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Measurement of fluid flow in closed conduits — Coriolis mass flowmeters

Mesure de débit des fluides dans les conduites fermées — Débitmètres massiques à effet Coriolis

Reference number
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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.

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, *Dynamic mass flow measurement*.

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

Introduction

This International Standard has been prepared as a guide for those concerned with the testing, inspection, installation, operation and calibration of Coriolis mass flowmeters (Coriolis mass flowmeter assemblies) for any kind of fluids.

Measurement of fluid flow in closed conduits — Coriolis mass flowmeters

1 Scope

This International Standard defines the application criteria for Coriolis mass flowmeters and discusses appropriate considerations regarding the fluids to be measured, the installation, the performance and operation of Coriolis mass flowmeters.

The content of this International Standard is general. It is primarily applied to the metering of liquids and within certain limiting conditions to gases, mixtures of liquids and gas or mixtures of liquids and solids.

NOTE 1 Many Coriolis mass flowmeters provide the capability to measure density. Users are advised to contact the manufacturers for further information regarding density measurement accuracy, calibration procedures, calculation of volume and other density-related issues.

2 Normative reference

The following standard contains provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent edition of the standard indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 4006:1991, *Measurement of fluid flow in closed conduits — Vocabulary and symbols.*

3 Definitions

For the purpose of this International Standard the definitions given in ISO 4006 apply. The following definitions are given only for terms used for Coriolis flowmeters or for terms the meaning of which might be usefully recalled.

3.1 Coriolis mass flowmeter: Flowmeter which uses the interaction between the mass flow of the fluid and the oscillations of the vibrating conduits for mass flowmetering purposes.

The Coriolis mass flowmeter consists of a primary device and a secondary device.

3.2 primary device (flow sensor): Mechanical assembly consisting of a vibrating conduit, vibration drive system, measurement sensor(s), supporting structure and housing.

3.2.1 vibrating conduit: Oscillating tube(s) through which the fluid to be measured flows.

3.2.2 vibration drive system: Means for inducing the oscillation of the vibrating conduit.

3.2.3 measurement sensor(s): Sensor(s) to monitor oscillations and to detect the effect of the Coriolis force.

3.2.4 supporting structure: Support for the vibrating conduit.

3.2.5 housing: Environmental protection for the vibrating conduit(s), vibration drive and sensor.

The user should consider whether the housing should also provide secondary containment.

3.3 secondary device (transmitter): Electronic control system providing the drive and transforming the signals from the primary device to give meaningful output(s) of mass flow and possibly other parameters. It also provides corrections derived from parameters such as temperature.

3.4 flowrate: Quotient of the quantity of fluid passing through the cross-section of a conduit and the time taken for this quantity to pass through this section.

3.4.1 mass flowrate, q_m**:** Flowrate in which the quantity of fluid which passes is expressed as a mass.

3.5 sensor calibration factor: Numerical factor(s) unique to each primary device, which enables the primary and secondary devices to be matched.

3.6 zero instability: Magnitude of the irregular output signal at zero flow.

3.7 flashing: Phenomenon which occurs when the line pressure falls to or below the vapour pressure of the liquid, often due to local lowering of pressure because of an increase in the liquid velocity.

3.8 cavitation: Phenomenon related to and following flashing if the pressure recovers and the vapour bubbles collapse (implode), potentially causing damage.

Cavitation will cause a measurement error and can damage the primary device.

4 Principle of operation

4.1 General

Coriolis mass flowmeters 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. 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 acquires two components of acceleration:

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

b) a transverse acceleration a_t (Coriolis) equal to $2\omega v$ at right angles to a_r and in the direction shown in figure 1.

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

From this illustration it can be seen that when a fluid of density ρ flows at constant velocity v along a conduit rotating as in figure 1, any length Δx of the conduit experiences a transverse Coriolis force of magnitude $\Delta F_C = 2\omega v \rho A \Delta x$, where A is the cross-sectional area of the conduit interior. Since the mass flowrate δq_m can be expressed as

$$\delta \frac{\mathrm{d}}{\mathrm{d}t} m = \rho v A$$

we then have that

$$\Delta F_C = 2\omega \delta q_m \Delta x$$

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

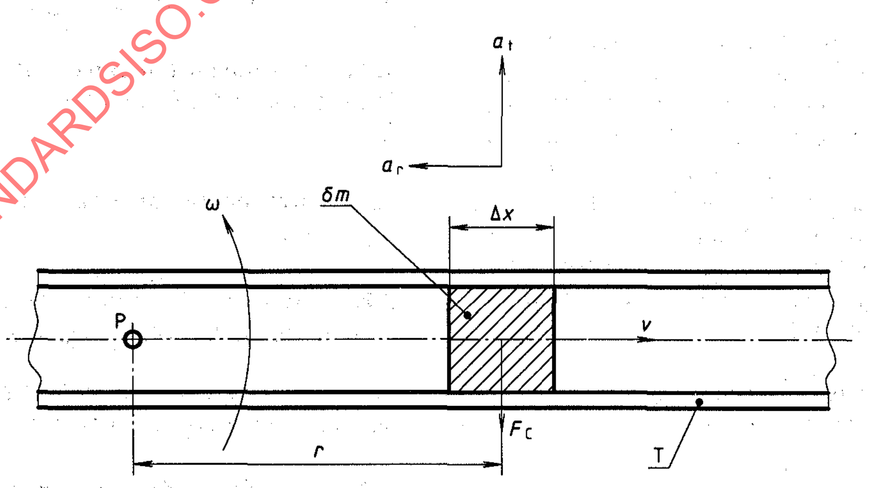


Figure 1 — Generation of Coriolis force

In commercial designs of Coriolis mass flowmeters, the generation of inertia forces through continuous rotary motion is not practical and instead the necessary forces are generated by oscillating the vibrating conduit. The smallest driving force required to keep the conduit in constant vibration occurs when the frequency of vibration is at, or close to, a natural frequency of the filled conduit. In most meters the flow tube is anchored at two points and vibrated at a position midway between the two anchors, this giving rise to opposite oscillatory rotations of the two halves of the conduit. The conduits can be of looped or straight design.

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 to produce a secondary twisting vibration which results in a small phase difference in the relative motions at the sensing points.

It should be noted that Coriolis forces (and hence deflection of the conduit) only exist when both axial motion and forced vibration are present. When there is forced vibration but no flow, or flow with no vibration, no deflection will occur and no output from the meter will result.

4.2 Practical implementation

Due to the nature of a Coriolis mass flowmeter, the primary device requires the secondary device to provide the drive and process the subsequent signal. This means that the primary element will have an associated sensor calibration factor, usually supplied by the manufacturer. This sensor calibration factor has to be matched with the secondary device when combining a new primary and secondary device. Additional coefficients must be entered if density or volume outputs are required. All the outputs are usually scaled separately.

5 Coriolis mass flowmeter selection

The prime requirement of the metering systems is that it shall measure mass flow with the specified accuracy. Consideration shall be given to, and the manufacturer should specify, the following points.

5.1 Accuracy

a) compliance of the intended installation and operating conditions compared with the manufacturer's published data;

b) the calibration method and frequency.

5.2 Physical installation

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

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

c) hazardous area classification;

d) climatic and environmental effects on the sensor, e.g. humidity, corrosive atmospheres, mechanical shock, vibration and electromagnetic field.

5.3 Application and fluid property effects

a) operating flowrates and whether flow is unidirectional or bidirectional, continuous, intermittent or fluctuating;

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

c) effects of corrosive additives or contaminants on the meter and the quantity and size of foreign matter, including abrasive particles, that may be carried in the liquid stream;

d) range of operating temperatures;

e) range of operating pressures and whether the pressure on the liquid is adequate to prevent cavitation and flashing;

f) the pressure loss which will result from the flow of the process fluid through the primary device and whether this is acceptable.

5.4 Secondary device

a) electrical, electronic, climatic and safety compatibility;

b) required output options;

c) ease and security of programming;

d) outputs with adequate stability and response times;

e) output(s) for indicating system errors.

6 Inspection and testing

As Coriolis mass flowmeters are an integral part of the process 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/performance checks, the following optional tests may be performed to satisfy the mechanical requirements:

— dimensional check;

— hydrostatic test, in accordance with a traceable standard, as specified by the customer;

— 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 shall be presented in certified reports, when requested.

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

— material certificates, for all pressure-containing parts;

— certificate of conformance (electrical area classification);

— certificate of performance;

— calibration test results.

7 Layout and installation

7.1 General

The manufacturer shall state the preferred installation arrangement and any restrictions that apply.

The installation should be designed to provide a maximum operating life. If needed, strainers, filters, air/vapour eliminators or other protective devices should be provided upstream of the meter to remove solids or vapours that could cause premature wear or measurement error.

The installation meay provide facilities for calibrating each meter, and if so should be capable of duplicating normal operating conditions at the time of calibration.

7.2 Full pipe requirement

The primary device shall be mounted in such a position that it will be completely filled with the fluid being metered, as otherwise the measuring performance of the instrument will be impaired. The manufacturer shall state what provisions if any are required to purge or drain trapped gases or liquids from the instrument.

7.3 Orientation

Solids settlement, plugging, coating, trapped gas or trapped condensate can affect the meter performance. Whether the primary device should be mounted vertically or horizontally depends on the layout of the vibrating conduit and the application.

7.4 Flow conditioning/straight length requirements

The performance of a Coriolis mass flowmeter is usually not affected by fluid swirl and non-uniform velocity profiles induced by upstream and downstream piping configurations. No special straight piping lengths are normally required. However, good piping practices shall at all times be observed.

7.5 Valves

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

7.6 Cleaning

For certain applications (e.g. hygienic services), provisions to clean the Coriolis mass flowmeter *in situ* shall be provided.

Cleaning can be accomplished by

— mechanical means (pigging or ultrasonic);

— hydrodynamic means;

— sterilization;

— chemical or biological means.

7.7 Pulsations and vibrations

The manufacturer should specify the operating resonant frequency range of his instrument to enable assessment of possible influences of process or other external mechanically imposed frequencies.

The manufacturer's recommendations shall be observed regarding

- application of pulsation dampers;
- application of vibration isolators/flexible connections;
- mounting/clamping of the instrument.

7.8 Cavitation/flashing

Both cavitation and flashing in a Coriolis mass flowmeter (and immediately up/down stream thereof) must at all times be avoided, as they impair the accuracy and integrity of the flowmeter.

WARNING — Because of the relatively high fluid velocities in Coriolis mass flowmeters, local dynamic pressure loss inside the meter can lead to cavitation.

7.9 Pipe stress and torsion

The primary device will be subjected to axial, bending and torsional forces during operation. Changes in these forces as a result of process temperature and pressure variations can affect the performance of the Coriolis mass flowmeter. Care should be taken with clamping arrangements.

A spoolpiece equal in size to the Coriolis mass flowmeter should be used during the construction phase of a new piping unit. This prevents excessive stresses being exerted on the Coriolis mass flowmeter during assembly of the pipework.

7.10 Cross-talk between primary devices

If two or more Coriolis mass flowmeters are to be mounted close together, the manufacturer should be consulted for methods for avoiding cross-talk and interference between the primary devices.

8 Meter performance

8.1 Fluid parameters

8.1.1 Density and viscosity effects

The Coriolis measurement principle is to the first approximation not density- or viscosity-dependent. However, wide variations in viscosity or density can influence the performance of a Coriolis mass flowmeter.

8.1.2 Multiphase flow

Liquid mixtures and mixtures of solids in liquids can be measured satisfactorily in certain application. Multiphase applications involving free gas can cause additional measurement errors and in some cases can stop operation.

8.1.3 Influence of process fluid

Erosion, corrosion and coating of the vibrating conduit can cause additional measurement errors.

8.2 Process parameters

8.2.1 Temperature effects

Temperature changes affect the output of the primary device. Compensation for this effect is usually incorporated in the secondary device.

8.2.2 Pressure effects

Static pressure changes can affect the accuracy of the primary device. As this is a minor effect, compensation is not normally applied.

8.2.3 Vibration/acceleration effects

The primary device can be sensitive to mechanical, hydraulic and acoustic vibration. See 7.7.

8.2.4 Pulsation effects

Pulsating flow may affect the performance of a Coriolis mass flowmeter.

8.3 Zero adjustment

Zero instability (see 3.6) introduces systematic bias into meter output. The Coriolis mass flowmeter zero should be adjusted after initial installation or any subsequent change to the installation. The zero of some meters may require adjustment at the process temperature, pressure and density. Inadequate compensation for temperature effects on the elasticity of the vibrating conduit can contribute to this error. It is recommended that the zero be checked each week during the first month of operation. If the change in zero is small, then the frequency of checking can be reduced.

In addition to zero instability, zero offsets can occur caused by the effects of temperature, pressure etc. Manufacturers should specify how to check and adjust the zero point, and the recommended intervals between checks.

9 Calibration

The calibration of a Coriolis mass flowmeter is similar to the calibration of any other flowmeter. The calibration consists of comparing the output of the meter, either analog or digital, with a suitable standard of higher accuracy.

As the Coriolis mass flowmeter is a mass flow device, wherever possible calibration should be carried out against a mass or gravimetric standard (see ISO 4185). Mass comparison should be used at all times where practical.

Calibration against a volume standard (see ISO 8316), combined with density determination, may be needed for many applications, especially for field calibrations. The errors introduced by this method have to be carefully assessed. A master-meter should be used carefully, to ensure stability of the master and to avoid interference between the master and the meters under test.

Where possible, calibration should be carried out using products and conditions as close to those of final application as possible. For Coriolis mass flowmeters the meter has to be zeroed in the calibration circuit and re-zeroed on installation in the final application. Detailed calibration advice, suggested procedures and calibration levels are given in annex A.

10 Safety

The following safety precautions should be considered when using Coriolis mass flowmeters.

10.1 Mechanical aspects

10.1.1 Mechanical stress

The meter should be designed to withstand all loads originating from the conduit system, temperature, pressure and vibration. The user must respect the design limitations of the primary element at all times. All meters shall be hydrostatically tested at 1,5 times the rated operating pressure to ensure that they will withstand the pressures encountered during use.

10.1.2 Erosion

Fluids can cause erosion within the conduits due to solid particles or cavitation under flowing conditions. The effect of erosion is installation-dependent and must be assessed on an individual basis.

10.1.3 Corrosion

Corrosion, including galvanic corrosion, of the wetted materials can adversely affect the operating life of the primary device. Care should be taken when selecting the material of construction to ensure that the process fluids, including materials used for cleaning the piping, are compatible with the materials of construction. Special attention should be given to corrosion and galvanic effects in no-flow or empty conduit conditions. All process-wetted materials must be specified.

10.2 Housing design

If the vibrating conduit of the Coriolis mass flowmeter were to fail, the housing containing the conduit can be exposed to unfavourable conditions which could 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 escape from the housing.

In order to avoid such problems, certain housing designs provide

a) pressure containment;

b) burst discs or pressure relief valves, fluid drains or vents.

Annex A
(informative)

Calibration techniques

A.1 Introduction

The calibration of a Coriolis mass flowmeter is similar to the calibration of any other flowmeter. It consists of comparing the output of the meter under test with a suitable standard of adequate accuracy. There are basically three types or levels of calibration, described in A.5.1:

Level 1 — Preliminary sensor and transmitter-calibration.

Level 2 — Basic production or routine-calibration.

Level 3 — Extended calibration.

Coriolis mass flowmeters should ideally be calibrated by the use of gravimetric calibrators. The overall uncertainty in the flowrate measurement will include those of the density measurement and the flow measurement, and can be calculated in accordance with ISO 5168, ISO 7066-1 and ISO 7066-2.

A.2 Methods of calibration

A.2.1 General

The two main methods used to calibrate flowmeters are either gravimetric (ISO 4185) or volumetric (ISO 8316) methods. Master-meter methods can also be used. In gravimetric methods time and mass are measured, and in volumetric methods a known volume is collected over a measured period of time. The mass or volume can be determined either statically or dynamically, as detailed in ISO 4185 and ISO 8316 respectively, or alternatively using the start-stop method described in A.2.2. If this latter method is used to calibrate Coriolis mass flowmeters, the run time must be long enough to account for errors introduced by flowrate variations at the start and end of the run. Temperature corrections must be applied to the data as required, especially for volumetric methods. Care should be taken to reduce, or account for, evaporation of the test liquid. For gravimetric methods, formation of condensation on the tank must be avoided, and account should be taken of convective upthrust if the tank is hot.

With static and dynamic weighing calibrators, the net mass should be corrected for buoyancy to yield mass in vacuum. If a correction for buoyancy is not applied (e.g. for LPG applications), then the calibration certificate shall be clearly marked to this effect. In dynamic weighing the readings are taken while the liquid is flowing into the weighing tank. Full test rig details and the associated uncertainty calculations can be found in ISO 4185.

A.2.2 Laboratory gravimetric calibrators

In the start-stop method an initial tank weight is determined. Fluid is then permitted to flow into the tank for a measured time period before the valve is closed and the second weight reading is taken. The difference between the two readings is the mass passed in the measured time. Flowrate will change at the start and end of the run as the valve is operated. Consequently to minimize this effect the run time must be long compared with the valve operating time so as not to introduce additional uncertainty. The meter must also have a sufficiently fast response time and not be affected by the sudden changes in flowrate at the beginning and end of the test.

A.2.3 Laboratory volumetric techniques

Volumetric systems are widely used in standards laboratories for the direct calibration of volumetric meters. If they are to be used for calibrating mass meters, a means to convert the measured volume to mass is required. The calculation of density can be made from measurements of fluid temperature and pressure, along with a knowledge of the fluid properties, and this can then be used to convert the volume to mass.

Volumetric pipe provers (including compact devices) along with a density determination or calibrated fluid densitometers provide another means of calibrating Coriolis mass flowmeters.

A.2.4 Master-meter methods

Coriolis mass flowmeter calibration using a master-meter technique can be carried out provided the stability and accuracy of the master is fully documented and has been proved to provide an adequate uncertainty on mass units.

It must be stressed that the uncertainty found when using a master-meter method will be a factor, normally 5 times, larger than the uncertainty associated with the primary calibrator.

An acceptable master volumetric meter (such as a turbine or PD type) can be used but, as outlined above, errors in the density determination must be accounted for in the uncertainty. If a master Coriolis mass flowmeter is used, the meter shall be permanently connected to the pipework to minimize zero-drift effects due to pipe stress and shall have been regularly calibrated. Full documentation of the zero drift shall be produced across the full range of working temperatures, pressures and fluids used. In addition extreme care is required to ensure that the master and test Coriolis mass flowmeters do not interfere with each other through the pipework or any electrical connection.

A.2.5 Field calibration

Because of the lack of acceptable and certified field calibration equipment available, mass meters can be calibrated in an indirect way using volumetric meter provers with fluid densitometers and master-meters. Standards exist for the operation and use of meter provers.

Gravimetric systems can also be used in the field.

A.2.6 Frequency of calibration

It is suggested that an annual calibration of Coriolis mass flowmeters for nonfiscal applications is sufficient but more frequent calibrating may be required where the meter is used for fiscal duties.

A.2.7 Reference conditions

If it is necessary to convert the indicated mass to volume, then the volume should be expressed at defined reference conditions of temperature and pressure. However, the actual calibration can be at any temperature or pressure within the operating limits of the Coriolis mass flowmeter.

A.3 Calibration conditions

A.3.1 Stability of flow

The flow must be stable to within ± 5 % of the flowrate reading throughout the calibration.

A.3.2 Temperature and pressure

Temperature and pressure changes should not occur at each test point during the calibration process. Fluid temperature should be held constant to within 1 °C. It is recommended that throughout the entire sequence of test flowrates the fluid temperature should not vary by more than 5 °C. The pressure downstream of the meter should be high enough to ensure that no flashing or cavitation occurs within the pipe.

A.3.3 Density and viscosity considerations

Generally fluids of known properties are used for calibration purposes, (e.g. water, kerosine etc.). However, for the lowest levels of uncertainty it is recommended that the test fluid should simulate the actual fluid on which the meter is to be used. Often this is not possible and therefore fluids of similar density and viscosity should be used. Variations in sensor calibration factor may be expected if the meter is calibrated on one fluid and used on a second, but the magnitude of the effects will depend on the meter design.

Since there can be secondary effects of density and viscosity on the performance of the meter, it is recommended that, as far as possible, the properties of the test fluid should simulate those of the fluid on which the meter is to be used.

A.3.4 Installation considerations

Coriolis mass flowmeters rely on an installation as free as possible from stress and vibration. The recommendations of the supplier should be followed when installing a Coriolis mass flowmeter in a line prior to calibration. It is to be noted that this installation cannot replicate the field installation.

The test rig should not introduce any external influences into the performance of the meter during the calibration. These can include flow pulsations, inlet pressure variations and temperature changes. Generally standard test rigs have been designed and have been independently certified, so that these effects are negligible.

A.4 Calibration uncertainty

The calibration rig should be traceable to accepted standards and the performance should be verified by intercomparison with other comparable flow facilities using high quality transfer standard flowmeters. It is essential that the calibration rig uncertainty is lower than that of the meter.

Errors arising during calibration are of two types: random and systematic. To estimate the overall uncertainty of the calibration rig, they should be combined using the procedure given in ISO 5168. (See also ISO 7066-1.)

A.5 Calibration procedures

A.5.1 Test flowrates

Calibration must be preceded by an appropriate warmup and hydraulic run-in time.

The sequence of the calibration flowrates must not introduce any systematic error into the evaluation data. It is therefore recommended that the test flowrates are arbitrarily set and that duplicate flowrates are chosen at random to ensure valid calibration data.

A number of different conventions are used to choose test flowrates. In all cases the choice should cover the flow range of the meter and give an indication of the repeatability.

For the basic production and extended calibration certificates, the following information is recommended to meet with International Standards for quality control:

- unique certificate number, repeated on each page along with the page number and the total number of pages;
- date of certificate issue and date(s) of test;
- unique client identification;
- test laboratory name and location;
- fluid used;
- unique identification of test instrument;
- procedures and traceability of the test facility, given or referenced;
- uncertainty statement, along with the calculation method;
- ambient conditions, if relevant;
- relevant test data and results of the calculation, along with relevant process parameters. The data should be presented in chronological order;
- authorized signature.

A.5.2 Preliminary sensor and transmitter calibration

This calibration (Level 1) establishes the sensor flow factor and any other sensor constants at a specific flowrate. A matched transmitter or secondary electronics are not required.

If required, a similar calibration can be carried out on the transmitter with a simulated sensor.

A.5.3 Basic production calibration (routine calibration)

This calibration (Level 2) is the standard calibration performed by the manufacturer's laboratories, mainly to demonstrate that the meter accuracy is within the stated specifications.

The test fluid, most commonly water, is mentioned in the calibration certificate. There are two approaches to determining the maximum flowrate of the basic meter calibration:

a) Customer specification: Calibration points are made at 100 %, 50 % 20 % and again at 100 % of full scale.

b) Standard specification: The calibrated full scale is determined at a fluid velocity of 3 m/s in the vibrating conduit. Calibration points are made at 100 %, 50 % 20 % and again at 100 % of full scale.

The data to appear on the Level 2 calibration certificate will vary among the various test centres. However, all the information listed in figure A.1 shall be included. It is recommended that the certificate have the standard format as a summary of the calibration as shown in figure A.1. To minimize confusion, a statement should be included on the certificate detailing how repeatability has been calculated.

A.5.4 Extended calibration

A Level 3 calibration may be performed by the manufacturer's laboratories etc. on request from a user. It can be performed both in the laboratory and in the field. Its purpose is to provide a full description of the main Coriolis mass flowmeter performance regarding accuracy, linearity, repeatability, etc. at the desired operating flowrate and with the fluids of interest.

The choice of test sequence is made depending on the expected use of the meter. However, in each case the meter should be calibrated using both increasing and decreasing flowrates. The number and order of test rates should be chosen to demonstrate the full linearity, repeatability and hysteresis of the meter system at selected process conditions. Usually between 15 and 30 test measurements are taken.

The meter characteristics should be reflected in the way the data is presented. The calibration should also show any peculiarities of the calibration itself. Data can be presented in tabular or graphical form (or preferably both). A suggested graphical data presentation is given in figure A.1.

The tabular form should present the meter error or equivalent as a function of flowrate. A graphical presentation of this data is useful so that any spurious data can be quickly identified. The tabular data should also reflect the order in which the tests were performed. Repeatability data should show any time-dependent variations in either flowrate and/or meter output.

Linearity refers to the constancy of the meter calibration factor over a specified flow range. The calibration certificate shall state the published and actual linearity limits. Statements on the uncertainty and the method of traceability give the user confidence in both product and manufacturer.

The pressure drop at the maximum specified flowrate using the calibration fluid (usually water) is a very valuable piece of data, particularly if the inlet pressure is limited.

The pressure and temperature limits stated on the certificate determine the operating conditions.

The uncertainty of measurement should be quoted for the calibration and the traceability of the facility provided to give confidence in the result. Reference to ISO 5168 to specify this value is strongly recommended.

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

Supplier: ....

Primary device: Type number ....

Serial number ....

Sensor calibration factor ....

Secondary device: ....

Type number ....

Serial number ....

Output calibrated mA — pulsed — density etc. ....

Test conditions

Calibration fluid: ....

Viscosity: .... at .... °C

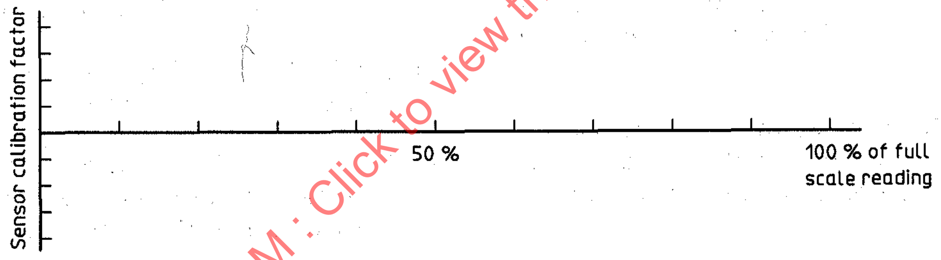
Density: .... at .... °C

Temperature of test fluid: .... °C

Pressure at inlet to test meter: .... bar

Facility traceable to: ....

q_m	**% of full scale**	**Sensor calibration factor**
....	....	....
....	....	....
....	....	....



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

Pressure drop at maximum flow: ....

Repeatability: at flowrate of .... is ± .... % reading

at flowrate of .... is ± .... % reading

Expressed as: ....

Linearity across flow range: ± .... % reading

Average meter calibration factor: ....

....

Date of test: .... Signature: ....

Figure A.1 — Typical Level 2 and Level 3 calibration protocols

Annex B
(informative)

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1) To be published. (Revision of ISO 5168:1978)

2) To be published.