INTERNATIONAL STANDARD

ISO 10790

Second edition
1999-05-01

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

Mesure de débit des fluides dans les conduites fermées — Lignes directrices pour la sélection, l'installation et l'utilisation des mesureurs à effet Coriolis (mesurages de débit-masse, masse volumique et débit-volume)

Reference number
ISO 10790:1999(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 10790 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 12, *Mass methods.*

This second edition cancels and replaces the first edition (ISO 10790:1994), which has been extended to include all measured and inferred parameters obtainable from a Coriolis meter including mass flow, density, volume flow and other related parameters.

Annexes A, B, C and D of this International Standard are for information only.

Introduction

This International Standard has been prepared as a guide for those concerned with the selection, testing, inspection, operation and calibration of Coriolis meters (Coriolis meter assemblies) for any kind of fluid.

A list of related standards is given in the bibliography.

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

1 Scope

This International Standard gives guidelines for the selection, installation, calibration, performance and operation of Coriolis meters for the determination of mass flow, density, volume flow and other related parameters of fluids. It also gives appropriate considerations regarding the fluids to be measured.

The primary purpose of Coriolis meters is to measure mass flow. However, some of these meters offer additional possibilities for determining the density and temperature of fluids. From the measurement of these three parameters, volume flow and other related parameters can be determined.

The content of this International Standard is primarily applied to the metering of liquids. This International Standard also gives guidance within specified limits, to the metering of other fluids, mixtures of solids or gas in liquids, and mixtures of liquids. Although Coriolis meters may be used for gas measurement, specific guidance for gas measurement is not within the scope of this International Standard.

2 Terms and definitions

For the purpose of this International Standard, the following terms and definitions apply.

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

2.2
flow sensor (primary device)
mechanical assembly consisting of an oscillating tube, drive system, measurement sensor(s), supporting structure and housing

2.2.1
oscillating tube(s)
tube(s) through which the fluid to be measured flows

2.2.2
drive system
means for inducing the oscillation of the tube(s)

2.2.3
sensing device
sensor to detect the effect of the Coriolis force and to measure the frequency of the tube oscillations

2.2.4
supporting structure
support for the oscillating tube(s)

2.2.5
housing
environmental protection of the flow sensor

2.2.6
secondary containment
housing designed to provide protection to the environment in the event of tube failure

2.3
transmitter (secondary device)
electronic control system providing the drive and transforming the signals from the flow sensor, to give output(s) of measured and inferred parameters; it also provides corrections derived from parameters such as temperature

2.4
flow rate
ratio of the quantity of fluid passing through the cross-section of the flowsensor and the time taken for this quantity to pass through this section

2.4.1
mass flow rate
flow rate in which the quantity of fluid which passes is expressed as mass

2.4.2
volume flow rate
flow rate in which the quantity of fluid which passes is expressed as volume

2.5
accuracy of measurement
closeness of the agreement between the result of a measurement and a true value of the measurand [VIM[1]]

2.6
repeatability
<of results of measurements> closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement [VIM[1]]

2.7
uncertainty of measurement
parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand [VIM[1]]

2.8
error
<of measurement> result of a measurement minus a true value of the measurand [VIM[1]]

2.9
calibration factor(s)
numerical factor(s) unique to each sensor derived during sensor calibration, which when programmed into the transmitter ensures that the meter performs to its stated specification

2.9.1
flow calibration factor(s)
associated with mass flow measurement

2.9.2
density calibration factor(s)
associated with density measurement

2.10
zero offset
measurement output indicated under zero flow conditions, usually as a result of stress being applied to the oscillating tubes by the surrounding pipework and by process conditions

NOTE The zero offset can be reduced by means of a zero adjustment procedure.

2.11
zero stability
magnitude of the meter output at zero flow after the zero adjustment procedure has been completed, expressed by the manufacturer as an absolute value in mass per unit time

NOTE The stated value for zero stability is valid for stable conditions where the fluid is free of bubbles and heavy sediment.

2.12
flashing
phenomenon which occurs when the line pressure drops to, or below, the vapour pressure of the liquid

NOTE This is often due to pressure drops caused by an increase in the liquid velocity.

2.13
cavitation
phenomenon related to and following flashing if the pressure recovers causing the vapour bubbles to collapse (implode)

3 Coriolis meter selection criteria

3.1 General

The Coriolis meter should be selected to measure parameters within the required range and accuracy. Consideration should be given to the following points when selecting a Coriolis meter.

3.2 Accuracy

The expression of accuracy varies depending on the parameter to which it applies. For specific recommendations on mass flow, density and volume flow accuracies, see 5.2, 6.3 and 7.3, respectively. For other parameters see clause 8.

NOTE Manufacturers' accuracy statements should be given for specified reference conditions. If the conditions of use are significantly different from those of the original calibration, the meter's performance may be affected.

3.3 Physical installation

3.3.1 General

The manufacturer should describe the preferred installation arrangement and state any restrictions of use. See annex C.

The installation arrangement should be designed to provide a maximum operating lifetime. If needed, strainers, filters, air and/or vapour eliminators or other protective devices should be placed upstream to the meter for the removal of solids or vapours that could cause damage or provoke errors in measurement.

Coriolis meters are generally placed in the mainstream of the flow but can also be placed in a by-pass arrangement for density measurements.

3.3.2 Installation criteria

Consideration should be given to the following points:

a) the space required for the Coriolis meter installation, including provision for external prover or master-meter connections, should in-situ calibration be required;

b) the class and type of pipe connections and materials, as well as the dimensions of the equipment to be used;

c) the hazardous area classification;

d) the climatic and environmental effects on the sensor, for instance temperature, humidity, corrosive atmospheres, mechanical shock, vibration and electromagnetic field;

e) the mounting and support requirements.

3.3.3 Full-pipe requirement

The primary device should 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 liquids from the instrument.

3.3.4 Orientation

Plugging, coating, trapped gas, trapped condensate or settlement of solids can affect the meter's performance. The orientation of the sensor will depend on the intended application of the meter and the geometry of the oscillating tube(s). The orientation of the Coriolis meter should be recommended by the manufacturer.

3.3.5 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 upstream- or downstream-piping configurations. Although special straight-piping lengths are normally not required, good piping practices should be observed at all times.

3.3.6 Valves

Valves upstream and downstream to a Coriolis meter, installed for the purpose of isolation and zero adjustment, can be of any type, but should provide tight shutoff. Control valves in series with a Coriolis meter should be installed downstream in order to maintain the highest possible pressure in the meter and thus reduce the chance of cavitation or flashing.

3.3.7 Cleaning

For certain applications (for instance hygienic services), the Coriolis meter may require in-situ cleaning which can be accomplished by:

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

b) self-draining;

c) hydrodynamic means:

— sterilization (steaming-in-place, SIP);

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

NOTE 1 Care should be taken to avoid cross-contamination after cleaning fluids have been used.

NOTE 2 Chemical compatibility should be established between the sensor wetted-materials, process fluid and cleaning fluid.

3.3.8 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 can largely be addressed by appropriate mounting or clamping of the instrument.

In environments with high mechanical vibrations or flow pulsations, consideration should be given to the use of pulsation damping devices (see 3.4.7) and/or vibration isolators and/or flexible connections.

3.3.9 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 upstream and/or downstream of them), should be avoided at all times. Flashing and cavitation may cause measurement errors and may damage the sensor.

3.3.10 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 should 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 pipework.

3.3.11 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 should be consulted for methods of avoiding cross-talk.

3.4 Effects due to process conditions and fluid properties

3.4.1 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. Refer to clauses 5.3, 6.4, 7.4 and 8.3.

3.4.2 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) the operating flow rates and the following flow characteristics: unidirectional or bi-directional, continuous, intermittent or fluctuating;

b) the range of operating densities;

c) the range of operating temperatures;

d) the range of operating pressures;

e) the pressure on the liquid adequate to prevent cavitation and flashing;

f) the permissible pressure loss;

g) the range of operating viscosities;

h) the properties of the metered fluids, including vapour pressure, two-phase flow and corrosiveness;

i) the 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.

3.4.3 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 should be taken to ensure that gas bubbles or condensate droplets are not trapped in the meter.

3.4.4 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.

3.4.5 Temperature effects

A change in temperature will 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.

3.4.6 Pressure effects

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

3.4.7 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 (see 3.3.8). The manufacturers' recommendations should be observed regarding the application and the possible use of pulsation damping devices.

3.4.8 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.

3.5 Pressure loss

A loss in pressure will occur as the fluid flows through the sensor. The magnitude of this loss will be 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 occurs under reference 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 ensure that it is sufficiently high to accommodate the loss in pressure across the meter.

3.6 Safety

3.6.1 General

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

3.6.2 Hydrostatic pressure test

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

3.6.3 Mechanical stress

The meter should 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.

3.6.4 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 should be assessed for each type of use of the meter.

3.6.5 Corrosion

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

3.6.6 Housing design

The housing should be designed primarily to protect the flowsensor 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) the pressure within the housing might exceed the design limits;

b) the fluid might be toxic, corrosive or volatile and might leak from the housing.

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

— secondary pressure containment;

— burst discs or pressure-relief valves, fluid drains or vents, etc.

For guidelines on specifying secondary pressure containment, see annex B.

3.6.7 Cleaning

For general guidelines see 3.3.7.

Care should 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 .

3.7 Transmitter (secondary device)

Coriolis meters are multivariable 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) the electrical, electronic, climatic and safety compatibility;

b) the mounting, i.e. integrally or remotely mounted;

c) the required number and type of outputs;

d) the ease and security of programming;

e) the outputs demonstrating adequate stability and reasonable response times, and in the case of an analogue output including the minimum and maximum span adjustments;

f) the output(s) indicating system errors;

g) the required input options, for instance remote zero adjustment, totalizer resetting, alarm acknowledgement;

h) the type of digital communication.

4 Inspection and compliance

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.

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

- dimensional check;
- additional hydrostatic test, in accordance with a traceable procedure, as specified by the user;
- radiographic and/or ultrasonic examination of the primary device to detect internal defects (i.e. inclusions) and verify weld integrity;

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

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

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

5 Mass flow measurement

5.1 Apparatus

5.1.1 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 Figure 1.

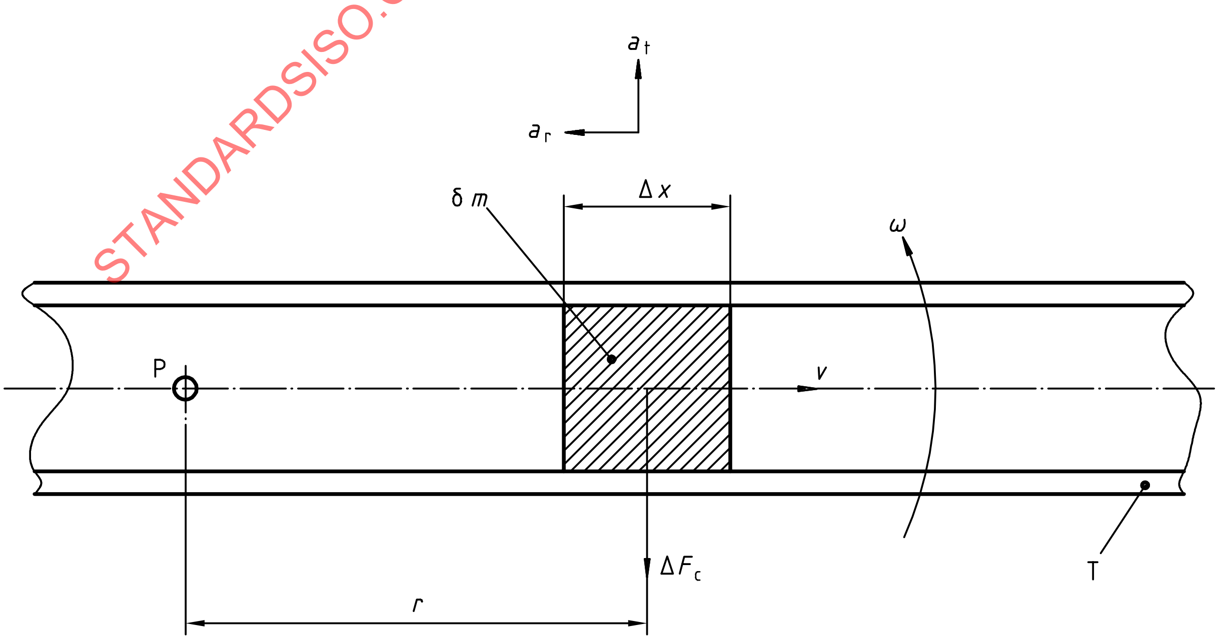

Figure 1 — Principle of operation of a Coriolis meter

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) a radial acceleration a_r (centripetal) equal to $\omega^2 \cdot r$ and directed towards P;

b) 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 $\Delta F_C = 2\omega \cdot v \cdot \rho \cdot A \cdot \Delta x$ where A is the cross-sectional area of the oscillating tube interior.

Since the mass flow rate q_m can be expressed as:

$$q_m = v \cdot \rho \cdot A \tag{1}$$

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

$$\Delta F_C = 2\omega \cdot q_m \cdot \Delta x \tag{2}$$

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.

5.1.2 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.

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.

5.1.3 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 they require further configuration. In the case of the measurement of density or volume, output requirements necessitate the entry of other coefficients into the software. All outputs are usually scaled separately.

5.2 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.

5.3 Factors affecting mass flow measurement

5.3.1 General

Refer also to annex C for further details.

5.3.2 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 (see 5.4) under operating conditions. See 3.4.8 for viscosity effects.

5.3.3 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 should be taken to ensure that gas bubbles or condensate droplets are not trapped in the meter. Special attention should be given under these circumstances to the zero-adjustment procedure (see 5.4).

5.3.4 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 (see 5.4).

5.3.5 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 (see 5.4) at the process pressure.

5.3.6 Installation

Stresses exerted on the sensor from surrounding pipework can introduce an offset in the meter output at zero flow. This offset should be checked after the initial installation or after any subsequent change in the installation. Another zero adjustment (see 5.4) should be performed if the offset is unacceptable.

5.4 Zero adjustment

Once the meter installation is complete, a zero adjustment is usually necessary to overcome the effects described in 5.3. To check or adjust the zero flow, the meter should be full and all flow stopped. It is recommended that the meter zero is first checked, and adjusted if the offset is unacceptable. Zero adjustment should 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 of the meter periodically.

NOTE Low flow cut-off is a transmitter setting which sets the meter output(s) to zero flow if the flow rate falls below a preset value.

5.5 Calibration of mass flow

Every Coriolis meter should be calibrated against a traceable standard by the manufacturer, and calibration certificates for the meter should be provided. The calibration factors determined by this procedure should be noted on the sensor data plate.

The calibration of a Coriolis meter is similar to the calibration of any other flowmeter. 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.

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 should be taken to avoid cross-talk (see 3.3.11).

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 should be checked (see 5.4). 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.

6 Density measurement under metering conditions

6.1 General

Coriolis meters can provide in-line density measurement under metering conditions. This section 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 clause 8.

6.2 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:

$$f_{\mathrm{R}} = \frac{1}{2\pi}\sqrt{\frac{C}{m}} \qquad (3)$$

with

$$m = m_{\mathrm{t}} + m_{\mathrm{fl}} \qquad (4)$$

and

$$m_{fl} = \rho_{fl} V_{fl} \tag{5}$$

where

f_R is the resonant or natural frequency;

C is the mechanical stiffness or the spring constant of the measuring tube arrangement;

m is the total oscillating mass;

m_t is the oscillating mass of the measuring tube(s);

m_{fl} is the oscillating mass of the fluid within the tube(s);

V_{fl} is the volume of fluid within the tube(s);

ρ_{fl} is the 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.

From equations (3), (4) and (5), ρ_{fl} can be determined.

$$\rho_{fl} = \left[\frac{C}{V_{fl} \left(2\pi f_R \right)^2} \right] - \frac{m_t}{V_{fl}} \tag{6}$$

and after simplification equation (6) becomes:

$$\rho_{fl} = K_1 + \frac{K_2}{f_R^{\,2}} \tag{7}$$

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:

$$f_R = \frac{1}{T_f} \text{ or } f_R = \frac{N_c}{t_w} \tag{8}$$

K_1 and K_2 are temperature dependent and should be automatically compensated by means of an integral temperature measurement (there also may be pressure dependence, see 6.4.3).

6.3 Relative density[1)]

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:

$$d = \frac{\rho_{fl}}{\rho_{w,ref}} \tag{9}$$

where

ρ_{fl} is the density of fluid under metering conditions;

$\rho_{w,ref}$ is the density of water under reference conditions.

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1) Formerly expressed as specific gravity.

6.4 Accuracy

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

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

6.5 Factors affecting density measurement

6.5.1 General

Refer also to 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 should be able to quantify the effect, or give guidance on the likely impact on the performance of the meter, for instance a temperature influence could be expressed as a density shift per degree change.

6.5.2 Temperature

Temperature changes can affect 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 precision 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 cause 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.

6.5.3 Pressure

Pressure usually has a minor effect on measurements of density and compensation is not normally necessary. However, for some designs 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.

6.5.4 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) can 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.

6.5.5 Flow

Density calibration is usually carried out under static conditions, i.e. without any fluid flowing. However, when in operation on a flowing fluid, hydraulic noise may influence the density measurement. Fluid velocities which may give 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.

6.5.6 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 should 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).

6.5.7 Installation

Generally, installation stresses do not influence the density measurement. However, for certain sensor designs there may be a minor orientation effect. In precision density applications, it may be necessary to calibrate the meter in its intended final orientation or alternatively perform a field adjustment (see 6.6.3).

6.6 Calibration and adjustment

6.6.1 General

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

6.6.2 Manufacturer’s calibration

Coriolis meters are calibrated by the manufacturer for density measurement, usually using air and water as reference fluids. The density calibration factors determined by this procedure are 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 should be available on request.

6.6.3 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 should 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 should be outlined in detail in the instruction manual.

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

7 Volume flow measurement under metering conditions

7.1 General

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

7.2 Volume calculation

Density is defined as its mass per unit volume, therefore, volume can be calculated from mass and density as follows:

$$V = \frac{m}{\rho} \qquad (10)$$

where

V is the volume under metering conditions;

ρ is the density under metering conditions;

m is the mass.

Equation (10) may be incorporated directly into the transmitter software provided the Coriolis meter is of a type that can measure both mass and density (see clauses 5 and 6). In reality, 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:

$$q_V = \frac{q_m}{\rho} \qquad (11)$$

where

q_V is the volume flow rate under metering conditions;

q_m is the mass flow rate.

The Coriolis meter may then provide the volume flow rate calculated from equation (11) as an output signal. The calculated volume flow rate may also be integrated with respect to time to obtain the total volume.

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

7.3 Accuracy

Some Coriolis meter manufacturers publish their expected accuracy for volume measurement. However, if this information is not available, the expected accuracy for volume flow measurement can be calculated from:

$$\varepsilon_V = \sqrt{(\varepsilon_m{}^2 + \varepsilon_\rho{}^2)} \qquad (12)$$

where

ε_V is the accuracy of the volume measurement;

ε_m is the accuracy of the mass measurement (see 5.2);

ε_ρ is the accuracy of the density measurement (see 6.4).

All the above values of accuracy are expressed in terms of ± % of the reading.

7.4 Special influences

7.4.1 General

Coriolis meters can 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, will 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 clauses 5 and 6.

7.4.2 Empty pipe effect

A Coriolis meter measuring liquid flow will 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 according to equation (10) (see 7.2) would be erroneously high. This problem can 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. Consultation with manufacturers may provide alternative methods of eliminating this problem.

7.4.3 Multiphase fluids

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

7.5 Factory calibration

7.5.1 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 clauses 5 and 6, 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 using equation (12) described in 7.3.

7.5.2 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 should 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 should be performed using the Coriolis meter in its operational installation using the process fluid.

8 Additional measurements

8.1 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 in 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 of 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.

8.2 Immiscible mixtures

8.2.1 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.

When two components do not mix, whether they be two immiscible liquids or a liquid and a solid, the relationship between density and concentration can only be defined by equations (13) and (14) given in 8.2.2. Examples of these types of mixtures are starch and water, sand and water and oil and water.

8.2.2 Mass fraction

Equations (13) and (14) describe the relationship between component A and component B respectively, as a mass fraction w expressed as a percentage.

$$w_{\mathrm{A}} = \frac{\rho_{\mathrm{A}}(\rho_{\mathrm{measured}} - \rho_{\mathrm{B}})}{\rho_{\mathrm{measured}}(\rho_{\mathrm{A}} - \rho_{\mathrm{B}})} \times 100 \quad (13)$$

$$w_{\mathrm{B}} = \frac{\rho_{\mathrm{B}}(\rho_{\mathrm{A}} - \rho_{\mathrm{measured}})}{\rho_{\mathrm{measured}}(\rho_{\mathrm{A}} - \rho_{\mathrm{B}})} \times 100 \quad (14)$$

where

w_{A} and w_{B} are the respective mass fractions of component A and component B in relation to the mixture;

ρ_{A} and ρ_{B} are the respective densities of component A and component B;

ρ_{measured} is the measured density of the mixture.

8.2.3 Volume fraction

Equations (15) and (16) describe the relationship between component A and component B, as a volume fraction φ expressed as a percentage.

$$\varphi_{\mathrm{A}} = \frac{\rho_{\mathrm{measured}} - \rho_{\mathrm{B}}}{\rho_{\mathrm{A}} - \rho_{\mathrm{B}}} \times 100 \quad (15)$$

$$\varphi_{\mathrm{B}} = \frac{\rho_{\mathrm{A}} - \rho_{\mathrm{measured}}}{\rho_{\mathrm{A}} - \rho_{\mathrm{B}}} \times 100 \quad (16)$$

where

φ_{A} and φ_{B} are the respective volume fractions of component A and component B in relation to the mixture;

ρ_{A}, ρ_{B} and ρ_{measured} are defined in equations (13) and (14) in 8.2.2.

The volume fraction is a simple rearrangement of equations (13) and (14).

8.2.4 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 can be calculated as follows:

$$q_{m,\mathrm{A}} = \frac{q_{m,\mathrm{T}} \times w_{\mathrm{A}}}{100} \quad (17)$$

$$q_{m,\mathrm{B}} = \frac{q_{m,\mathrm{T}} \times w_{\mathrm{B}}}{100} \quad (18)$$

where

$q_{m,\mathrm{T}}$	is the total mass flow rate of the mixture;
$q_{m,\mathrm{A}}$ and $q_{m,\mathrm{B}}$	are net mass flow rate of components A and B, respectively;
w_A and w_B	are defined in equations (13) and (14) in 8.2.2.

8.2.5 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 can be calculated.

$$q_{V,\mathrm{A}} = \frac{q_{V,\mathrm{T}} \times \varphi_\mathrm{A}}{100} \tag{19}$$

$$q_{V,\mathrm{B}} = \frac{q_{V,\mathrm{T}} \times \varphi_\mathrm{B}}{100} \tag{20}$$

where

$q_{V,\mathrm{T}}$	is the net total volume flow rate;
$q_{V,\mathrm{A}}$ and $q_{V,\mathrm{B}}$	is the net volume flow rate of components A and B, respectively;
φ_A and φ_B	are defined in equations (15) and (16) in 8.2.3.

8.3 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 a 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.

8.4 Solutions containing chemically-interacting components

The relationship between two soluble liquids which react chemically is complex. See annex D.

8.5 Special considerations 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.

Annex A
(informative)

Calibration techniques

A.1 Introduction

Coriolis meters are calibrated in the same manner as any other flowmeter. 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 clause A.2, as follows:

— Type 1 standard calibration — the details of which are specified by the manufacturer;

— Type 2 special calibration — the details of which are specified by the user.

Ideally, Coriolis meters should 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. The uncertainty calculation should be performed in accordance with ISO/TR 5168 [2], ISO/TR 7066-1 [3] and ISO 7066-2 [4]. Coriolis meters measure mass, therefore, quantities of fluid measured during a gravimetric calibration, should ultimately be expressed in units of mass, i.e. corrected for buoyancy.

NOTE Calibration strictly refers to the procedure by which the flowmeter 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 should be counted during the test to establish an acceptable calibration uncertainty.

There are three main methods for calibrating flowmeters: 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 should 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 should 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 should be accounted for.

A.2.2 Gravimetric methods

The test fluid should be collected in a weighing vessel. The mass of the vessel should 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 should be corrected for buoyancy. Care should 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 should be fully documented and should provide adequate uncertainty in mass units. If the master-meter is a volumetric device, its measurement should 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 should be taken to avoid cross-talk (see 3.2.10). The manufacturer should 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 pipework 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:

— the meter is installed in accordance with manufacturer’s recommendations;

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

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

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

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

— the 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% 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 should 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 should 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 should be minimized during the calibration process. For a single run, the temperature should 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 should be kept sufficiently high to avoid flashing or cavitation in the meter and/or in the vicinity of the meter. Ideally, proving should 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 should be used having properties that are the same or similar to the process fluid for which the meter is intended.

A.4.5 Installation

The recommendations outlined in 3.3 are also applicable to the meter installation during calibration.

A.5 Calibration certificate

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

- the unique attributed certificate number, repeated on each page along with the page number and the total number of pages;
- the certificate date of issue and the test date if it differs from the certificate date of issue;
- the identity of the party commissioning the test;
- the name and location of the test laboratory;
- the test fluid data such as product name or density; temperature; pressure;
- the unique identification of meter under test;
- the traceability of the test facility and its procedures;
- the uncertainty statement and calculation method;
- the relevant ambient conditions;
- the relevant test data and the results of the calibration, including meter output at zero flow at start and finish of calibration;
- the calibration data should be presented in chronological order;
- the orientation of the Coriolis meter;
- the configuration data within the transmitter at which the calibration is performed;
- the authorized signature.

A.6 Typical calibration certificate

A typical calibration certificate is given in Figure A.1.

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

Supplier: ....

Sensor: Type number ....
Serial number ....
Sensor calibration factor ....

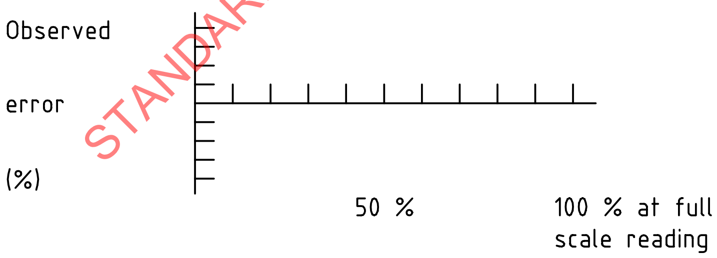
Transmitter: ....
Type number ....
Serial number ....

Output calibrated mA - pulsed - density etc. ....

Test conditions

Calibration fluid (product name) ....
Viscosity .... at.......................... °C
Density .... at.......................... °C
Temperature of test fluid .... °C
Pressure at inlet to test 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** (%)
....	....	....	....	....	....
....	....	....	....	....	....
....	....	....	....	....	....



Flow range min ....max. ....

Pressure drop at maximum flow ....

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

Figure A.1 — Typical calibration certificate

Annex B
(informative)

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 should 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 a 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 should be given to the following specific areas.

B.1.2 Materials

Care should be taken to establish that suitable wetted materials are 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 should be considered as well as standard material guides.

B.1.3 Velocity

Care should 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 should 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, usually ASME B31.3 [5] (or a recognized equivalent standard such as AD-Merkblätter, Druckbehälterverordnung/Germany or KHK/Japan);

b) the 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 should be available for checking the suitability of the connections to the Coriolis sensor.