer term, sensor failure.

4.5 Temperature Effects

A change in temperature may affect the properties of sensor materials and thus will influence the response of the sensor. A means of compensation for this effect is usually incorporated in the transmitter.

4.6 Pressure Effects

Static pressure changes may affect the accuracy of the sensor, the extent of which shall be specified by the manufacturer. These changes are not normally compensated except in cases of certain precision measurements and certain meter designs and sizes.

4.7 Pulsating Flow Effects

Coriolis meters generally are able to perform under pulsating flow conditions. However, there may be circumstances where pulsations can affect the performance of the meter. The manufacturers' recommendations shall be observed regarding the application and the possible use of pulsation damping devices.

4.8 Viscosity Effects

Higher viscosity fluids may draw energy from the Coriolis excitation system particularly at the start of flow. Depending on the meter design, this phenomenon may cause the sensor tubes to momentarily stall until the flow is properly established. This phenomenon should normally induce a temporary alarm condition in the transmitter.

5 PRESSURE LOSS

A loss in pressure may occur as the fluid flows through to the censor. The magnitude of this loss is a function of the size and geometry of the oscillating tube(s), the mass flow rate (velocity) and dynamic viscosity of the process fluid. Manufacturers should specify the loss in pressure which occur under references conditions and should provide the information necessary to calculate the loss in pressure which occurs under operating conditions. The overall pressure of the system should be checked to insure that it is sufficiently high to accommodate the loss in pressure across the meter.

6 CALIBRATION OF MASS FLOW

6.1 Every Coriolis meter shall be calibrated against a traceable National/International Standard by the manufacturer, and calibration certificates for the meter shall be provided. The calibration factors determined by this procedure shall be noted on the sensor data plate.

6.2 The calibration of a Coriolis meter is similar to the calibration of any other flow meter. The calibration consists of comparing the output of the meter against a traceable standard which has a better uncertainty, preferably at least three times better, than that required for the meter under test.

6.3 As the Coriolis meter is a mass flow device, it is preferable to perform the calibration against a mass or gravimetric reference. Calibration against a volume standard combined with density determination may be used in situations where mass or gravimetric methods are not available or not possible, especially when making field calibrations. The errors introduced by this method have to be carefully assessed. If a Coriolis master meter is used, care shall be taken to avoid cross-talk.

6.4 Calibration should, when possible, be performed using products and conditions as close as possible to those for the intended use. Prior to the start of the calibration, the zero of the meter shall be checked. The

Coriolis meter may need to have a zero adjustment in the calibration test rig and again in the final installation. Detailed calibration advice, calibration intervals, suggested procedures, calibration levels and an example of a calibration curve are given in Annex A.

7 SAFETY

7.1 General

The meter should not be used under conditions which are outside the meter's specification. Meters should also conform to any necessary hazardous area classifications.

7.2 Hydrostatic Pressure Test

The wetted parts of the fully-assembled flow sensor shall be hydrostatically tested in accordance with the appropriate standard.

7.3 Mechanical Stress

The meter shall be designed to withstand all loads originating from the oscillating tube(s) system, temperature, pressure and pipe vibration. The user should respect the limitations of the sensor at all times.

7.4 Erosion

Fluids containing solid particles or cavitation can cause erosion of the measuring tube(s) during flow. The effect of erosion is dependent on meter size and geometry, particle size, abrasives and velocity. Erosion shall be assessed for each type of use of the meter.

7.5 Corrosion

Corrosion, including galvanic corrosion, of the wetted materials can adversely affect the operating lifetime of the sensor. The construction material of the sensor shall be selected to be compatible with process fluids and cleaning fluids. Special attention shall be given to corrosion and galvanic effects in no-flow or empty-pipe conditions. All process-wetted materials shall be specified.

7.6 Housing Design

The housing shall be designed primarily to protect the flow sensor from deleterious effects from its surrounding environment (dirt, condensation and mechanical interference) which might interfere with operation. If the vibrating tube(s) of the Coriolis meter were to fail, the housing containing the tube(s) would be exposed to the process fluid and conditions which could possibly cause housing failure. It is important to take into consideration the following possibilities:

a) pressure within the housing might exceed the design limits; and
b) fluid might be toxic, corrosive or volatile and might leak from housing.

In order to avoid such problems, certain housing designs provide:

a) secondary pressure containment (*see* Annex B); and
b) burst discs or pressure-relief valves, fluid drains or vents, etc.

For guidelines on specifying secondary pressure containment, *see* Annex B.

7.7 Cleaning

7.7.1 For general guidelines, *see* **3.1**(h).

7.7.2 Care shall be taken to ensure that cleaning conditions (fluids, temperatures, flow rates, etc) have been selected to be compatible with the materials of the Coriolis meter.

8 TRANSMITTER (SECONDARY DEVICE)

Coriolis meters are multi-variable instruments providing a wide range of measurement data from only a single point in the process. In selecting the most appropriate transmitter, consideration should be given to:

a) electrical, electronic, climatic and safety compatibility;
b) mounting, that is, integrally or remotely mounted;
c) required number and type of outputs;
d) ease and security of programming;
e) outputs demonstrating adequate stability and reasonable response times, and in the case of an analogue output including the minimum and maximum span adjustments;
f) output(s) indicating system errors;
g) required input options, for instance remote zero adjustment, totalizer resetting alarm acknowledgement; and
h) type of digital communication.

9 INSPECTION AND COMPLIANCE

9.1 As Coriolis meters are an integral part of the piping (in-line instrumentation), it is essential that the instrument be subjected to testing procedures similar to those applied to other in-line equipment.

9.2 In addition to the instrument calibration and/or performance checks, the following optional tests may be performed to satisfy the mechanical requirements:

a) dimensional check;
b) additional hydrostatic test, in accordance with a traceable procedure, as specified by the user; and

c) radiographic and/or ultrasonic examination of the primary device to detect internal defects (that is, inclusions) and verify weld integrity.

Results of the above tests shall be presented in a certified report, when requested.

9.3 In addition to the above reports, the following certificates shall be available at final inspection:

a) material certificates, for all pressure-containing parts;
b) certificate of conformance (electrical area classifications);
c) certificate of compliance; and
d) calibration certificate and test results.

10 MASS FLOW MEASUREMENT

10.1 Apparatus

10.1.1 *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 centre of rotation. This principle is shown in Fig. 1.

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

a) a radial acceleration a_t (centripetal) equal to $w^2.r$ and directed towards P;
b) a transverse acceleration a_t (Coriolis) equal to $2\ w.v$ at right angles to a_t and in the direction shown in Fig. 1.

To impart the Coriolis acceleration a_t to the particle, a force of magnitude $2\ w.v.\delta_m$ 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 Corlolis force, ΔF_C, which is defined as follows:

$$\Delta F_C = 2\ w.v.\delta_m$$

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

Since the mass flow rate q_m can be expressed as:

$$\Delta F_C = 2\ w.q_m.\Delta_r$$

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.

10.1.2 *Coriolis Sensor*

In commercial designs of Coriolis meters, inertia forces are generated by oscillating the tube rather than from a continuous rotary motion.

The smallest driving force required to keep the tube in constant oscillation occurs when the frequency of oscillation is at, or close to, the natural frequency of the filled tube.

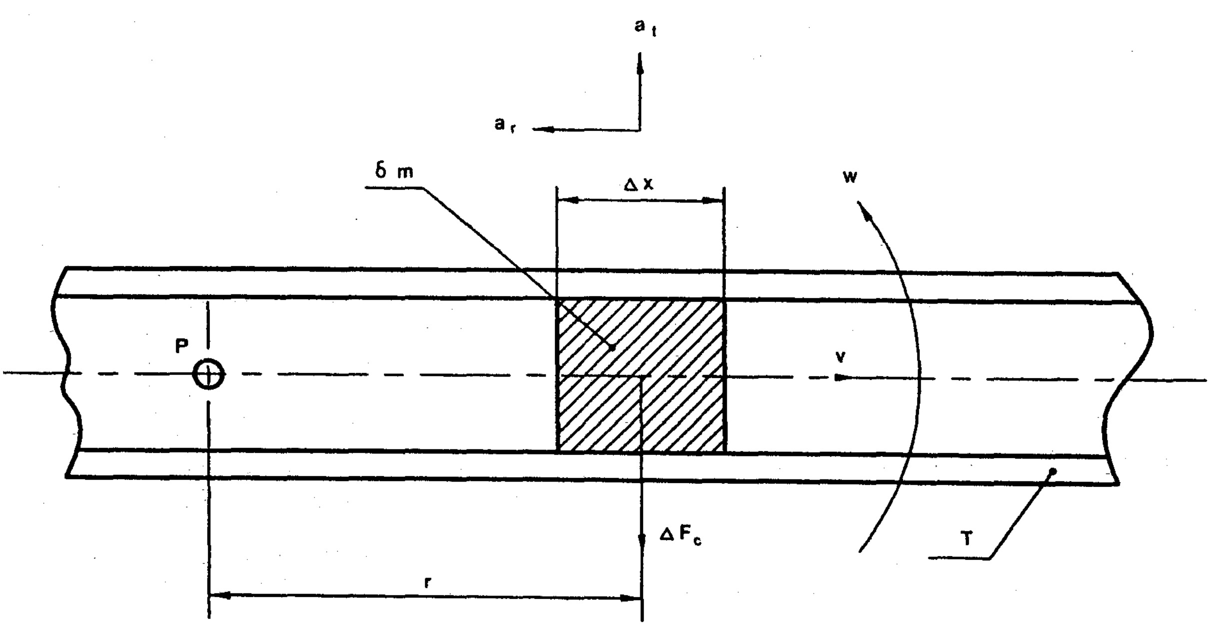


FIG. 1 PRINCIPAL OPERATION OF CORIOLIS METER

In most meters the flow tube is fixed between two points and oscillated at a position midway between these two points, thus giving rise to opposite oscillatory rotations on the two halves of the tube. Meters can have a single tube or two parallel tubes which can be straight or looped.

When no flow is present, the phases of the relative displacements at the sensing points are identical, but when flow is present Coriolis forces act on the oscillating tube(s), causing a small displacement/ deflection or twist which can be observed as a phase difference between the sensing points.

Coriolis forces (and hence distortion of the tube) only exist when both axial motion and forced oscillation are present. When there is forced oscillation but no flow, or flow with no oscillation, no deflection will occur and the meter will give no output.

The sensor is characterized by flow calibration factors which are derived during manufacture and calibration. These values are unique for each sensor and are normally recorded on a calibration certificate and/or a data plate secured to the sensor housing.

10.1.3 *Coriolis Transmitter*

A Coriolis meter requires a transmitter to provide the drive energy and to process the subsequent signals. It is necessary to match the transmitter to the sensor by entering the calibration factors from the sensor data plate.

The mass flow rate is usually integrated over time in the transmitter to give the total mass.

The transmitter may contain application software which can be used to evaluate additional parameters but their requirements necessitate the entry of other coefficients into the software. All outputs are usually scaled separately.

10.2 Accuracy

The term accuracy, expressed as a percentage of the reading, is often used by manufacturers and users as a means of quantifying the expected error limits. For mass flow, the term accuracy includes the combined effects of linearity, repeatability, hysteresis and zero stability.

Linearity, repeatability and hysteresis are combined and expressed as a percentage of the reading. Zero stability is given as a separate parameter in mass per unit time. In order to determine the complete accuracy value, it is necessary to calculate zero stability as a percentage of the reading at a specified flow rate, and add this value to the combined effects of linearity, repeatability and hysteresis.

Repeatability is often given as a separate parameter, expressed as a percentage of the reading. It is calculated in a similar way to accuracy.

Accuracy and repeatability statements are usually made for reference conditions which are specified by the manufacturer. These reference conditions should include temperature, pressure, density range and flow range.

11 FACTORS AFFECTING MASS FLOW MEASUREMENT

11.1 General

See also Annex C for further details.

11.2 Density and Viscosity

Density and viscosity usually have a minor effect on measurements of mass flow. Consequently, compensation is not normally necessary. However, for some designs and sizes of meters, density changes may induce an offset in the meter output at zero flow and/ or a change in the meter calibration factor. The offset can be eliminated by performing a zero adjustment under operating conditions.

11.3 Multiphase Flow

Liquid mixtures, homogeneous mixtures of solids in liquids, and homogeneous mixtures of liquids with a low ratio of gas may be measured satisfactorily in many cases. Multiphase applications involving non-homogeneous mixtures can cause additional measurement errors and in some cases can stop operation. Care shall be taken to ensure that gas bubbles or condensate droplets are not trapped in the meter. Special attention shall be given under these circumstances to the zero-adjustment procedure.

11.4 Temperature

Temperature changes affect the flow calibration factor of the sensor and compensation is necessary. Compensation for this effect is usually performed by the transmitter. However, large differences in temperature between the oscillating tube(s) and the ambient temperature can cause errors in the temperature compensation. The use of insulation materials can minimize these effects. Temperature variations may also induce an offset in the meter output at zero flow. Thus, it is necessary to check the meter zero at the process temperature.

11.5 Pressure

Pressure usually has a minor effect on measurements of mass flow and compensation is not normally necessary, However, for some designs and sizes of meters, pressure changes can affect the flow calibration factor and, in this case, compensation is necessary. Pressure changes may also induce an offset in the meter output at zero flow. This effect can be eliminated by performing a zero adjustment at the process pressure.

11.6 Installation

Stresses exerted on the sensor from surrounding pipe work can introduce an offset in the meter output at zero flow. This offset shall be checked after the initial installation or after any subsequent change in the installation. Another zero adjustment shall be performed, if the offset is unacceptable.

12 ZERO ADJUSTMENT

Once the meter installation is complete, a zero adjustment is usually necessary to overcome the effects described above. To check or adjust the zero flow, the meter shall be full and all flow stopped by turning off the down-stream valve first followed by the up-stream valve. It is recommended that the meter zero is first checked, and adjusted if the offset is unacceptable. Zero adjustment shall be made under process conditions of temperature, pressure and density. It is essential that the fluid remain stable and that there are no bubbles or heavy sediment and no movement. Zero adjustment is usually initiated by pressing a zero button in the transmitter or by remote control.

The level of the zero adjustment can be checked by observing the meter output at zero flow. However, before viewing the output, it is essential that the low flow cut-off setting in the transmitter be set to zero or alternatively, an output unaffected by the low flow cut-off setting be used. If appropriate, the bi-directional function may need to be activated. It is advisable to check the zero the meter periodically.

13 DENSITY MEASUREMENT UNDER METERING CONDITIONS

13.1 General

Coriolis meters can provide in-line density measurement under metering conditions. This clause outlines how density and relative density measurements are made on fluids under metering conditions. It also includes recommendations for density calibration. Density-based inferred measurements such as standard density and concentration are dealt with in **8**.

13.2 Principle of Operation

Coriolis meters are normally operated at their natural or resonant frequency. For a resonant system there is a very close relationship between this frequency and the moving mass. With good approximation, the natural frequency of a Coriolis meter viewed as a resonant system can be written as:

$$f_R = \frac{1}{2\pi}\sqrt{\frac{C}{m}}$$

with

$$m = m_t + m_{fl}$$

where

- f_R = resonant or natural frequency;
- C = mechanical stiffness or the spring constant of the measuring tube arrangement;
- m = total oscillating mass;
- m_t = oscillating mass of the measuring tube(s);
- m_{fl} = oscillating mass of the fluid within the tube(s);
- V_{fl} = volume of fluid within the tube(s); and
- ρ_{fl} = density of the fluid.

The mechanical stiffness or the spring constant of the measuring tube arrangement depends on the design of the meter and the Young's modulus of elasticity of the tube material.

The density of the fluid, ρ_{fl} can be determined.

$$\rho_{fl} = \left[\frac{C}{V_{fl}(2\pi f_R)^2}\right] - \frac{m_t}{V_{fl}}$$

and after simplification it becomes:

$$\rho_{fl} = K_1 - \frac{K_2}{F_R^2}$$

where

K_1 and K_2 are coefficients for the density measurement, determined during the calibration process.

The frequency can be determined by measuring the period of the tube oscillation, T_f, or by counting cycles, N_c during a time window (gate), t_w:

$$f_R = \frac{1}{T_f} \quad \text{or} \quad f_R \frac{N_c}{t_w}$$

K_1 and K_2 are temperature dependent and should be automatically by means of an integral temperature measurement.

13.3 Relative Density

Dividing the fluid density under process conditions by the density of pure water under reference conditions, results in the relative density, d, under process conditions, as follows:

$$d = \frac{\rho_{fl}}{\rho_{w,ref}}$$

where

ρ_{fl} = density of fluid under metering conditions; and

$\rho_{w.ref}$ = density of water under reference conditions.

13.4 Accuracy

The term accuracy is often used by manufacturers and users as a means of quantifying the expected error limits. For density, the accuracy includes the combined effects of linearity, repeatability and hysteresis. Density accuracy is expressed as an absolute value in mass per unit volume (that is, g/cm^3 or kg/m^3).

Accuracy and repeatability statements are usually given for reference conditions which are specified by the manufacturers. These reference conditions should include temperature, pressure, density range and flow range. If properly installed, the meter should measure density within these accuracy limits.

13.5 Factors Affecting Density Measurement

13.5.1 *General*

See also Annex C for further details.

The measurement of density can be influenced by changes in process conditions. In certain applications, these influences may be significant and manufacturers shall be able to quantify the effect, or give guidance on the likely impact on the performance of the meter, for instance could be expressed as a density shift per degree change.

13.5.2 *Temperature*

Temperature changes can effect the density calibration factor of the sensor. Therefore, compensation for these changes is necessary and is performed automatically by the transmitter. However, due to non-linearity of the density equation, the effect may not be entirely eliminated. In order to minimize this effect in pension applications, it may be necessary to calibrate at the operating temperature. Large differences in temperature between the oscillating tube(s) and the ambient temperature can errors in temperature compensation. The use of insulation materials can minimize these effects.

NOTE — In certain applications, for instance cryogenic liquids, there may be a transient temperature influence, resulting from a step change in process temperature (thermal shock) which will momentarily influence the density measurement. This may also need to be taken into account.

13.5.3 *Pressure*

Pressure usually has a minor effect on measurements of density and compensation is not normally necessary. However, for some design and sizes of meters, pressure changes can affect the density calibration factor. In this case, compensation is necessary and it may be necessary to perform the calibration at process operating pressure.

13.5.4 *Multiple Phases*

The density of liquid mixtures, homogeneous mixtures of solids in liquids or homogeneous mixtures of liquids with a low ratio of gas may be measured satisfactorily. In some circumstances, multiphase applications (particularly gas bubbles in liquids) mean cause additional measurement errors and even stop operation. The degree to which bubbles or suspended solids can be tolerated without influencing the density measurement will depend on their distribution in and coupling with the carrier fluid. For example, large pockets of air in water are more troublesome than homogeneously distributed bubbles in a highly viscous liquid. The suitability of a Coriolis meter for density measurement of a multiphase system will depend on its intended use. The choice of an appropriate meter should only be made after careful consideration and consultation with the manufacturer.

13.5.5 *Flow*

Density calibration is usually carried out under static conditions, that is, without any fluid flowing. However, when in operation on a flowing fluid, hydraulic noise may influence the density measurement. Fluid velocities which may given rise to such an effect will vary depending on the sensor size and geometry. For precise density measurements at velocities within these ranges, it is advisable to perform the density calibration under flowing conditions. Some manufacturers offer automatic compensation for flow effects on density measurement.

13.5.6 *Corrosion, Erosion and Coating*

Corrosion and erosion will decrease the mass of the measuring tube; conversely, coating will increase the mass of the tube. Both of these effects will induce errors in the density measurement. In applications where these effects are likely, care shall be taken in specifying suitable materials, selecting the most appropriate meter size (limiting) velocity, and where necessary, applying regular cleaning.

By monitoring the density measurement trend, it may be possible to diagnose excessive corrosion, erosion or coating within the measuring tube(s).

13.5.7 *Installation*

Installation stresses do not influence the density measurement. For certain sensor designs there may be a minor orientation effect. In precision density applications, it may be necessary to calibrate the meter in is intended final orientation or alternatively perform a field adjustment.

13.6 Calibration and Adjustment

13.6.1 *General*

Coriolis meters may be calibrated during manufacture and/or by field adjustment. Only single-phase, clean liquids shall be used for calibration or adjustment. The measuring tubes shall be clean and free of coating or deposits and shall be flushed immediately prior to calibration. Any deviation from these requirements may result in significant measurement errors.

13.6.2 *Manufacturer's Calibration*

Coriolis meters should be calibrated by the manufacturer for density measurement, usually air and water as reference fluids. The density calibration factors determined by this procedure shall be as given by the manufacturer, usually noted on the sensor data plate. If a precision density measurement is required, a special calibration may be necessary using multiple fluids of similar densities, temperatures and pressures for the final use. In these circumstances, a density calibration certificate for the meter shall be available on request.

13.6.3 *Field Adjustment*

The advantage of field adjustment is that it can be performed by the user with the process fluid in the measuring tubes. It is essential that the density measurement from the Coriolis meter remain stable before the adjustment is made. The user should know the density of the fluid within the meter to the required uncertainty.

The transmitter shall be equipped with facilities to support a field adjustment with the meter filled with one or more liquids. Field adjustment is recommended if installation effects, for instance meter orientation, are to be eliminated.

The procedure necessary to accomplish a field adjustment shall be outlined in detail in the instruction manual.

NOTE — The Coriolis meter density measurement may often be used as an indication of the stability of the system which may be helpful in diagnosing potential application and/or installation problems.

14 VOLUME FLOW MEASUREMENT UNDER METERING CONDITIONS

14.1 General

Coriolis meters directly measure fluid mass flow rate and density under metering conditions. They are generally used where measurements of either, or both, of these parameters are of key importance. There are applications where the advantages of a Coriolis meter may be very beneficial, but the desired measurement is volume under metering conditions. Coriolis meters may be effectively used for volume flow measurement.

14.2 Volume Calculation

Volume may be calculated from mass and density as follows:

$$V = \frac{m}{\rho}$$

where

V = volume under metering conditions;

ρ = density under metering conditions; and

m = mass.

Above equation may be incorporated directly into the transmitter software provided the Coriolis meter is of a type that may measure both mass and density. The mass part of the above equation is measured as a function of time (mass flow rate) and therefore the volume calculated is also a function of time.

$$q_v = \frac{q_m}{\rho}$$

where

q_v = volume flow rate under metering conditions; and

q_m = mass flow rate.

The Coriolis meter may then provide the volume flow rate calculated from above equation as an output signal. The calculated volume flow rate may also be integrated with respect to time to obtain the total volume.

The calculated volume flow is based on dynamic mass flow and dynamic density measurements made under process conditions. Volume flow in this form is a dynamic measurement under process conditions, not under reference conditions.

14.3 Accuracy

The manufacturer should specify the expected accuracy for volume measurement. If this information is not available, the expected accuracy for volume flow measurement may be calculated from:

$$\varepsilon_v = \varepsilon_m^2 + \varepsilon_p^2$$

where

ε_v = accuracy of the volume measurement;

ε_m = accuracy of the mass measurement; and

ε_p = accuracy of the density measurement.

NOTE — All the above values of accuracy are expressed in terms of ± percent of the reading.

14.4 Special Influences

14.4.1 *General*

Coriolis meters may only give a computed value of the volume and as such, the reliability can be only as good as the data entered into the volume equation. On this basis, any variation in the fluid or in process parameters which may have an influence on the reliability of mass flow and density measurements may have a combined effect on the reliability of the calculated volume measurement. For specific effects of variations in process conditions on mass flow and density measurements, *see* **5** and **6**.

14.4.2 *Empty Pipe Effect*

A Coriolis meter measuring liquid flow may respond to tubes becoming empty or liquid being displaced by vapour by a drop in the density reading falling close to zero. If this were to occur while there was still a small indicated mass flow present, the calculation of the liquid volume would be erroneously high (*see* **14.2**). This problem may be avoided by incorporating a suitable low-density cut-off setting, designed to inhibit any flow measurement being performed unless the meter is properly filled with liquid. Manufacturer may provide alternative methods for eliminating this problem.

14.4.3 *Multiphase Fluids*

Liquid volumes cannot be measured reliably, if there is more than one phase present.

14.5 Factory Calibration

14.5.1 *Mass Flow and Density*

When comparing a Coriolis meter volume output with a known volume standard, it is impossible to distinguish between the inaccuracy of the instrument's mass flow measurement and the inaccuracy of the density measurement. Therefore, for calibration purposes, Coriolis meters should always be considered as mass flow and density measuring devices.

These two parameters should first be calibrated in accordance with the recommendations given in **10** and **11**, before the meter can be used for volumetric measurements. Once the meter has been calibrated for mass flow and density, a theoretical prediction of the volume accuracy can be determined.

14.5.2 *Volume Check*

The expected value of accuracy for volume measurement may be checked by performing a volumetric test against a known volume standard. In addition to the standard calibration certificate on request manufacturers shall be able to provide test data showing volume flow rates and corresponding volumetric errors. These errors can be determined using the mass flow calibration data and the precise calibration fluid density. The volume determination can also be checked by means of a field test, which shall be performed using the Coriolis meter in its operational installation using the process fluid.

15 ADDITIONAL MEASUREMENTS

15.1 General Considerations for Multi-Component Systems

The density measurement made by a Coriolis meter is a function of the composite density of the process fluid of the tube(s). If the fluid contains two components and the density of each component is known, the mass or volume fraction of each component can be determined.

By combining the (independent) mass flow rate and density (or concentration) measurements, the net mass flow each component of a two-component mixture can also be calculated. Net flow measurements are limited to two-component systems for instance oil and water, and are useful in a wide variety of applications. For example, flow rates of each component of two-component systems such as water-and-oil mixtures liquid-and-solid slurries, sugar measurements and other two-component systems can be determined using a Coriolis meter.

Theoretically a Coriolis meter will measure the average density of multi-component fluids, including two-phase systems. This is generally true in the case of slurries (solids carried by a liquid). However, measurements of a gas phase in a liquid stream or conversely, a liquid in a gas stream, can be difficult to make due to structural; influences within the sensing element. Consult the manufacturer, if two-phase flow is to be measured.

15.2 Immiscible Mixtures

15.2.1 *General*

An immiscible liquid is a liquid containing two components which do not mix. The total volume is the sum of the individual volumes under metering conditions.

15.2.2 *Mass Fraction*

The relationship between component A and component B respectively, as a mass fraction w expressed as a percentage.

$$w_A = \frac{\rho_A(\rho_{measured} - \rho_B)}{\rho_{measured}(\rho_A - \rho_B)} \times 100$$

$$w_B = \frac{\rho_B(\rho_A - \rho_{measured})}{\rho_{measured}(\rho_A - \rho_B)} \times 100$$

where

w_A and w_B = respective mass fractions of component A and component B in relation to the mixture;

ρ_A and ρ_B = respective densities of component A and component B; and

$\rho_{measured}$ = measured density of the mixture.

15.2.3 *Volume Fraction*

The relationship between component A and component B, as a volume fraction φ expressed as a percentage.

$$\varphi_A = \frac{\rho_{measured} - \rho_B}{\rho_A - \rho_B} \times 100$$

$$\varphi_B = \frac{\rho_A - \rho_{measured}}{\rho_A - \rho_B} \times 100$$

where

φ_A and φ_B = respective volume fractions of component A and component B in relation to the mixture.

15.2.4 *Net Mass Flow Rate*

By combining the total mass flow rate and the mass fraction measurements, the net mass flow rate of each of two-components may be calculated as follows:

$$q_{m.A} = \frac{q_{m.T} \times w_A}{100}$$

$$q_{m.B} = \frac{q_{m.T} \times w_B}{100}$$

where

$q_{m.T}$ = total mass flow rate of the mixture; and

$q_{m.A}$ and $q_{m.B}$ = net mass flow rate of components A and B, respectively.

15.2.5 *Net Volume Flow Rate*

By combining the total volume flow rate and volume fraction measurements, the net volume flow rate of each of two-components may be calculated as follows:

$$q_{v.A} = \frac{q_{v.T} \times \varphi_A}{100}$$

$$q_{v.B} = \frac{q_{v.T} \times \varphi_B}{100}$$

where

$q_{v.T}$ = net total volume flow rate;

$q_{v.A}$ and $q_{v.B}$ = net volume flow rate of components A and B, respectively; and

φ_A and φ_B = respective volume fractions of components A and B in relation to mixture (*see* **15.2.3**).

15.3 Miscible Liquids Containing Chemically Non-interacting Components

A miscible liquid consists of two components which mix completely or dissolve together and the total volume of the liquid may be different from the sum of the individual volumes at metering conditions.

When two liquids are completely miscible, such as alcohol and water, the mass fraction (of either liquid component) *versus* density is usually read from table values. It is not possible to obtain general equation valid for all miscible liquids due to the non-linear relationship between mass fraction and density. It is necessary to derive an equation for each mixture (*see* Annex D).

15.4 Solutions Containing Chemically-Interacting Components

The relationship between two soluble liquids which react chemically is complex, *see* Annex D.

15.5 Special Consideration for Temperature and Pressure

The previous equations and discussions (as well as those in Annex D) assume constant temperature and pressure conditions. In any mixture, temperature and pressure will affect the density of each of the two components differently. Therefore, corrections are required. Typically, pressure has a small influence on the density and can be considered negligible, particularly if the pressure is almost constant. Any influence can be characterized by making a calibration. Temperature has a much larger influence and on-line corrections are necessary. Coriolis meters provide temperature measurement for material property corrections of the sensing element. This is a convenient measurement to use for liquid property corrections within the transmitter, however, it may be necessary to make a separate temperature measurement for precision applications.

16 MARKING

The meter shall be marked with at least the following information:

a) Manufacturer's name or trade-mark;
b) Serial number;
c) Maximum flow rate, q_{Max} in actual volume units; and
d) Maximum allowable operating pressure.

16.1 BIS Certification Marking

The product may also be marked with the Standard Mark.

16.1.1 The use of the Standard Mark is governed by the provisions of *Bureau of Indian Standards Act*, 1986 and the Rules and Regulations made thereunder. The details of conditions under which the licence for the use the Standard Mark may be granted to manufacturers or producers may be obtained from the Bureau of Indian Standards.

ANNEX A

(*Clause* 6.4)

CALIBRATION TECHNIQUES

A-1 INTRODUCTION

Coriolis meters are calibrated in the same manner an any other flow meter. Calibration involves comparing the output of the meter under test with a suitable standard of adequate certainty. There are two levels of calibration, described in detail in **A-2**, as follows:

a) *Type* 1 *standard calibration* — the details of which are specified by the manufacturer; and
b) *Type* 2 *special calibration* — the details of which are specified by the user.

Ideally, Coriolis meters shall be calibrated using gravimetric techniques. However, volumetric methods can also be used, provided the overall uncertainties of the mass flow measurement include the uncertainty of both volume and density measurements. Coriolis meters measure mass, therefore, quantities of fluid measured during a gravimetric calibration, should ultimately be expressed in units of mass that is corrected for buyoyance.

NOTE — Calibration strictly refers to the procedure by which the flow meter is checked against a traceable reference and does not include adjustment to the calibration factors.

A-2 CALIBRATION METHODS

A-2.1 General Considerations

When calibrating Coriolis meters, it is advisable to collect data from the transmitter output(s) which is (are) independent of any damping settings. A sufficient number of pulses shall be counted during the test to establish an acceptable calibration uncertainty.

There are three main methods for calibrating flow meters: gravimetric, volumetric and by use of a master-meter. In each case, two operational techniques can be used.

a) *Dynamic (flying) start/stop* — data collection starts and stops while the fluid is maintained at a stable flow rate. The transmitter-signal processing time may result in a delay in the pulsed output. This shall be taken into consideration when using a dynamic method in which small amounts of liquid are measured, for instance small volume provers and diverter-based test facilities.
b) *Static start/stop* — data collection starts and stops at zero flow conditions. In this case, the run time shall be sufficiently long to account for errors induced by flow rate variations at the start and end of the run. The transmitter-signal processing time may result in a lag in the pulsed output. Therefore, even after the valve has been closed and the flow has stopped, the meter's electronics may continue to indicate flow. Errors due to this delayed pulse output shall be accounted for.

A-2.2 Gravimetric Methods

The test fluid shall be collected in a weighing vessel. The mass of the vessel shall be recorded before the test starts and after the test is completed. The difference between these two readings is the collected mass and in the case where air or gas is displaced, the collected mass shall be corrected for buoyancy. Care shall be taken to avoid evaporation and the formation of condensation on the tank walls. Calibration is made by comparing the transmitter totalizer with the collected mass.

A-2.3 Volumetric

The Coriolis meter can be calibrated using an established volumetric method, for instance collecting the test fluid in a certified vessel or using a volume prover. However, the collected quantity (volume) must be converted into mass by multiplication by the fluid density. The density can be measured dynamically using an on-line densitometer or, if the fluid density is constant, by sampling methods. If the properties of the fluid are well known, the density can also be determined by measuring the fluid temperature and pressure within the vessel.

A-2.4 Master-Meter (Reference Meter)

A master-meter can also be used to calibrate a Coriolis meter using established methods. The stability and accuracy of the master-meter shall be fully documented and should provide adequate uncertainty in mass units. If the master-meter is a volumetric device, its measurement shall be converted to mass using the density. The density can be measured dynamically using an on-line densitometer or, if the fluid density is constant, using sampling methods. If the properties of the fluid are well known, the density can also be determined by measuring the fluid temperature and pressure during the test.

If the master-meter is a Coriolis device, care shall be taken to avoid cross-talk. The manufacturer shall be consulted for methods of avoiding cross-talk.

A-2.5 Calibration Frequency

A Coriolis meter should not drift, if it is correctly installed and used with clean, non-abrasive fluids. The frequency of calibration of the meter is governed by the criticality and nature of the operating conditions. It may be appropriate to reduce or increase the frequency of calibration as data is gathered. For fiscal and/or custody transfer applications, this frequency may be prescribed by regulation, or agreed between the relevant parties, and may be once or twice per year.

If the meter installation conditions vary, for instance as a result of pipe work modification in the vicinity of the meter, it is likely that the meter zero offset will be affected. This can be corrected by conducting a zero adjustment. A zero adjustment is needed if the meter output at zero flow conditions is greater than the meter zero stability specified by the manufacturer.

A-3 CALIBRATION PROCEDURES

The procedures adopted for all meter calibration methods should ensure that:

a) meter is installed in accordance with manufacturer's recommendations;

b) meter under test, and the test facility itself, is filled completely with test fluid before and after the test to prevent any effect from air;

c) calibration is preceded by an appropriate warm-up period and hydraulic run-in time;

d) all transmitter configuration data is recorded prior to the start of the test;

e) meter output is monitored at zero flow before and after the test; and

f) test flow rates are selected to cover the operating flow range of the meter when it is in service.

A-4 CALIBRATION CONDITIONS

A-4.1 Flow Stability

The flow must be kept stable to within ±5 percent of the selected flow rate for the duration of the calibration test at that flow rate.

A-4.2 Zero Adjustment

First, a zero flow condition shall be established (and checked) in the test rig. If the meter output at zero flow conditions is within the zero stability value specified by the manufacturer, a zero adjustment will not be necessary. However, if the output at zero flow conditions is seen to be unsatisfactory, a single zero adjustment shall be made only at the start of the calibration and not between runs. It is recommended that the fluid conditions be recorded as part of the zero adjustment.

A-4.3 Temperature and Pressure

Variations in fluid temperature and pressure shall be minimized during the calibration process. For a single run, the temperature shall be held constant to within 1°C, and to within 5°C for the entire duration of the calibration. The fluid pressure within the test rig shall be kept sufficiently high to avoid flashing or cavitations in the meter and/or in the vicinity of the meter. Ideally, proving shall be performed under the normal operating pressure and temperature conditions of the intended use.

A-4.4 Density and Viscosity

Depending on the Coriolis meter design, the performance may be affected by variations in fluid density and viscosity. In these cases, test fluids shall be used having properties that are the same or similar to the process fluid for which the meter is intended.

A-5 CALIBRATION CERTIFICATE

The following data shall be included on a meter calibration certificate:

a) unique attribute certificate number, repeated on each page along with the page number and the total number of pages;

b) certificate date of issue and the test date if it differs from the certificate date of issue;

c) identity of the party commissioning the test;

d) name and location of the test laboratory;

e) test fluid data such as product name or density; temperature pressure;

f) unique identification of meter under test;

g) traceability of the test facility and its procedures;

h) uncertainty statement and calculation method;

j) relevant ambient conditions;

k) relevant test data and the results of the calibration, including meter output at zero flow at start and finish of calibration;

m) calibration data shall be presented in chronological order;

n) orientation of the Coriolis meter;

p) configuration data within the transmitter at which the calibration is performed; and

q) authorized signature.

A-6 TYPICAL CALIBRATION CERTIFICATE

A typical calibration certification format is given below:

Certificate No.: .... Page ....of..............

Supplier: ....

Sensor: Type number ....

Serial number ....

Sensor calibration factor ....

Transmitter: ....

Sensor: Type number ....

Serial number ....

mA-pulsed-density etc ....

Output calibrated: ....

Test Conditions

Calibration fluid (product name) ....

Viscosity .... at .... °C

Density .... at .... °C

Temperature of test fluid .... °C

Pressure at inlet to the meter .... bar

Output at zero flow before calibration ....

Output at zero flow after calibration ....

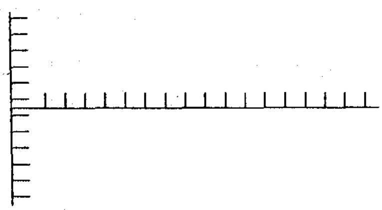
Orientation ....

Facility traceable to ....

Uncertainty of test facility ....

q_m	*Percent of Scale*	*Indicated Mass*	*Mass Reference*	*Observed Error* (%)	*Specification* (%)
....	....	....	....	....	....
....	....	....	....	....	....
....	....	....	....	....	....
....	....	....	....	....	....

Observed error (%)



50% 100% at full scale reading

Flow range minimum ....maximum ....

Pressure drop at maximum flow ....

Configuration data at which calibration was performed
(may be printed on separate sheet, belonging to this certificate)

ANNEX B

(*Clause* 7.6)

SECONDARY CONTAINMENT OF CORIOLIS METERS

B-1 SAFETY GUIDELINES FOR THE SELECTION OF CORIOLIS METERS

B-1.1 General Considerations

When the Coriolis meter is used in critical applications, such as in offshore oil and gas production and in the metering of flammable or toxic substances, care shall be taken to verify that the integrity of the meter can be maintained up to test pressure over the expected lifetime under true process conditions.

It is generally thought that because Coriolis meters have thin-walled vibrating tubes, they are vulnerable to stress fatigue resulting in tube failure. This is common misconception and has often led to a gross over-specification of these meters or in some cases, their avoidance altogether.

Experience amongst manufacturers demonstrates that when used in normal operation, the stresses induced within a Coriolis meter are too small to instigate fatigue.

When Coriolis meters are specified for a particular application, special attention shall be given to the following specific areas.

B-1.2 Materials

Care shall be taken to establish that suitable wetted materials re-selected for compatibility with the process fluid(s) being metered including cleaning fluids. Material incompatibility is the most common source of Coriolis-tube fracture and can be totally avoided at the sensor selection stage. Standard material guides do not necessarily apply to thin-walled, vibrating tubes. Manufacturers' recommendations shall be considered as well as standard material guides.

B-1.3 Velocity

Care shall be taken to ensure that no erosion takes place within the sensor when measuring the flow of abrasive products. Thinning of the measuring tube through erosion can eventually lead to catastrophic failure. Manufacturers shall be able to specify the maximum flow velocity not subject to erosion for a given sensor size.

B-1.4 Tube Pressure Rating

In order to guarantee conformance for the tube pressure rating, the manufacturer should provide the following information:

a) ASME Codes to which the tubes have been designed (or a recognized equivalent standard); and
b) design calculations pertaining to the codes mentioned in (a) for the wall thickness, pressure ratings, etc.

B-1.5 Flange Pressure Rating

Similarly, appropriate ASME design Codes shall be available for checking the suitability of the connections to the Coriolis sensor.

B-1.6 Pressure Testing

Evidence shall be available from the manufacturer to confirm that the full-assembled sensor has passed an appropriate pressure test. This evidence shall be available in terms of a certificate or a test procedure.

When the above criteria can be fulfilled for any given use, secondary containment should not be necessary.

B-2 SECONDARY CONTAINMENT

B-2.1 Appropriate Use

While the principles laid down in **B-1** serve as safety guidelines for meter selection, there may be situations where all of the above-mentioned criteria cannot be satisfied. For example, if some concern remains regarding material compatibility due to the unknown nature of the process fluids which will pass through the meter, then secondary containment may be required. In this case, the following issues shall be addressed regarding the integrity of the secondary containment offered.

B-2.2 Design Integrity

Evidence shall be available from the manufacturer demonstrating that the containment vessel has been designed specifically for the given purpose and in accordance with a recognized standard.

B-2.3 Pressure Testing

In addition to the provision of design calculations demonstrating the suitability of a containment vessel, it may be necessary for manufacturers to perform test on the fully assembled containment vessel. Such pressure tests shall be conducted using suitable purge connections in the containment case. Test should conform to an established procedure and shall be supported by the necessary documentation and test certificates.

B-2.4 Selection of Appropriate Secondary-Containment Pressure Ratings

General guidelines for specifying the pressure rating of secondary-containment vessels are as follows:

a) Maximum continuous containment pressure > Process relief pressure; and

b) Containment burst pressure > Plant design pressure.

The secondary-containment of a Coriolis meter will only be subjected to pressure under abnormal conditions (tube fracture), which would, from necessity, be for a limited duration and a single occurrence. On this basis, it may be possible to accept a pressure specification for the containment vessel of the Coriolis meter which is less rigorous than that of the rest of the pipe work. Such compromises should only be made within design and/ or test code requirements.

In cases where the process design pressure is higher than that of the secondary containment pressure, the safety of the Coriolis meter installation can be enhanced by installing a pressure switch in the secondary containment for use as a trip alarm. Alternatively, a bursting disc or relief valve can be used.

ANNEX C

(*Clauses* 11.1 *and* 13.5.1)

CORIOLIS METER SPECIFICATIONS

C-1 The following is the minimum amount of information to be specified by the manufacturer for a Coriolis meter:

Identification	Manufacturer Model number (Measuring principles)
Primary measurements	Mass flow/density/temperature Ranges of above
Output signals	Analogue Pulse Digital Display Discrete
Performance	Accuracy for specified conditions Zero stability Repeatability Operating influences on temperature Operating influences on pressure Operating influences on gas ratio by volume Pressure drop under specified conditions
Operating limits	Density Pressure Temperature Viscosity
Mechanical	Tube geometry Materials of construction Tube dimensions Overall dimensions Weight Process connections Secondary containment
Electrical	Power supply
Certification	Safety approvals Fiscal approvals Secondary containment General documentation

ANNEX D

(*Clauses* 15.3, 15.4 *and* 15.5)

MASS FRACTION MEASUREMENT EXAMPLES

D-1 MISCIBLE LIQUIDS CONTAINING CHEMICALLY NON-INTERACTING COMPONENTS

D-1.1 Relationship Between Density and Mass Fraction

Figure 2 is an example of the relationship between density and mass fraction for two miscible liquids, water and ethanol at 20°C.

Pure water and pure ethanol have the following densities:

a) Water = 0.999 823 g/cm^3

b) Ethanol = 0.789 34 g/cm^3

For example, a density of 0.789 34 g/cm^3 is given for a mass fraction of 100 percent ethanol and a density of 0.999 823 g/cm^3 for a mass fraction of 0 percent ethanol (or 100 percent water) in Fig. 2. Other intermediate values of density can be determined from the non-linear curve given in Fig. 2.

D-1.2 Mass Fraction

The value of mass fraction, expressed as a percentage, is determined directly from table values or the curve fit of a graph similar to Fig. 2.

D-1.3 Volume Fraction

The net volume of two components that are soluble is difficult to quantify in absolute terms. If a volume of component A and a volume of component B are mixed, the resulting volume does not equal the sum of volume A and volume B. This results from a change in the interstitial occupancy of solute molecules in the mixture. In practice, users may need to know the volume fraction before mixing for better volume-flow control.

$$\varphi_A = \frac{\frac{w_A}{\rho_A}}{\left(\frac{w_A}{\rho_A} + \frac{w_B}{\rho_B}\right)} \times 100$$

$$\varphi_B = \frac{\frac{w_B}{\rho_B}}{\left(\frac{w_A}{\rho_A} + \frac{w_B}{\rho_B}\right)} \times 100$$

where

φ_A = volume fraction of component A expressed as a percentage,

φ_B = volume fraction of component B expressed as a percentage,

w_A, w_B = respective mass fractions of component A and component B in relation to the mixture, and

ρ_A and ρ_B = respective densities of component A and component B.

D-1.4 Net Flow Calculation

Once the mass or volume fractions are known, net mass and volume flow calculations are identical to those indicated in **15.2.4** and **15.2.5**.

D-2 SOLUTIONS CONTAINING CHEMICALLY-INTERACTING COMPONENTS

D-2.1 Relationship Between Density and Mass Fraction

The relationship between two soluble liquids which chemically interact is complex. An example is sulphuric acid and water; the acid ionization changes the solution density. As shown in Fig. 3, the relationship between concentration and density is not defined by a simple curve that is a single density value can correlate to two difference values of mass fraction. In such cases, it is important for the user to understand the relationship between density and mass fraction and to work within a sufficiently narrow range of mass fraction in order to correlate a single value curve for density.

D-2.2 Mass Fraction

The value of mass fraction, expressed as a percentage, is read directly from table values or the curve fit of a graph similar to Fig. 3.

D-2.3 Volume Fraction

The determination of volume fraction, expressed as a percentage, before mixing is calculated in the same manner as described in **D-1.3**.

D-2.4 Net Flow Calculation

Once the mass or volume fractions are known, net mass and volume flow calculations are identical to those given above.

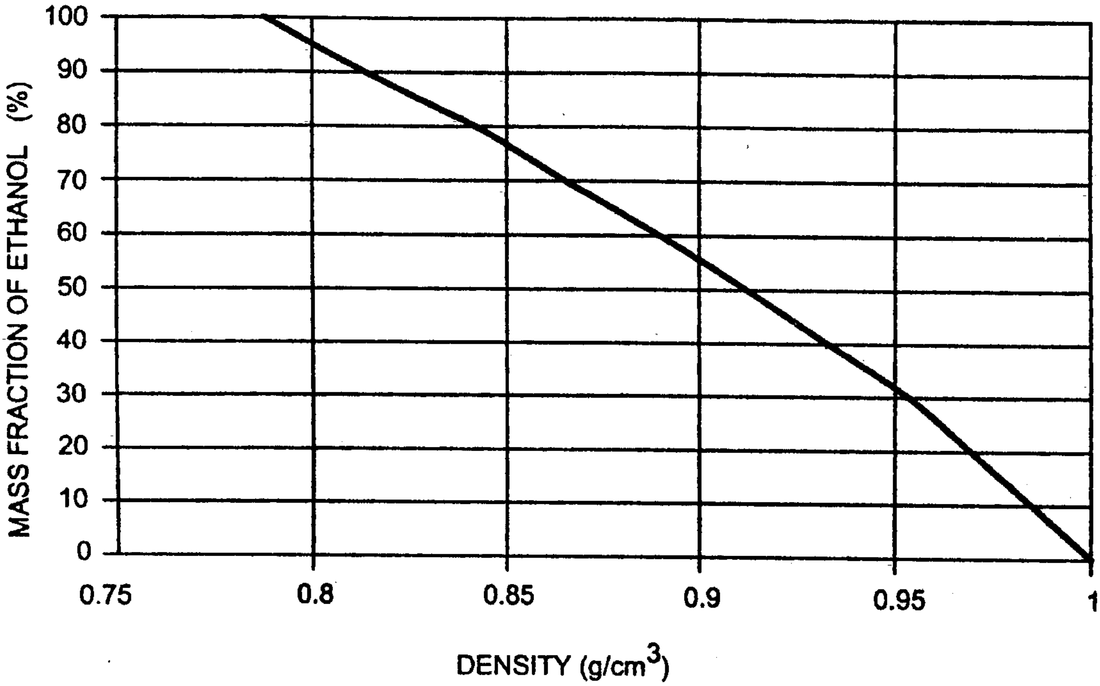


FIG. 2 MASS FRACTION *VERSUS* DENSITY CURVE FOR ETHANOL AND WATER

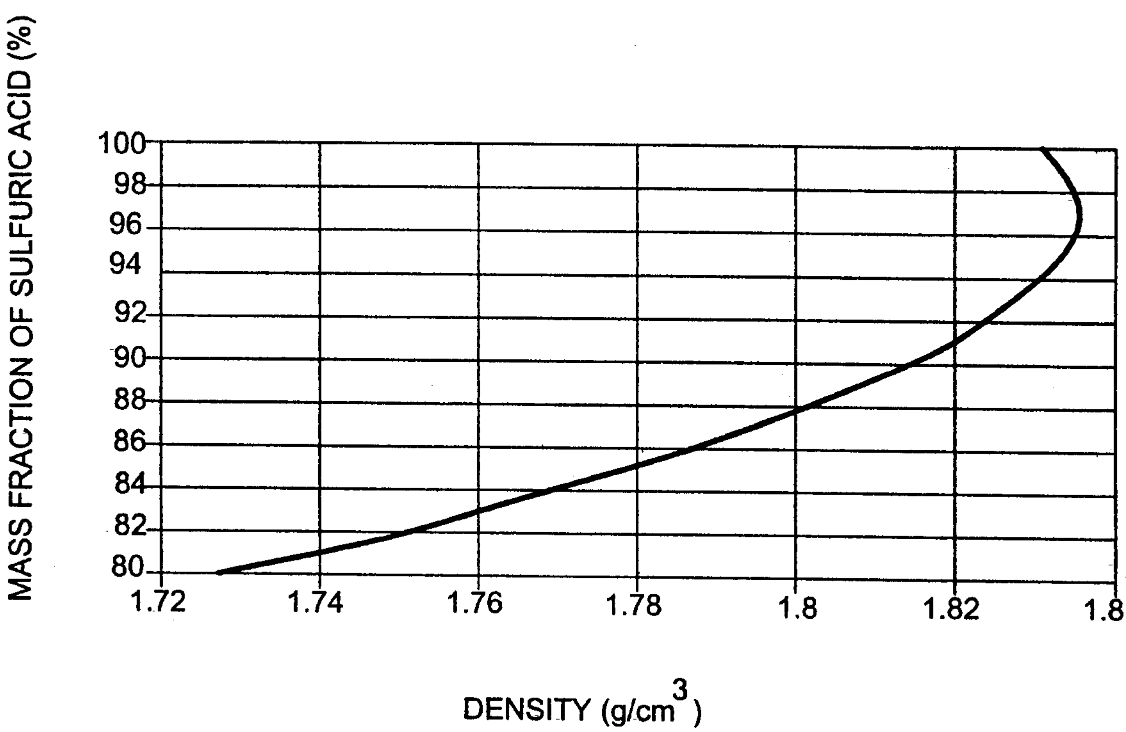


FIG. 3 MASS FRACTION OF SULPHURIC ACID *VERSUS* DENSITY

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