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Refrigerated hydrocarbon fluids — Dynamic measurement — Requirements and guidelines for the calibration and installation of flowmeters used for liquefied natural gas (LNG) and other refrigerated hydrocarbon fluids

Hydrocarbures liquides réfrigérés — Mesurage dynamique — Exigences et lignes directrices pour l'étalonnage et l'installation de débitmètres utilisés pour le gaz naturel liquéfié (GNL) et autres hydrocarbures liquides réfrigérés

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 28, *Petroleum and related products, fuels and lubricants from natural or synthetic sources*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Reliable, accurate and commonly agreed measurement methods are a first requirement for the trade of goods. In the LNG distribution chain, there is a commonly agreed measurement practice, as described in various International Standards and in the GIIGNL *Custody transfer handbook*[10]. The LNG industry is committed to improve measurement accuracy to reduce financial risks and to optimize mass and energy balances throughout the LNG measurement chain. Dynamic measurement technologies have the potential to reduce measurement uncertainty. As an extension of the traditional distribution chain for LNG, a new market of professional consumers for LNG is developing related to transport fuel and metrological infrastructure. In this respect, the availability of the following tools for dynamic flow measurement is essential:

— primary standards for the determination of the amount of an LNG substance and calibration of working standards;

— LNG test and calibration facilities (for volume and mass flow) for the calibration of equipment for custody transfer, allocation or process control under operational conditions;

— stable meters for the determination of volume and mass flow under cryogenic conditions;

— guidelines for the selection and installation of cryogenic flowmeters;

— guidelines for zeroing and adjusting cryogenic flowmeters, including tips and traps;

— guidelines for the further dissemination of traceability by (master meter) calibration techniques, including correction methods for parasitic metrological effects;

— guidelines for the calibration of volume and mass flowmeters with alternative fluids such as water.

This document provides designers of metering stations and end-users with a set of valuable guidelines to enable a better performance of liquid flowmeters under cryogenic operating conditions. The document focuses on LNG as a medium, however, it is assumed that much of the information is also directly applicable to other cryogenic fluids.

Refrigerated hydrocarbon fluids — Dynamic measurement — Requirements and guidelines for the calibration and installation of flowmeters used for liquefied natural gas (LNG) and other refrigerated hydrocarbon fluids

1 Scope

This document specifies the metrological and technical requirements for flowmeters intended to be used for the dynamic measurement of liquefied natural gas (LNG) and other refrigerated hydrocarbon fluids. For LNG static volume measurement used in custody transfer, see ISO 10976.

This document sets the best practice for the proper selection and installation of flowmeters in cryogenic applications and identifies the specific issues that can affect the performance of the flowmeter in use.

Moreover, it offers a calibration guideline for laboratory and on-site conditions (mass or volume) by either using LNG or other reference fluids. The choice of calibration fluid will depend on the capabilities of the available flow calibration facilities and the ability to achieve the required overall measurement uncertainty demanded by the intended application.

This document is applicable, but is not limited, to the use of Coriolis and ultrasonic flowmeters for dynamic measurements of LNG.

In principle, LNG and other refrigerated liquid hydrocarbons are considered in this document. Recommendations in this document are based on the available test results with LNG. These results are probably applicable to other cryogenic fluids.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10790, *Measurement of fluid flow in closed conduits — Guidance to the selection, installation and use of Coriolis flowmeters (mass flow, density and volume flow measurements)*

ISO 12242, *Measurement of fluid flow in closed conduits — Ultrasonic transit-time meters for liquid*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1.1
master meter
MM
flowmeter calibrated against a primary standard with sufficiently low uncertainty and used to calibrate the meter under test

3.1.2
measurement error
measured quantity value (3.1.3) minus a reference quantity value

3.1.3
measured quantity value
quantity value representing a measurement result

3.1.4
measurement uncertainty
non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used

Note 1 to entry: A list of metrological definitions can be found in ISO/IEC Guide 99.

3.1.5
stored zero value
S_{ZV}
value stored in the flowmeter transmitter representing a meter reading at a no flow condition

3.1.6
turndown ratio
ratio of maximum and minimum flow rates

3.1.7
zero adjustment
dedicated procedure to set a new *stored zero value* (3.1.5), with the aim to keep the flowmeter within its *zero offset limit* (3.1.9)

3.1.8
zero offset
Z_{O}
average mass or volume flow rate reading observed under zero (no) flow conditions

Note 1 to entry: In this instance, the (Coriolis) flowmeter's low flow cut-off filter is disabled, and the flow direction in the electronics is set to bi-directional.

3.1.9
zero offset limit
Z_{OL}
maximum permissible *zero offset* (3.1.8) specified by the manufacturer

Note 1 to entry: Some Coriolis mass flowmeter manufacturers also state a specific zero offset for verification and adjustment.

3.1.10
zero verification
procedure to check that the actual *zero offset* (3.1.8) of the flowmeter has not exceeded the *zero offset limit* (3.1.9)

3.2 Abbreviated terms

CMF Coriolis mass flowmeter

LNG liquefied natural gas

MM master meter

MUT meter under test

USM ultrasonic flowmeter

4 Flowmeter selection

4.1 Considerations of meters specific to LNG metering

Table 1 gives an overview of the considerations for the selection of the appropriate flowmeter for a specific situation.

Table 1 — Flowmeter selection considerations

Parameter	Coriolis flowmeter	Ultrasonic flowmeter
Type of measurement	Mass flow measurement, density measurement.	Volumetric flow measurement (at actual conditions).
Diameter of the meter	Limited line size.[a]	Availability for larger lines.[b]
Required space to install the meter	Relative large meter body dimensions.	Relative small meter body dimensions.[c]
Pressure drop	Considerable pressure drop at high flow rates. Possibility of LNG flashing.	Low pressure drop.
Turndown ratio	Large rangeability; the flowmeter can be applied to a large range of flow rates.	Large rangeability; the flowmeter can be applied to a large range of flow rates.
Diagnostics	Density, gain of excitation (gas detection), tube temperature.	Multiple paths flow profile, speed of sound, gain, signal to noise ratio (gas detection).
Straight length requirements (flow profile)	Not required to have a straight length upstream of the flowmeter. This is because CMFs are typically not affected by swirling and non-uniform flow velocity profiles induced by upstream or downstream piping configurations.	For meters with a small number of paths (< 4) a significant straight length up and downstream of the meter is required to achieve sufficient accuracy. This is because meters with small number of paths may be sensitive to swirl and non-uniform flow velocity profiles induced by upstream or downstream piping configurations. Multipath types may not be sensitive to swirling and non-uniform flow velocity profiles induced by upstream or down-stream piping configurations.
Bi-directional flow	Suitable for bi-directional flow.	Suitable for bi-directional flow.

[a] Typically meters with a diameter up to 12" are available.

[b] Typically meters with a diameter up to 36" are available.

[c] The total setup could be relatively large due to a long upstream straight pipe length.

[d] The stiffness change of the vibrating tube due to cryogenic temperatures has a significant impact, however, it can be corrected for by the temperature model.

Table 1 *(continued)*

Parameter	Coriolis flowmeter	Ultrasonic flowmeter
Reynolds number sensitivity	Generally low sensitivity to Reynolds number for low viscosity fluids such as LNG. For very high viscosity fluids the flowmeter error is dependent on the Reynolds number, especially for laminar-turbulent transition. The viscosity changes due to changes in the composition are anticipated to be negligible.	Depending on the number of paths there is a moderate to high sensitivity on the Reynolds number. The viscosity changes due to changes in the composition are anticipated to be negligible.
Sensitivity to vibrations	Could be affected by vibrations when the frequency is near the vibration frequency of the tube.	Insensitive to vibrations.
Mechanical stress	Sensitive to mechanical stress. Impact of mechanical stress can be monitored for zero flow conditions.	Insensitive to mechanical stress.
Pressure	Small effect for pressures up to roughly 30 bar. Can be corrected for based on available correction models and internal or external pressure measurement.	Smaller effect, can be corrected for based on available correction models and internal or external pressure measurement.
Temperature	Thermal expansion of the meter body may be compensated for based on internal/external temperature measurement.[d]	Thermal expansion of the meter body may be compensated for by an internal/external temperature measurement.
Others	Measured flow and density can be influenced by bubbles caused by (local) boiling and/or cavitation in the flow.	Measured flow can be influenced by bubbles caused by (local) boiling and/or cavitation in the flow. Consider velocity limits to prevent cavitation around transducers.

[a] Typically meters with a diameter up to 12" are available.

[b] Typically meters with a diameter up to 36" are available.

[c] The total setup could be relatively large due to a long upstream straight pipe length.

[d] The stiffness change of the vibrating tube due to cryogenic temperatures has a significant impact, however, it can be corrected for by the temperature model.

4.2 Coriolis flowmeter

The CMF is a device that measures mass flow rate as well as fluid density. Its fundamental operational principle is based on vibration mechanics and its interaction with the fluid dynamics. Because of its working principle, the flowmeter is capable of determining the density of the fluid when it matches a resonance frequency that corresponds to the fluid mass enclosed in the measuring tube's finite volume.

The mass flow rate is directly linked to the Coriolis force that is present when the fluid moves at a certain velocity and in combination with the measuring tube's angular motion. As this occurs, a secondary oscillation mode will take place, thus generating a phase shift in the measuring tube displacement. Such a phase shift is proportional to the mass flow rate, and is therefore used as a primary output signal to determine flow.

NOTE More information on the CMF is given in Annex A.

4.3 Ultrasonic flowmeter

The ultrasonic transit-time flowmeter is a sampling device that measures discrete path velocities using one or more pairs of transducers. Each pair of transducers is located at a known distance apart such that one is upstream of the other. The upstream and downstream transducers send and receive pulses of ultrasound alternately. The times of arrival are used in the calculation of average axial velocity. At any given instant, the difference between the apparent speed of sound in a moving liquid and the speed of sound in that same liquid at rest is directly proportional to the liquid's instantaneous velocity. As a consequence, a measure of the average axial velocity of the liquid along a path can be obtained by transmitting an ultrasonic signal along the path in both directions and subsequently measuring the transit-time difference.

The volumetric flow rate of a liquid flowing in a completely filled closed conduit is defined as the average velocity of the liquid over a cross section multiplied by the area of the cross section. Thus, by measuring the average velocity of a liquid along one or more ultrasonic paths (i.e. lines, not the area) and combining the measurements with knowledge of the cross-sectional area and the velocity profile over the cross section, it is possible to obtain an estimate of the volumetric flow rate of the liquid in the conduit.

NOTE More information on the ultrasonic flowmeter is given in Annex B.

5 Process conditions

5.1 Temperature effects

5.1.1 Loading procedures

Both CMF and USM applications require a stable and consistent single-phase flowing medium in order to correctly measure the flow. It is particularly important to consider this requirement when loading at cryogenic temperatures as potentially large temperature variations and heat gain increase the likelihood of a two-phase flow. This will at least be the case if the meter/pipes connecting the meter are at ambient temperature prior to loading.

Several mitigating actions may be employed to increase the likelihood of maintaining a cryogenic single-phase liquid flow. One effective way to accomplish this is by keeping the meter cooled down, not only during loading operations, but at all times, e.g. by using a proper circulating loop. A disadvantage is the increased cost of cooling the cryogenic medium as the circulation will increase the heat gain. In general, a low-flow velocity, large pipe diameter, and poorly insulated meter and flow lines should be avoided as this will add to the probability of boiling and two-phase flow.

Maintaining the temperature of the meter at cryogenic conditions will minimize stresses on the pipe material, which is desirable.

Depending on the loading product, it is common practice to cool down the meter and pipes from ambient to cryogenic conditions prior to transfer. For LNG application, gas and liquid nitrogen are often used for this purpose. Starting from an ambient temperature, cold nitrogen gas can be introduced to gradually lower the temperature and avoid stress from temperature shock. Small amounts of liquid nitrogen are then injected to boil off and further cool down the system.

For some applications (e.g. in a small-scale LNG transfer), it is not possible to cool the meter and pipes with liquid nitrogen because it is not accessible at the location. In this case, purging the system with cold natural gas is allowed.

After loading, the temperature will have to change from cryogenic to ambient conditions. It is common to let the remaining liquid boil off from meter/pipes and this can cause a two-phase metering condition.

Depending on the conditions, at loading, both the CMF and USM can apply compensation to account for changes in process conditions such as temperature. Any such compensation can increase the measurement uncertainty and shall be considered specifically for the actual application. Therefore, it is advisable to consult the flowmeter manufacturer.

5.1.2 Temperature effects on CMF measurements

One fundamental design parameter for CMFs at cryogenic temperatures is the consideration of the measuring tube's material properties and its behaviour at very low temperatures. This is quite relevant, since the Young's modulus of elasticity of tube material at standard conditions (e.g. water at laboratory temperature) is significantly different from the cryogenic conditions, and, more importantly, its value is defined by a nonlinear relationship with the temperature. Further, because of the cryogenic temperatures, the volume of the measuring tubes changes significantly. Disregarding these effects can cause a shift in the calibration curve and thus a measurement bias.

Since CMF manufacturers are aware of these effects, a dedicated algorithm is implemented in CMF software to correct for the Young's modulus dependence on temperature, thermal contraction and any other relevant parameters, if applicable.

In general, straight-measuring tube CMFs are more sensitive to cryogenic temperatures, as the axial stress created in the tube can be very high and can exceed the material strength. A bent-measuring tube CMF is a more robust sensor, since the axial stress generated at cryogenic temperatures is much smaller, i.e. within the allowable material strength, and thus it gives a better zero-point stability.

Some independent studies on the performance of CMFs under cryogenic conditions indicate that most meters are suitable for cryogenic flow measurements. However, the closeness of the flow measurement to the reference value will vary according to the correction algorithm developed by the manufacturer, and the data concerning the sensor's material properties obtained from a fitted polynomial curve. It is worth noting that, despite having a reliable source of data, the tube material properties and/or the influence of the manufacturing process can cause a shift from the reference data, thus causing unaccountable axial stress on the sensor.

5.1.3 Temperature effects on USM measurements

For all ultrasonic meters, the flow correction factor due to changes in meter geometry at cryogenic temperatures can be given as a straightforward analytical solution, see ISO 12242. Owing to this, the correction has a very small uncertainty and the only uncertainties related to this correction are those associated with the material constants.

The flow correction factor due to a change in the meter body temperature, ΔT, is shown by Formula (1):

$$K_{bt} = (1+\alpha\Delta T)^3 = \left(1+3\alpha\Delta T+3(\alpha\Delta T)^2+(\alpha\Delta T)^3\right) \quad (1)$$

where

K_{bt} is the thermal correction factor;

ΔT is $T_{operating} - T_{calibration}$;

α is the thermal expansion coefficient.

Formula (1) may be simplified without a significant loss of accuracy to Formula (2):

$$K_{bt} = 1+3\alpha\Delta T \quad (2)$$

5.2 Pressure effects

5.2.1 Coriolis flowmeter

Operating a CMF at fluid pressures higher than the calibration reference conditions will lead to changes in the mechanical characteristics of the measuring tube, thus modifying the CMF fundamental vibration frequency, and, if not corrected, could create significant flow measurement errors.

The fluid pressure effect may be interpreted in mechanical terms as an additional axial stress acting on the measuring tube. From manufacturers' data and independent tests, it has been found that pressure effects can differ with measuring tube geometry. For most bent-tube CMFs, the sign of the pressure sensitivity (percentage of error per bar) is negative, while for most straight-tube CMFs it is positive.

Currently, the majority of CMFs have a relatively small sensitivity to pressure changes. However, if there is a need to quantify the CMF's impact on the measurand, then the end-user is advised to follow the manufacturer's recommendations. Alternatively (if applicable), a pressure sensor may be employed to make a real-time correction to the measurand, thus minimizing the CMF's pressure sensitivity. The latter shall be taken into consideration only if the CMF pressure-induced error exceeds the maximum error tolerated by the process measurement, or if the operational pressure is so significantly high that the manufacturer advises using an auxiliary pressure sensor.

5.2.2 Ultrasonic flowmeter

The influence of pressure on the performance of a USM, if operated at fluid pressures different than the calibration pressure, is almost negligible. Only an expansion caused by the meter body due to a pressure difference will affect the internal diameter, and hence will cause an under- or over-reading. This will only be significant if the pressure difference is substantial. In this case, the flowmeter should have the capability to correct for it. A general formula to calculate the pressure correction factor is shown by Formula (3):

$$K_{pb} = 1 + \frac{C_{pb}}{100} \times \left(P_{process} - P_{cal}\right) \tag{3}$$

where

K_{pb}	is the correction factor used for the pressure expansion;
C_{pb}	is the linear pressure coefficient, in %/kPa;
$P_{process}$	is the process pressure, in kPa;
P_{cal}	is the reference pressure, in kPa.

A typical pressure correction factor for a pressure difference is C_{pb} = 0,000 04 %/kPa.

NOTE A generic formula to calculate the effect of volume increase due to pressure is shown by Formula (4):

$$\frac{\Delta A_i}{A_i} = \frac{D_i + w}{w} \times \frac{P}{E} \tag{4}$$

where

ΔA_i	is the difference of the internal cross-sectional area;
A_i	is the internal cross-sectional area;
D_i	is the internal pipe diameter;
w	is the wall thickness;
P	is the pressure;
E	is the elasticity modulus.

5.3 Mechanical vibrations

5.3.1 Coriolis flowmeter

In some cases, CMFs are exposed to external vibrations or pulsations. Such vibrations can be induced by mechanical means (i.e. a pumping system), the environment or by the fluid dynamics in the pipeline.

In general, a CMF is designed in such a way so that the effect of the external vibration is minimized, whereby it has no relevant impact on the CMF measurement.

In cases where the end-user deals with a severe vibration application, it is recommended to use flexible piping or isolation pipe supports to minimize the vibration, or to contact the manufacturer for further assistance.

5.3.2 Ultrasonic flowmeter

USMs are built out of a robust metal body and the principle of operation is based on measuring the time differences between two ultrasonic pulses travelling across the pipe diameter in opposite directions. Currently, there is no proof of sensitivity of the meter reading to mechanical vibration.

5.4 Cavitation

5.4.1 Coriolis flowmeter

Cavitation in CMFs is defined as the process of formation of the vapour phase of a liquid within the measuring tube. This phenomenon occurs when the hydrostatic pressure is decreased, which is caused by a reduction in the cross-sectional area. The decrease in hydrostatic pressure causes a decrease in the boiling point, which can cause the liquid to start boiling. This phenomenon is also known as "cavitation".

As the liquid cavitates within the measuring tube, it forms tiny vapour bubbles, which grow as they collapse on one another (implosion). If the fluid velocity at the measuring tube continues to increase (the pressure continues to fall), then the vapour bubbles will continue growing in the same manner (see Figure 1).

In terms of linearity, the cavitation effect plays a significant role, since the two-phase condition can generate a significant measurement error depicted by a nonlinear response at the upper flow range of the CMF.

Unlike other nonlinear effects upon CMFs, this is perhaps the easiest to handle, since cavitation can be prevented by setting the operating process conditions properly. In this respect, there are six fundamental recommendations to avoid cavitation:

a) use the correct size of the CMF according to the process conditions;

b) avoid low upstream pressure;

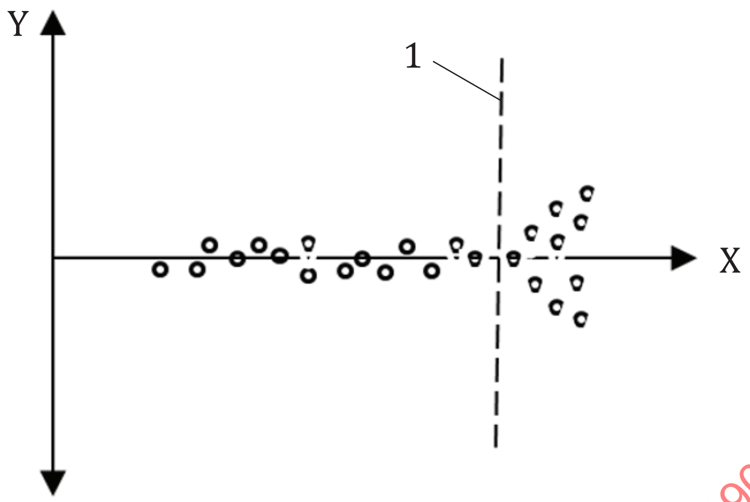
c) avoid fluid velocities out of the manufacturer's specifications;

d) use the correct operational window and pressure/temperature relation (see the phase envelope);

e) ensure proper venting at a high point to prevent vapour pockets growing over time;

f) ensure enough recirculation (cooling) over the line piece to minimize the influence of ambient heat gain.

Figure 1 depicts a sudden spread of the measurement error in the CMF response, due to the early presence of cavitation in the measuring tube(s).



Key

1 early presence of cavitation

X flow, in kg/h

Y relative error, in %

Figure 1 — Early presence of cavitation in a Coriolis flowmeter

5.4.2 Ultrasonic flowmeter

Cavitation in the USM is unlikely to happen when the transducers are built-in in such a way that no cavities are present (the transducers are flush with the inner pipe wall). If cavitation takes place in the meter, the readout will be unstable and, in some cases, will completely stop due to the attenuation of the sound pulse.

5.5 Thermodynamic properties of LNG

The fluid properties for density and viscosity for LNG can be found in the tables in Annex F.

6 Installation

6.1 Valves

For both CMFs and USMs, it is recommended to use valves that are fully leak-tight. Flow regulating valves (control valves) should be installed downstream to ensure that the fluid remains in a single phase and no flashing or cavitation occurs.

6.2 Swirl and non-uniform profiles

6.2.1 Coriolis flowmeter

The performance of a CMF in single-phase flow is not affected by swirls or non-uniform velocity profiles induced by upstream or downstream-piping configurations.

Caution shall be exercised with respect to inducing external stress or vibration on the flow tubes when planning and carrying out the installation of Coriolis meters as explained in ISO 10790.

6.2.2 Ultrasonic flowmeter

Ultrasonic meters can be sensitive to hydraulic influences. In other words, distortions of the axial velocity profile or the introduction of non-axial flow components or swirling flow resulting from bends, valves and other pipe fittings upstream of the meter can result in measurement errors if not addressed in either the meter design or the system configuration.

It is possible to make some general statements about factors affecting the magnitude of such hydraulic installation effects. For example, it is generally true that USMs employing a larger number of measurement paths are less sensitive to hydraulic effects than meters with fewer paths. It can also be shown that meters with measurement paths arranged in crossed pairs can be effective in reducing the effects of non-axial and swirling flows.

Ultimately, type evaluation data are required to properly judge the sensitivity of a given meter design to hydraulic disturbances. It is recommended for LNG applications that the uncertainty component owing to hydraulic effects for a given meter design and upstream pipe configuration is based on laboratory test data in accordance with the type testing requirements of ISO 12242.

6.3 Flow conditioners

Flow conditioners may be installed upstream to achieve the desired hydraulic conditions for ultrasonic meters. However, a flow conditioner creates a pressure drop, which could result in flashing of the LNG upstream of the meter. Therefore, if it is demonstrated, by reference to ISO 12242, that a flowmeter design achieves the uncertainty required for custody transfer without a flow conditioner, upstream flow conditioners should not be used.

The pressure loss owing to the use of a flow conditioner can be calculated as shown by Formula (5):

$$\Delta P = 0{,}5\, \rho k v^2 \tag{5}$$

where

ΔP is the pressure loss, in bar;

v is the fluid velocity in the pipe, in m/s;

k is the loss coefficient for a given type of conditioner (–);

ρ is the fluid density, in kg/m^3.

Typical loss coefficients for flow conditioners are in the range of 2 to 5. Once the pressure loss has been calculated, pressures and temperatures can be calculated to ensure that the LNG is kept comfortably below the boiling point in order to avoid cavitation, see Figure F.1.

6.4 Pipe stress and torsion

6.4.1 Coriolis flowmeter

Depending on the type and construction of the meter, the CMF can be sensitive to pipe stresses. Consult the manufacturer and consider the use of bellows.

The flow sensor is subjected to axial, bending and torsional forces during operation. Changes in these forces, resulting from variations in the process temperature and/or pressure, can affect the Coriolis mass flow measurement. Care should be taken to ensure that no forces are exerted on the CMF from the clamping arrangements.

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

6.4.2 Ultrasonic flowmeter

Since a USM is built from a robust metal meter body, the influence of pipe stress and torsion is negligible.

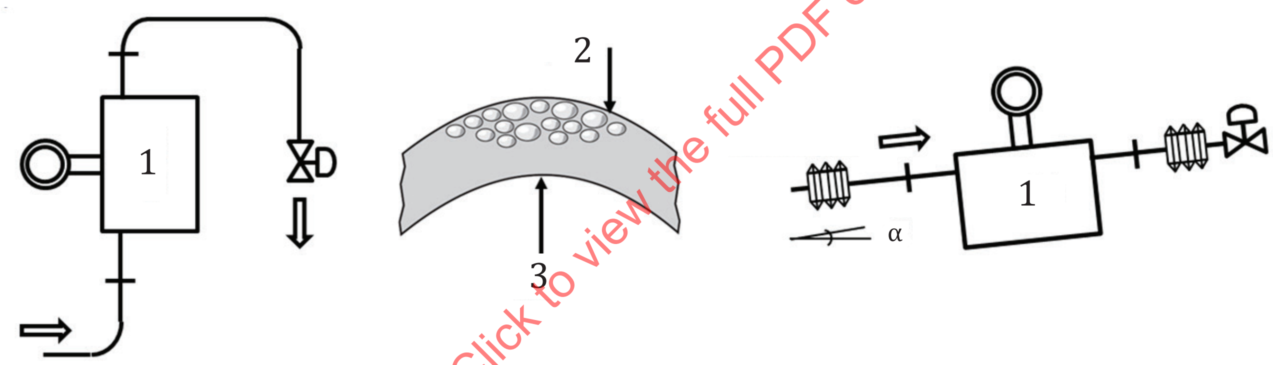
6.5 Flowmeter installation recommendations

6.5.1 Coriolis flowmeter

The preferred installation orientation is vertical, see Figure 2 a), with an upward flow direction. By using this configuration, the entrained solids will sink downward, and the gases will go upward when the fluid is not flowing. This installation also allows the measuring tubes to be completely drained and to protect them from solid build-up.

The CMF should not be installed at the highest point of the system, or with the bent measuring tube(s) oriented upwards, see Figure 2 b), as gas may accumulate. For high-end calibrations/applications, i.e. a flow rate smaller than 10 % of the range and uncertainties smaller than, for example, 0,2 % actual, bellows are recommended to reduce possible mechanical stress, see Figure 2 c).

The second alternative is to place the CMF horizontally with a slight angle α and the transmitter head up in order to avoid gas accumulation, see Figure 2 c).



a) **Vertical installation of a CMF**

b) **Gas entrapment in an upward-oriented CMF measuring tube**

c) **Horizontal CMF installation for LNG flowmeters**

Key

1 CMF

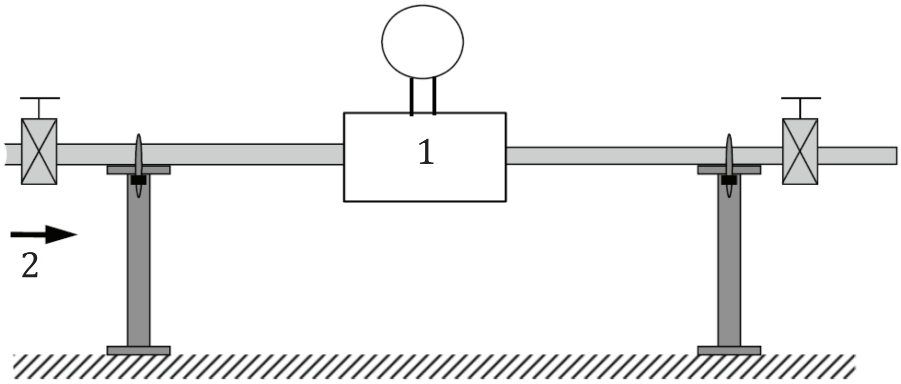
2 gas entrapment

3 bent measuring tube

Figure 2 — Coriolis flowmeter installation recommendations

When mounting the CMF, the meter's expansion and contraction of piping due to the large temperature changes should be considered, and sufficient piping flexibility and sliding mounts designed at both sides of the meter, see Figure 3.

Measures should also be taken to prevent alignment stresses from being exerted on the CMF by connecting pipes. Under no circumstances should the CMF be used to align the pipe work. This may be checked with the zero verification.



Key

1 CMF

2 flow direction

Figure 3 — Example of piping and support for a Coriolis flowmeter

6.5.2 Ultrasonic flowmeter

USMs should be installed horizontally with enough straight length upstream of the flowmeter, see Figure 4.

Contact the manufacturer for guidelines on the minimum length of the upstream piping. The minimum required straight pipe length downstream of the meter shall be three times the diameter in accordance with ISO 12242 with no exceptions for LNG applications. The USM installation should be completely free of bubbles.

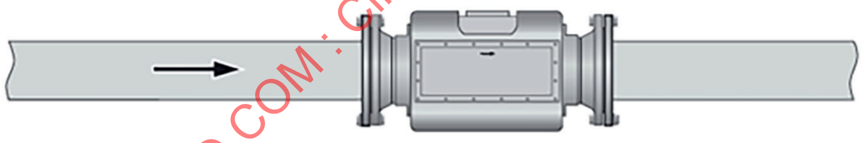


Figure 4 — Horizontal installation of a ultrasonic flowmeter

6.6 Crosstalk and sensitivity to noise

6.6.1 Coriolis flowmeter

If two or more CMFs are intended to be mounted close to each other, interference through mechanical coupling could occur. This is often referred to as “crosstalk”. The manufacturer should be consulted for methods of avoiding crosstalk.

The mechanical design of an installation should recognize the need to avoid interference or crosstalk. Testing should be carried out after installation, as the flowmeter errors introduced can be significant but not obvious in normal operation. If observed, the manufacturer should be consulted.

6.6.2 Ultrasonic flowmeter

Ultrasonic gas flowmeters can be affected by acoustic noise, particularly by noise generated by pressure regulating valves (gas applications). Currently, there are no reports of similar problems in LNG applications or liquid applications in general. The reason for this is twofold: the generation and propagation of noise is worse in gas applications than in liquid applications, and ultrasonic transducer frequencies used in liquid applications are higher than those used in gas applications and hence are further away from the high amplitude components in the spectrum of acoustic noise. In liquid applications, USMs are not sensitive to noise because noise frequencies are typically in the range of (300 to 600) kHz and the flowmeter transducers' frequencies are in the range of (1 to 2) MHz.

The phenomena of crosstalk between transducers is not applicable to USMs because each individual flowmeter transducer is listening only to its dedicated opponent across the pipe section.

6.7 Zero offset — Verification and adjustment procedures

6.7.1 Coriolis flowmeter

6.7.1.1 General

The instructions given in 6.7.1.2 to 6.7.1.6 shall be considered when executing the zero verification and adjustment procedures.

6.7.1.2 Pre-settings and prerequisites

a) Set up the zero verification parameters specified by the manufacturer, such as:

   1) low flow cut-off filter (disable);

   2) flow direction to "bi-directional" with totalizer mode activated;

   3) flow damping deactivated,

   4) special register as combination, directly representing the Z_0 over a short time,

   5) data logging (optional).

b) Zero verification or adjustment procedures shall be made as close as possible to the process conditions of fluid temperature, pressure and density. Permissible process variable ranges are defined by manufacturers.

6.7.1.3 Zero verification

The procedure described in this subclause is based on three determinations of Z_0. One or two determinations of Z_0 may be allowed/justified during verification after consultation with the manufacturer and/or local weigh and measures officer.

a) Let the process fluid circulate through the CMF at the maximum possible flow rate intended for the test until process variables are stable.

b) Make sure no vapour is in the system (i.e. purging) to prevent two-phase flow and/or gas entrapment in the CMF measuring tubes. The presence of entrained gas will often be detected by fluctuating measurement values (i.e. driving frequency/current, current gain) and, eventually, a significant change in Z_0.

c) Stop the flow in the system by using one of the possible methods:

   1) close the CMF upstream and downstream valves and stop the pumping system (no flow); or

   2) run the pumping system at a reduced speed and close the CMF downstream valve (upstream valve remains open).

   The selected method will depend on the availability/positioning of the valves at the calibration facility or user's measurement site. Before continuing the test, make sure that the valve(s) do not leak to avoid incorrect results. The stopping method shall be discussed with the user for safety reasons related to the fact that the pressure increases.

d) Check that the pressure at the CMF remains constant during the test and/or monitor one of the process parameters, in order to prevent the fluid from outgassing.

6.7.1.4 Zero offset determination

a) Write the actual stored zero value (S_{ZV}) before proceeding with the zero offset (Z_0) calculation and record the Z_0 by using one of the two possible options:

   1) totalizer mode (collected mass divided by time);

   2) direct Z_0 mass flow reading (special register).

   For the specific case of LNG measurements, it is not recommended to monitor the CMF readout for a long time, since this can cause unstable process conditions, thus affecting the Z_0 determination. A typical zero monitoring time is about 30 s. However, longer times can be allowed if the process conditions remain stable at the metering point.

b) Open the valve(s) and let the fluid circulate through the CMF until the system reaches stable process conditions.

c) Repeat steps 6.7.1.3 c), 6.7.1.3 d), a) above and b) above for the number of times specified by the manufacturer (typically 3× to 5×).

d) Determine the maximum and minimum Z_0 readings:

   1) ($Z_{0,max}$ and $Z_{0,min}$) and calculate the difference between readings (ΔZ_0);

   2) $\Delta Z_0 = Z_{0,max} - Z_{0,min}$.

e) Calculate the average zero offset (Z_0,average) from the acquired samples.

6.7.1.5 Decision criteria for a correct zero verification or required zero adjustment

Select the decision criterion that matches the zero verification outcome in accordance with Table 2.

Table 2 — Decision criterion if zero adjustment is required

IF	$\Delta Z_0 < Z_{0L}$ and all $Z_0 < Z_{0L}$	Then: no zero adjustment is required
	$\Delta Z_0 < Z_{0L}$ and one $Z_0 > Z_{0L}$	Then: zero adjustment is required
	$\Delta Z_0 > Z_{0L}$	Then: possible reasons: — unstable process conditions — zero verification procedure not performed accordingly — unstable zero of the CMF possible actions: — repeat the zero verification procedure — contact the manufacturer for further guidance

6.7.1.6 Zero adjustment

Follow Table 3 to check if a zero adjustment is required.

a) Write the actual S_{ZV} before proceeding with the zero adjustment.

b) Follow steps 6.7.1.3 a) to d) for initialization.

c) Select the zero adjustment function of the CMF in use and START the adjustment routine.

NOTE 1 Some CMF manufacturers have an additional software feature that displays an error message if the fluid velocity at the measuring tube exceeds a prescribed magnitude during the adjustment procedure.

d) If stable process conditions are not achieved after a while, open the valve(s) and let the fluid circulate through the CMF until the system reaches stable process conditions.

e) Repeat the zero adjustment function, i.e. steps b) to d) above, for the number of times recommended by the manufacturer (typically 3×) and note the obtained zero adjustment values.

NOTE 2 The S_{ZV} will be the result of the last performed zero adjustment routine.

f) Determine the maximum and minimum zero adjustment readings:

1) ($S_{ZV,max}$ and $S_{ZV,min}$) and calculate the difference between readings (ΔS_{ZV});

2) $\Delta S_{ZV} = S_{ZV,max} - S_{ZV,min}$.

g) Calculate the S_{ZV} average from the acquired samples.

h) Perform a zero verification (1×) to validate the zero-adjustment procedure after having flow.

Table 3 — Decision criteria for a correct zero adjustment

IF	$\Delta S_{ZV} \leq Z_{OL}$	Then: the zero adjustment is correct
	$\Delta S_{ZV} > Z_{OL}$	Then: the zero adjustment is not correct Possible reasons: — unstable process conditions — zero adjustment procedure not performed accordingly — unstable zero of the CMF Possible actions: — repeat the zero adjustment procedure — contact the manufacturer for further guidance

6.7.2 Ultrasonic flowmeter

Since USMs are based on time differences, the influence on their zero offset due to changes from reference conditions to cryogenic process conditions and/or mechanical stress on the meter is negligible.

6.8 Temperature management

6.8.1 Thermal insulation

The quality of insulation of LNG pipelines plays a crucial role in flow metrology. This subclause provides a brief summary on insulation aspects.

The insulation of cryogenic pipelines has two functions:

— maintain cold service conditions by limiting heat ingress and temperature variations;

— limit condensation on the outside of the pipeline in order to prevent a rapid deterioration of the external surface of the pipe jacket.

The piping and piping equipment shall be insulated, where required, to:

— minimize the heat gain to avoid metrological issues such as bubble formation in the pipeline and connected pipe volume effects;

— enhance a better temperature control of the flowing LNG in the measurement piping;

— provide protection against condensations, ice formations, etc.

The following insulation types will have a positive effect on the metrological performance:

— vacuum-insulated piping (best method);

— insulating material (foam, fibre, powder and aerogel types);

— cold inert dry gas flushing around non-insulated process piping in a coldbox, mostly used in cases where waste cryogenic nitrogen gas is available.

When insulation is put into place, precautions shall be taken so that no water shall penetrate the insulation. Water, in the form of vapour, liquid or ice, in an insulation system will reduce the efficiency of the insulation material.

In the event of any maintenance being carried out on the meter body, the meter shall be warmed up before any insulation is removed. If any enclosures or transducer pockets are to be opened to the atmosphere, it is essential that the meter body temperature is above freezing to avoid frosting within the enclosure. On completion of the maintenance and prior to cooling down, the meter body insulation shall be re-fitted.

If any work needs to be carried out on the meter, such as maintenance, insulation or recalibration, then the meter shall first be at ambient temperature.

NOTE If the meter is not reaching ambient temperature, then a high risk of iced clogging exists.

The insulation thickness should be calculated in accordance with ISO 12241. The impact of the heat transfer rate on the interconnected volume and upstream piping of the first meter shall be evaluated. The operating condition of the flowing LNG should remain in the subcooled region (see the subcool margin given in F.4).

The quality and type of installation shall be determined according to the following requirements:

— low sensitivity of the insulation material to moisture;

— resistant to large temperature gradients;

— suitable for very low temperatures.

6.8.2 Cooling procedure

The normal operating temperature of LNG at atmospheric pressure is about −160 °C. Therefore, before a metering system can be placed into service, the meter and associated pipeline shall first be cooled down.

Before commencing the cooling down procedure, all moisture and non-inert gases should be removed. This can be achieved by purging with ambient nitrogen.

Practically purging is performed until the O_2 content is below 1 % (volume) and water dew-point is below −40 °C.

The practical approach for cooling is 10 °C/hour dependant on the pipe diameter. It shall never be greater than 30 °C/hour.

In order to avoid any thermal shocks and any potential distortion of the pipeline, the cooling down process begins with injecting cold nitrogen gas until the system has reached a stable temperature. The temperature should be below −130 °C before introducing the cryogenic fluid. In order to purge any nitrogen gas remaining from the initial cooling process, it is preferred to inject gasified LNG after the initial cooling down to continue the cooling at a rate of 10 °C/hour. The problem with this approach is that the LNG retracts heat faster than nitrogen and therefore the cooling gradient is harder to control. Experience shows that cooling down with LNG is carried out as a batch process, where small portions of LNG are supplied to the pipeline and time is given to naturally vaporize the LNG to cool the line. The process is repeated until the pipeline is below −130 °C.

For vacuum-insulated pipelines, the cooling down procedure is much more sensitive, as the inner line cools down faster than the outer vacuum jacket and this could result in a failure of the internal welds.

Therefore, cooling down vacuum-insulated pipelines should be started with liquid nitrogen in a controlled manner.

During the cooling down, care should be taken to achieve homogenous cooling. The temperature should be measured at the bottom and top of the pipeline/meter. Differences will always be present between the bottom and top of the piping when cooling with LNG, as liquid vaporizes from the bottom upwards. This temperature difference should not be more than 30 °C to avoid significant stresses in the piping material.

When cooling down sections of pipeline, the shrinking of the piping should be closely monitored. The pipeline should always be free for movement on supports without the possibility of obstructions due to shrinking. The cooling down sessions and pipe shrinkage shall be monitored during the whole process. One way of monitoring shrinkage is to use permanent markings on the piping before and after the cooling down process. This will indicate the extent of piping shrinkage when moving from ambient to cold conditions.

After the cooling down process, the cryogenic liquid should be circulated until the desired cryogenic conditions are achieved. The circulation flow rate will depend on the installation size.

It is recommended to regard the process as stable when the temperature variation does not significantly affect the zero procedure. The indicated mass flow rate by the meter at zero flow shall be within the limits of the intended application.

The variation of the process temperature should not influence the measurement conditions specified by the proper working of the meter. This process is dependent on the size of the facility, thermal insulation and other factors.

When the pipeline is in a stable condition, LNG could be introduced into the system. The process of cooling down can take some time and the meter manufacturer should be aware that the initial injection of cold gas could cause a very rapid temperature reduction inside the flowmeter body. The transducer design should take this into account.

6.8.3 Warming procedure

For maintenance or other operational reasons, the metering system may be taken out of service and warmed up. The cooling down process can take many hours. The pipeline will be isolated prior to the LNG being vented. As the LNG vaporizes, the pipeline will empty. If the metering system needs to be emptied from its content for safety reasons, then the pipeline will be purged to reach the ambient temperature. The rate of change of temperature is unlikely to be as severe as the cooling down process.

The upwards temperature gradient needs be controlled in accordance with 6.8.2 in a reverse direction. It will be more easy to control. Practically, this is done by supplying ambient nitrogen to the system until all the liquid is vaporized and an ambient temperature is reached.

In practice, purging/venting is performed until the CH_4 content is below 1 % (volume). This ensures all hydrocarbons are removed from the pipeline and a safe opening of the system is possible.

When heating up sections of pipeline, the expansion of the lines should also be closely monitored. The pipeline should always be free for movement on support without the possibility of obstructions due to this expansion. The warming sessions and pipeline expansion shall be monitored during the whole process. One way of monitoring expansion is to use permanent markings on the piping supports before and after the warming process. This will indicate the extent of pipeline expansion when moving from cold to ambient conditions.

7 Calibration

7.1 General considerations

Follow the hardware instructions for the calibration facility given in Annex C.

The following aspects should be considered for an adequate calibration:

a) verify whether the calibration condition represents the field conditions;

b) avoid flashing by making sure the LNG is subcooled: this can either be accomplished by increasing the line pressure to increase the boiling point and thus create some cooling margin or by cooling the LNG by means of a heat exchanger (e.g. based on liquefied nitrogen);

c) the MUT is installed at the calibration line with the appropriate thermal insulation (the use of insulation depends on use in the field);

d) remove any remaining gas from the system by sufficient purging just before the zeroing procedure;

e) perform the zero offset verification and/or adjustment procedure at least for the MUT;

f) wait until the pressure, temperature and flow have reached a prescribed steady condition;

g) perform sufficient repetitions to achieve a sufficiently low standard deviation of the mean (depending on the required calibration uncertainty). Usually three to six repetitions are sufficient.

Calibration facilities for LNG flowmeters should consider following ISO/IEC 17025.

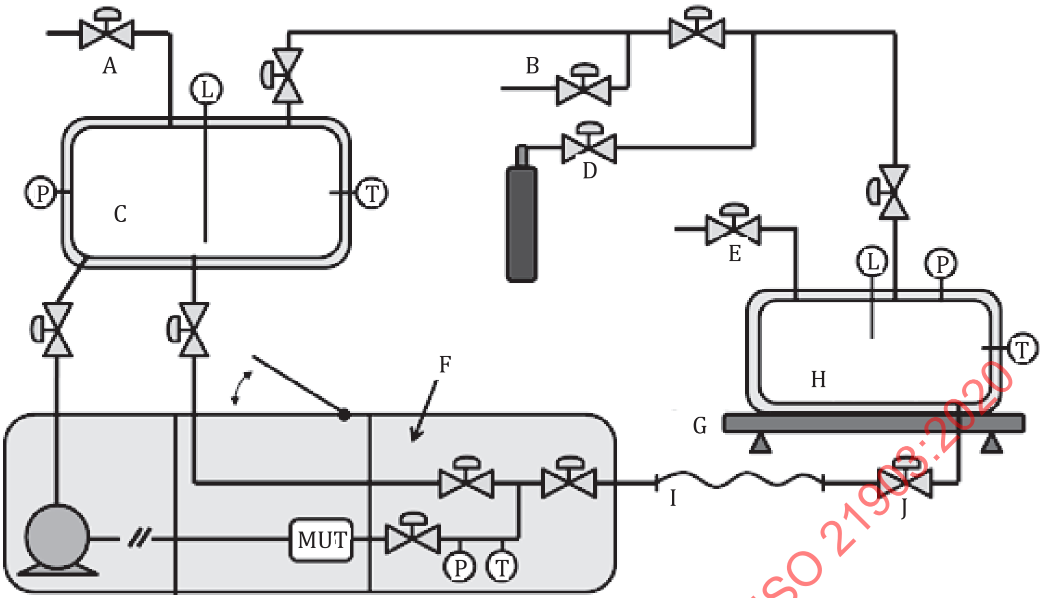
Examples of calibration data are presented in Annex D.

It is acceptable to calibrate an ultrasonic flowmeter for LNG using an alternate fluid. In this case, follow the conditions and procedures given in Annex E.

7.2 Calibration in a laboratory

7.2.1 Gravimetric method

A scheme of an LNG primary standard is shown in Figure 5. This facility consists mainly of a 1 m^3 supply tank, a cryogenic pump, a MUT calibration line, a control valve to set the prescribed flow, a nitrogen pressurization line, a flexible connecting tube between the MUT calibration line and the collection vessel, and a 0,5 m^3 collection vessel placed upon a weighing system. This size of the collection tank is sufficient for flow rates up to 25 m^3/h, which allows for a net calibration time of 1 min.



Key

A	LNG supply	H	collection vessel (0,5 m^3)
B	$CH4+N_2$ exhaust	I	flexible connecting tube
C	supply tank (1 m^3)	J	bypass valve
D	N_2 inlet	L	liquid level transmitter
E	exhaust	P	pressure transmitter
F	isolation material	T	temperature transmitter
G	weighing system		

Figure 5 — Scheme of an LNG primary flow standard

The general principle of calibration is as follows (for more elaborate explanation, see Reference [12]):

— the supply tank is filled with LNG at a temperature lower than −161 °C (the LNG boiling point temperature) to avoid vaporization during the calibration runs;

— a good measure to prevent the sudden flashing of LNG (due to imperfect thermal insulation and heat produced by the pumping system) is to increase the line pressure, so the LNG boiling point will be raised (e.g. $T_{\text{LNG boil}} = -142$ °C at $P = 3$ bar);

— the device under test (MUT) is installed at the calibration line;

— the cryogenic pump is switched on to let the LNG circulate through the MUT calibration line at the maximum calibration flow rate;

— to remove any remaining gas from the system, a purge cycle is initiated just before zeroing the weighing system; note that it is also important to purge the line connected to the weighing scale;

— the zero offset verification/adjustment is performed;

— the cryogenic pump is started once again;

— the operator waits until the pressure, temperature and flow reach a steady condition;

— the LNG is bypassed into the collection vessel for effects of weighing and the collection time is recorded in a synchronous way;

— once the collected LNG reaches a prescribed amount of mass (batch), the bypass valve is closed and the timer stops;

— the operator waits until the mass readout from the weighing system is nearly constant, meaning that non-sloshing is taking place inside the vessel;

— the average LNG mass flow is calculated as the quotient between the totalized LNG mass and the collection time; additional process variables corrections are considered in the extended calculation algorithm of this facility;

— the N_2 pressurization valve and the connecting tube valves are open, in order to push the LNG inside the collection vessel back to the supply tank;

— the N_2 pressurization valve and the connecting tube valves are closed, and the exhaust valve is open to release the N_2+CH_4 from the system; the remaining gas (CH_4) is the product of sudden vaporization, which occurs when the N_2 is in contact with the LNG at a much higher temperature;

— once the gases are completely released from the weighing system, the primary standard is set for another measurement run.

7.2.2 Master meter method

LNG-calibrated flowmeters may also be used as MMs or as a reference to calibrate other flowmeters, in a dedicated flow loop. In this case, the MUT is installed in series with the MM, with the aim to compare it to the flow measured by the MM and thus to estimate its measuring error.

A flow calibration facility of this kind shall conform to the following fundamental design specifications in order to carry out an adequate calibration:

— a steady flow, temperature and pressure;

— a fully developed velocity profile;

— appropriate thermal insulation;

— an upstream pressure that is significantly higher than the LNG vapour pressure, in order to avoid cavitation;

— a minimal temperature gradient between the MM and MUT;

— precautions to avoid bubble accumulation in cavities, e.g. use sloping lines and degassing valves at crucial locations;

— the shortest possible connecting volume between MUT and MM, in order to prevent additional measurement uncertainties due to the inventory volume effect;

— consideration of the additional pressure drop caused by an installed MUT (especially the CMF type);

— possibility of connecting different sizes;

— if possible, installing the flowmeter with the highest pressure drop downstream; the best location of the MM is upstream in order to:

  — avoid damage of the MM in case the MUT breaks down;

  — allow defined upstream flow conditions to remain stable for the MM;

  — operate the MM at constant operating conditions (pressure);

— in general, mounting the meter with highest pressure drop downstream.

For MMs, the following requirements apply:

— traceability to a recognized international or national flow standard;

— acceptable repeatability and reproducibility;

— a thorough characterization of the MM's temperature sensitivity and material properties (robust measurement correction algorithm);

— a stable calibration curve;

— minimal drift;

— an operational flow range out of the zero offset nonlinear effect (proper range of use);

— not exceeding the maximum designed fluid velocity of the flowmeter type (i.e. avoid cavitation in CMFs);

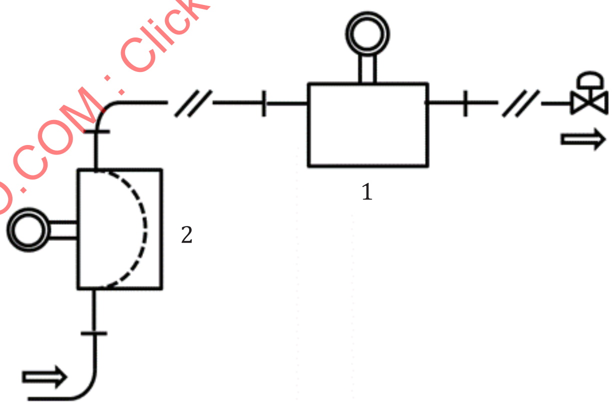
— a projection of several MMs to cover the calibration range of the MUT.

NOTE 1 The main benefit of using MMs is the possibility to have a wider calibration range, in comparison to the limited collection capacity of either a gravimetric method or a volumetric primary standard.

NOTE 2 The MM delivers the traceability to the MUT at the expense of an increased measurement uncertainty, relative to the primary standard.

It is recommended to install two MMs in series or to alternate two or more MMs in order to verify the consistency of the measurements (cross check). In this case, any deviation caused by the MMs will appear as a relative shift in the calibration factor between the two MMs.

Once the MMs are calibrated, their pipe configuration should not be further changed. Preferably, the MUT will be placed downstream of the MMs and the pressure and/or flow control valve should be placed downstream of the calibration setup (see Figure 6).



Key

1 meter under test

2 master meter

Figure 6 — Secondary flow standard master meter

7.3 Calibration in situ

7.3.1 Gravimetric method using a weighbridge

7.3.1.1 General

By using a weighbridge and two LNG road tankers, it is possible to make an infield calibration/proving of a mass (CMF) MUT. One road tanker is positioned onto the weighbridge and the other close by but not influencing the weighbridge. Road tankers are connected by an LNG flexible hose with a MUT-connected inline.

An assessment shall be made for the uncertainty of the setup (including the weighbridge) to accompany the measurement error.

This procedure is not restricted to the use of LNG road tankers but may also be applied to any tank, container or other device capable of keeping the LNG in a confined and controlled space without mass loss (i.e. no boil off or flaring of gas).

The mass MUT may be part of the road tanker measuring system or a separate standalone meter between road tankers.

In cases where there is a calibration, the method of calculating the measurement result and its associated uncertainty should be expressed as defined in ISO/IEC Guide 98-3.

The general procedure of calibration/proving of a MUT involves noting the indications of the quantity of static and dynamic mass according to the following steps:

— the static mass of the LNG road tanker fixed on the weighbridge, $M_{\text{full,WB}}$;

— the LNG transferred from the road tanker on the weighbridge to the other road tanker close by, with the mass of the LNG dynamically measured by the inline MUT, M_{MUT};

— the static mass of the LNG road tanker fixed on the weighbridge, $M_{\text{empty,WB}}$.

The calculation of the measurement result and the relative error of the mass of MUT, E_{MUT}, is shown by Formula (6):

$$E_{\text{MUT}} = \frac{M_{\text{MUT}} - M_{\text{c},\Delta\text{WB}}}{M_{\text{c},\Delta\text{WB}}} \times 100 \qquad (6)$$

where

M_{MUT} is the indicated mass of the LNG resulting from the dynamic measurement by the MUT;

$M_{\text{c},\Delta\text{WB}}$ is the corrected static mass measurement difference of the road tanker (full minus empty) from the weighbridge indications.

7.3.1.2 Preparations and conditioning

The flexible hose connecting the road tanker on the weighbridge with the LNG supply/MUT will have to be cooled down prior to calibration. When it is cooled down, it will turn stiff. This loss of hose flexibility potentially introduces an additional measurement uncertainty.

7.3.1.3 Calibration and proving procedure

The road tanker should be fixed on the weighbridge at all times during measurements. If this is not possible (e.g. due to the weighbridge location), see 7.3.2.

Road tanker cargo should be a closed system. If flaring or escape of gas from the cargo weight is allowed, this shall be accounted for in the calculation of mass.

Weather conditions (e.g. rain, wind) influencing the weighing conditions shall be avoided as much as possible.

7.3.1.4 Using a weighbridge

For the weighbridge/indicator the following applies:

— depending on the total mass transferred, a scale indicator with an optional resolution of 2 kg or better is preferred;

— the weighbridge shall be traceable to a recognized standard of mass;

— the weighbridge shall have an acceptable repeatability and reproducibility;

— the effect of weighbridge asymmetric loading/corner effects shall be characterized;

— there is high linearity and low/defined hysteresis;

— there is minimal drift.

7.3.2 Road tanker temporarily on weighbridge

If the road tanker cannot be fixed on the weighbridge for the duration of measurement (e.g. due to the weighbridge location), the following additionally applies to the above described procedure.

— As the mass of the road tanker will change after being driven due to the consumption of fuel, oil, etc., it is preferred to use a semi-trailer with a detachable tractor (the tractor should be disconnected from the semi-trailer and not placed on the weighbridge during the measurement of the cargo weight). A detachable semi-trailer also reduces the effects of road debris and dust build-up during transport.

— Proper care shall be taken to account for any additional hysteresis effects when loading/unloading the weighbridge according to this procedure.

7.3.3 Measurement uncertainty

Influences contributing to the uncertainty of measurement include, but are not limited to:

— uncertainty in the calibration value of the weighbridge;

— stability of the weighbridge;

— loading effect and hysteresis of the weighbridge;

— initial conditions during startup;

— different operating conditions regarding temperature and pressure;

— flow profile;

— mechanical installation effects;

— change in the mass of the road tanker due to water (rain), dust and road debris (which can be significant).

7.4 Interconnected pipe volume

The mass of the fluid contained in the interconnecting piping between the MM and MUT is an important parameter for the analyses of the calibration.

The interconnected pipe volume error is defined as the mass difference in the constant pipe volume between the MM and the MUT at the start and end of a calibration batch, leading to an additional error on the curve of the latter. It is calculated as shown by Formula (7):

$$M_v = (T_2 - T_1) \times s_T / 100 \times \rho_T \times \Delta V \qquad (7)$$

where

M_v	is the virtual loss (−) or gain (+) of the liquid mass flowing in or out of the interconnected volume, in kg;
T	is the operating temperature, in °C;
Indices 1,2	are the indices at time 1 and time 2 of the calibration batch (start and stop moment);
s_T	is the expansion coefficient ($\delta\rho/\delta T$) of the LNG at an average operating temperature, in % °C^{-1}, see Table 4;
ρ_T	is the density at an average operating temperature, in kg.m^{-3};
ΔV	is the interconnected volume between MM and MUT, in m^3.

Table 4 — Sensitivity factor of density at temperature, *T*, and pressure, *P*, $\delta\rho/\delta T$ (% °C^{-1})

Temperature (°C)	Overpressure (× 0,1 MPa) 0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6	6,5	7	7,5	8	8,5	9	9,5	10
−116																					
−118																					
−120																					
−122																				−0,44	−0,44
−124																		−0,43	−0,43	−0,43	−0,43
−126																	−0,42	−0,42	−0,42	−0,41	−0,41
−128															−0,41	−0,41	−0,41	−0,40	−0,40	−0,40	−0,40
−130														−0,40	−0,40	−0,40	−0,40	−0,39	−0,39	−0,39	−0,39
−132												−0,39	−0,39	−0,39	−0,39	−0,39	−0,39	−0,39	−0,38	−0,38	−0,38
−134											−0,38	−0,38	−0,38	−0,38	−0,38	−0,38	−0,38	−0,38	−0,38	−0,38	−0,37
−136										−0,37	−0,37	−0,37	−0,37	−0,37	−0,37	−0,37	−0,37	−0,37	−0,37	−0,37	−0,37
−138									−0,36	−0,36	−0,36	−0,36	−0,36	−0,36	−0,36	−0,36	−0,36	−0,36	−0,36	−0,36	−0,36
−140								−0,36	−0,36	−0,35	−0,35	−0,35	−0,35	−0,35	−0,35	−0,35	−0,35	−0,35	−0,35	−0,35	−0,35
−142							−0,35	−0,35	−0,35	−0,35	−0,35	−0,35	−0,35	−0,35	−0,35	−0,35	−0,35	−0,35	−0,35	−0,34	−0,34
−144						−0,34	−0,34	−0,34	−0,34	−0,34	−0,34	−0,34	−0,34	−0,34	−0,34	−0,34	−0,34	−0,34	−0,34	−0,34	−0,34
−146						−0,34	−0,34	−0,34	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33
−148					−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33	−0,33
−150				−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32
−152				−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32	−0,32
−154			−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31
−156			−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31	−0,31
−158		−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30
−160		−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30	−0,30
−162		−0,30	−0,30	−0,30	−0,30	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29
−164	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29
−166	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,29	−0,28
−168	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28
−170	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28
−172	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,28	−0,27	−0,27
−174	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27
−176	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27

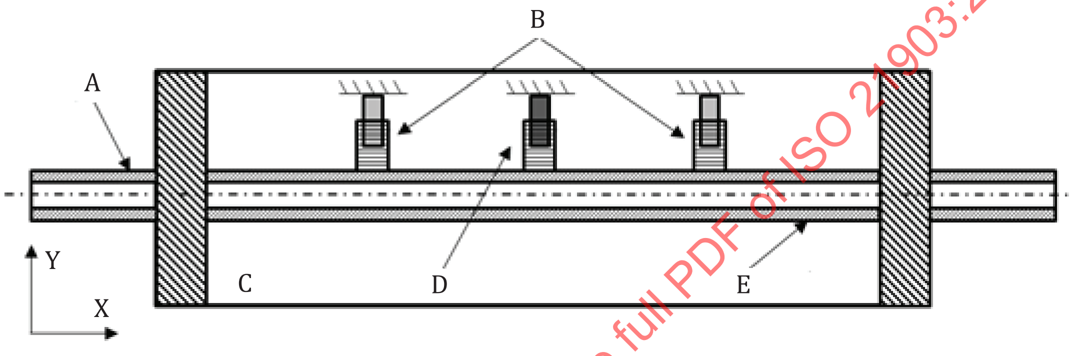
Table 4 *(continued)*

Temperature (°C)	Overpressure (× 0,1 MPa)																				
	0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6	6,5	7	7,5	8	8,5	9	9,5	10
−178	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27
−180	−0,27	−0,27	−0,27	−0,27	−0,27	−0,27	−0,26	−0,26	−0,26	−0,26	−0,26	−0,26	−0,26	−0,26	−0,26	−0,26	−0,26	−0,26	−0,26	−0,26	−0,26

Annex A
(informative)

Working principle Coriolis flowmeter

As shown by Figure A.1, a CMF consists primarily of a fluid-conveying pipe fixed at both ends (measuring tube), an electromagnetic driver, a displacement sensor, a housing that provides structural support and protection to the measuring tube, and dedicated electronics (transmitter) to process the meter's output signal and thus calculate the mass flow rate.



Key

A external pipe
B displacement sensors
C housing
D electromagnetic driver
E measuring tube

Figure A.1 — Basic components of a Coriolis flowmeter

As the name indicates, the CMF principle is based on the Coriolis force, which appears in oscillating and rotating systems. In this instance, the CMF is exemplified by a straight tube; however, its shape can vary depending on the manufacturer design and specific process applications. As for the measuring tube, this is excited by an external sinusoidal driving force, $\vec{F}_{\mathrm{d}}$, [see Formula (A.1)] at its natural frequency, ω_d, with the aim to operate at its fundamental vibrational mode, and therefore to minimize the energy required to make it oscillate (undamped system condition).

The basic governing formulae of a CMF are shown by Formulae (A.1) and (A.2):

$$\vec{F}_{\mathrm{d}} = \hat{\vec{F}}_{\mathrm{d}} \cdot \sin\left(\omega_d \cdot t\right) \tag{A.1}$$

$$\vec{F}_{\mathrm{C}} = 2 \cdot m_{\mathrm{f}} \cdot \vec{v}_f \times \vec{\Omega} \tag{A.2}$$

The basic CMF measurement principle can be divided into three stages, as described in a) to c).

a) **Empty pipe**: The driving force generated by the electromagnetic driver causes the system to oscillate about the x-axis, see Figure A.2. Moreover, a dedicated feedback loop uses the signal from the displacement sensors to control the voltage (gain) of the driver and thus keep the measuring tube at its natural frequency. Under this circumstance, the Coriolis force is not present, as the fluid velocity is zero, $\left(\vec{v}_f = 0\right)$.

Since there is no flow, the sinusoidal motion registered at the two displacement sensor locations are in phase, see Figure A.2.

b) **Fluid mass/no flow**: The CMF driving frequency decreases as the conveyed fluid mass in the measuring tube increases. There is no Coriolis force acting upon the system. This particular system response is the basis to explain how a CMF can be used to determine the fluid density by characterizing its natural frequency response with different fluids of well-known densities, ρ_f, see Formula (A.3):

$$\omega_d = \omega_d\left(\rho_f\right) = \sqrt{\frac{k}{m_T}} \qquad \text{(A.3)}$$

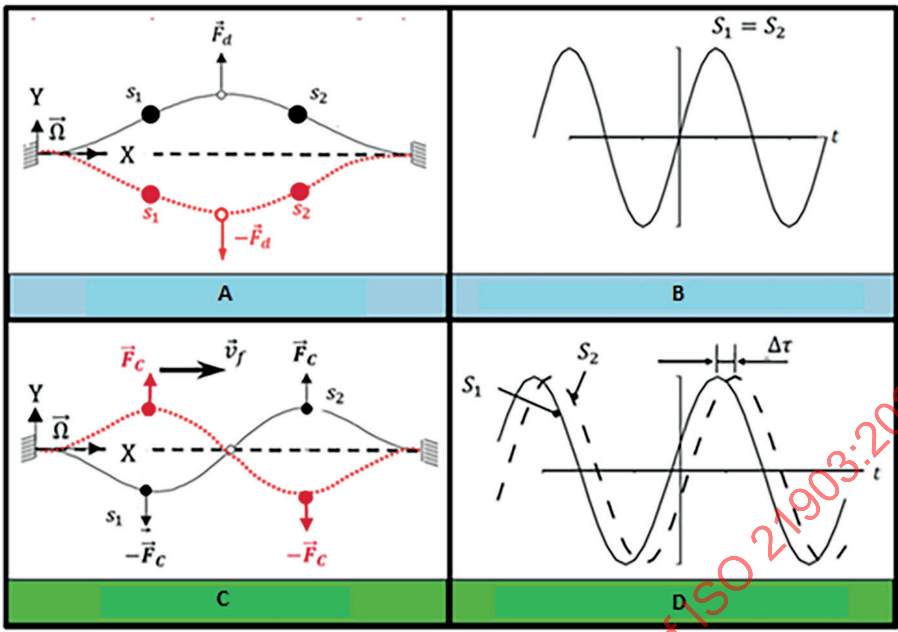
where

k is the stiffness coefficient of the measuring tube;

m_T is the effective mass.

c) **Flow:** When fluid starts circulating through the measuring pipe, the Coriolis force is generated, because the fluid velocity component is greater than zero $\left(\vec{v}_f > 0\right)$ and the presence of the system's angular velocity $\vec{\Omega}$. At the inlet section of the measuring tube, the Coriolis force tends to decelerate the movement of the measuring tube, whereas for the outlet section, the Coriolis force accelerates the movement. In the middle of the tube, the Coriolis force is always zero, since $\vec{\Omega}$ and $\vec{v}_f$ follow the same parallel direction, $\left(\vec{v}_f \times \vec{\Omega} = 0\right)$.

In terms of vibration mechanics, the system is then subjected to oscillate at its second fundamental vibration mode, as a result of the interaction between the Coriolis force and the driving force, see Figure A.2. This condition is also known as "superimposed mode".



Key

v_f	fluid bulk velocity, in m/s	F_d	force that is generated by the driver mechanism
Ω	angular velocity, in rad/s	F_c	Coriolis force
Y	direction of tube excitation	s_1	black position related to sensor 1
X	direction of fluid flow	s_2	red position related to sensor 2

S_1 sensor output signal representing the movement of the tube at location s_1

S_2 sensor output signal representing the movement of the tube at location s_2

NOTE A shows the driving mode, B (no flow) shows no phase shift between S_1 and S_2, C shows the Coriolis mode (flow) and D shows a phase shift between S_1 and S_2.

Figure A.2 — Graphical representation of the Coriolis flow measurement principle

The secondary motion (Coriolis mode) is rather small compared with the main vibration generated by the electromagnetic driver, but it causes a phase shift ($\Delta\varphi$) between the displacement sensor signals.

This phase shift is the key process parameter that relates the linear response of the CMF with the mass flow rate. Alternatively, the phase shift may be substituted by the time delay $\Delta\tau$ between the two displacement sensor signals, as shown by Formula (A.4):

$$q_m = C \cdot \Delta\tau \quad \text{(A.4)}$$

where

$\Delta\tau = \Delta\varphi / \omega_d$

$C = f_m \times f_k$

where

f_m is the meter factor, which is the product of a variable enclosing several vibration characteristics of the CMF;

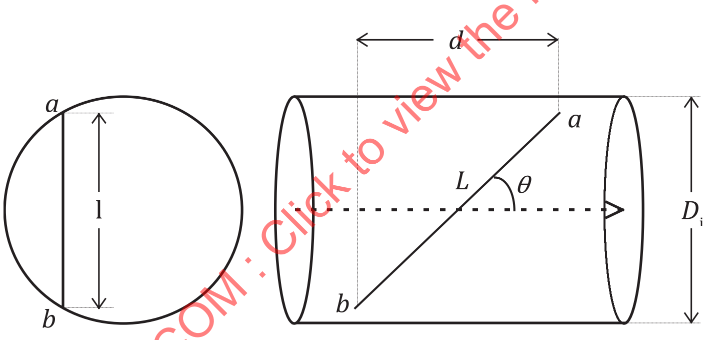
f_k is the calibration factor, which is determined by experimental means.

Annex B
(informative)

Working principle of the ultrasonic flowmeter

The ultrasonic transit-time flowmeter is a sampling device that measures discrete path velocities using one or more pairs of transducers. Each pair of transducers is located a known distance, *L*, apart such that one is upstream of the other (see Figure B.1). The upstream and downstream transducers send and receive pulses of ultrasound alternately, referred to as "contra-propagating transmission". The times of arrival are used in the calculation of the average axial velocity. At any given instant, the difference between the apparent speed of sound in a moving liquid and the speed of sound in that same liquid at rest is directly proportional to the liquid's instantaneous velocity. As a consequence, a measure of the average axial velocity of the liquid along a path can be obtained by transmitting an ultrasonic signal along the path in both directions and subsequently measuring the transit-time difference.

The volumetric flow rate of a liquid flowing in a completely filled closed conduit is defined as the average velocity of the liquid over a cross section multiplied by the area of the cross section. Thus, by measuring the average velocity of a liquid along one or more ultrasonic paths (i.e. lines, not the area) and combining the measurements with knowledge of the cross-sectional area and the velocity profile over the cross section, it is possible to obtain an estimate of the volumetric flow rate of the liquid in the conduit.



Key

a ultrasonic sensor location belonging to sound path a-b

b ultrasonic sensor location belonging to sound path a-b

D_i internal pipe diameter

L distance between transducers

θ angle of inclination of the ultrasonic signal with respect to the axial direction of the flow

d projected distance of the sound path in the direction or reverse direction of the axial flow

Figure B.1 — Measurement principle

Several techniques may be used to obtain a measure of the average effective speed of propagation of an ultrasonic signal in a moving liquid in order to determine the average axial flow velocity along an ultrasonic path line.

The basis of this technique is the direct measurement of the transit time of ultrasonic signals as they propagate between a transmitter and a receiver. The velocity of propagation of the ultrasonic signal is the sum of the speed of sound, *c*, and the flow velocity in the direction of propagation.

It can be shown that the transit time upstream and downstream, assuming flow velocity in the axial direction with zero flow velocity in the other two directions, can be given as shown by Formulae (B.1) and (B.2):

$$t_{\text{fluid\_up}} = \frac{L}{c - \bar{v}_{\text{a}} \cos\theta} \tag{B.1}$$

$$t_{\text{fluid\_dn}} = \frac{L}{c + \bar{v}_{\text{a}} \cos\theta} \tag{B.2}$$

Solving for velocity yields is as shown by Formulae (B.3) and (B.4):

$$\frac{1}{t_{\text{fluid\_dn}}} - \frac{1}{t_{\text{fluid\_up}}} = \frac{t_{\text{fluid\_up}} - t_{\text{fluid\_dn}}}{t_{\text{fluid\_up}} \cdot t_{\text{fluid\_dn}}} = \frac{2\bar{v}_a \cos\theta}{L} \tag{B.3}$$

$$\bar{v}_a = \frac{L}{2\cos\theta} \frac{\Delta t}{t_{\text{fluid\_up}} \cdot t_{\text{fluid\_dn}}} \tag{B.4}$$

where

L is the distance between the transducers;

Δt is the difference in transit times;

θ is the angle of inclination of the ultrasonic signal with respect to the x direction of the flow.

The individual path velocity measurements are combined by a mathematical function to yield an estimate of the mean pipe velocity, as shown by Formula (B.5):

$$\bar{v} = f(\bar{v}_{\text{a1}}, \ldots, \bar{v}_{an}) \tag{B.5}$$

where

$\bar{v}_{ai}$ is the axial flow velocity along ultrasonic path line;

n is the total number of paths.

Owing to variations in the path configuration and different proprietary approaches of solving formula (x), even for a given number of paths, the exact form of $f(\bar{v}_{a1}, \ldots \bar{v}_{an})$ can vary.

The relationship between the mean pipe velocity and the measured path velocities depends on the flow profile. In fully developed flow, the flow profile depends only on the Reynolds number and the pipe roughness.

The Reynolds number is calculated from the known internal diameter of the body, D, the mean axial liquid velocity, $\bar{v}$, and the actual density, ρ, and the dynamic viscosity, μ, as shown by Formula (B.6):

$$R = \frac{\bar{v} D \rho}{\mu} \tag{B.6}$$

One possible solution is to calculate the mean pipe velocity as a weighted sum of the path velocities and to apply a velocity profile factor to compensate for profile changes, as shown by Formula (B.7):

$$\bar{v} = K_p \sum_{i=1}^{n} w_i \bar{v}_{ai} \tag{B.7}$$

To obtain the volumetric flow rate, Q, the estimate of the mean pipe velocity is multiplied by the cross-sectional area of the measurement, as shown by Formula (B.8):

$$Q = A \cdot \overline{v} \tag{B.8}$$

Annex C
(normative)

Hardware for an LNG calibration facility

C.1 Piping design

Piping shall preferably be the vacuum-insulated type.

In cases where inner bellows are used for stress handling, an inner sleeve shall be added to avoid disturbances upstream of MMs or the MUT, see Figure C.1.

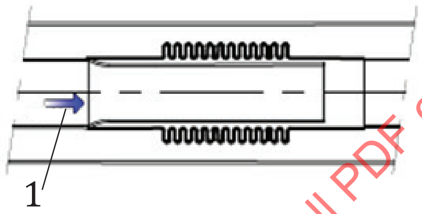


Figure C.1 — Sleeve covering the inner bellow ribs

The piping between the reference meter and the MUT should be sloping by at least 1° upwards [angle α in Figure 3 c)] to avoid the accumulation of bubbles.

Double pipe bends out of the plane shall be avoided to prevent the flow from generating a swirl. The swirl decay will be very small (but can be persistent over a length of more than 100 × pipe diameter) due to the low viscosity of LNG.

Valves installed in piping branching from a main pipeline shall be mounted as close as possible to the main pipe line to minimize:

— flow induced pulsations in the tee connection between the main pipe and the branch when the valve is fully closed;

— the creation of a gas pocket.

Gaskets shall not protrude in the pipe in any way.

The maximum allowable swirl angle is 2° (pitch angle) at the inlet of the meter run(s). In case of doubt, the theoretical swirl angle shall be simulated with computed fluid dynamics before approving the detail engineering design.

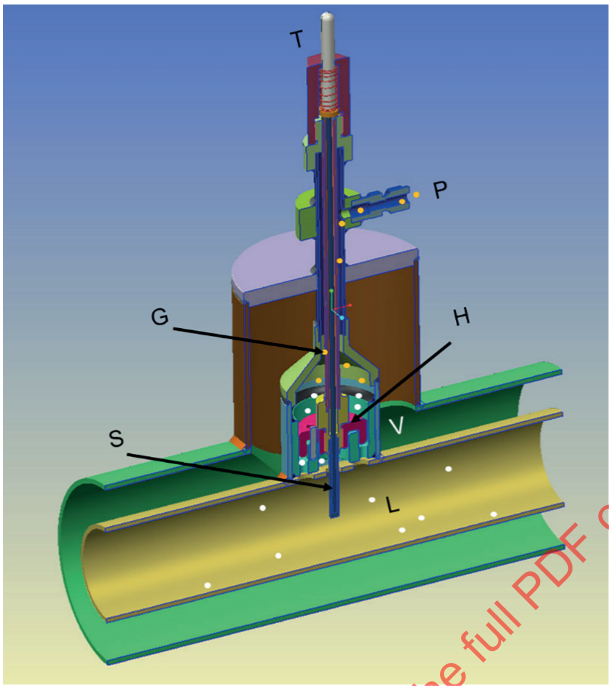
C.2 Design and location of the pressure connection points

Since most parts of a pressure transmitter impulse line(s) are outside the cryogenic environment, they are filled with LNG vapour. Hence, no correction for hydrostatic static pressure is expected.

The inner diameter of the impulse lines should be small enough to avoid large gas cavities in the system. The length should be just enough to have the transmitter working in an ambient environment.

The hole diameter made for a pressure measurement in pipelines shall not be smaller than the tubing inner diameter of the pulse lines.

Where temperature and pressure are measured at the same location, the pressure fitting may be connected to the temperature sensor cavity, see Figure C.2.



Key

T locking nut for the temperature element connected into the thermowell
P pressure connection point
G gas cavity (yellow dots)
H heat anchor-slider body (compensator for shrinking /expansion of the thermowell)
S sensor tip inside thermowell
L liquid (white dots)
V vacuum cavities

Figure C.2 — Example of a cryogenic precision thermowell/sensor/pressure tap assembly

C.3 Armature design, location of temperature sensors, thin and robust thermowell setup

Since temperature measurements have a large impact on the volumetric flow rate calibration uncertainty, examples and recommendations for detail designs are provided as follows.

— The temperature stem (protective tube around PT 100 element) preferably has a maximum diameter of 6 mm.

— The contact length of the sensor stem with the process LNG should be as much as possible. In this way, the heat inleak will be reduced/compensated to an acceptable value.

— The armature of the sensor is connected to the top flange or top-cap of a VIP tee-spool. Suggested tee-spools: 2" to 2", 4" to 2", 6" to 2" and so on where the dead end branches point vertical or to a maximum 30° out of plumb.

— Some LNG vapour will be trapped in the upper part of the dead end branch, which will help to reduce heat inleak.

— Since most of the temperature measurements are accompanied by a pressure measurement point, it is advised to combine the functionality of the tee-branch together with a pressure tubing connection to reduce the amount of separate process connections and inherently heat inleak.

— The sensor will be removable for calibration with a re-usable leak tight connection.

— The sensor stem length will enable the tip of the sensor to protrude in the loop pipeline at 1/3 of the pipe diameter (radial mounted probes). For axial mounted probes, the tip of the sensor will protrude at least 200 mm along the pipe centre.

— The total stem length shall be enough to be immersed at least 400 mm into the cryogenic liquid in the calibration dewar. Therefore, the thermowell will also be long to support the over-length of the stem. Calibration of the sensor will be preferably done without the thermowell.

— The sensor tip will be in contact with the thermowell bottom, preferably with a small amount of heat conducting paste.

— The stem movements (vibrations due to flow induced eddies) should be small. In the case of a radial mounted probe, a stem support (opened for LNG to flow in and out of the dead end branch) will be considered in cases where the stem vibrations exceed acceptable levels. When a stem support is used, it shall be designed in such a way that it allows small vertical movements but not any horizontal movements.

C.4 Mechanical tooling

— Welding protrusions are less than 1,6 mm.

— Burrs around fitting holes will be treated by smooth boring or polishing.

— Special care should be taken at the edges of pressure points. Edges shall be smooth and without irregularities.

Annex D
(informative)

Examples of calibration data

D.1 Gravimetric method using a calibration facility

A typical protocol from the primary calibration of a CMF is given Table D.1.

The calibration should be accompanied by an uncertainty claim, which is not shown in Table D.1. This can be found in Reference [17].

D.2 Master meter method using a calibration facility

A typical calculation example of a calibration of a master flowmeter by the MM method is given Table D.2. In this example, a USM is used as the reference meter.

The calibration should be accompanied by an uncertainty claim, which is not shown in Table D.2. This can be found in Reference [17].

Table D.1 — Example of the elaboration of measurement results for the determination of meter deviation with a primary standard

	Par.	Unit	Run 1	Run 2	Run 3	Run 4	Run 5[a]
Time	t1	s	1 027,16	100,54	405,67	203,45	50,34
	t2	s	1 128,45	201,04	556,27	354,15	251,12
	Dt	s	101,29	100,50	150,60	150,70	200,78
Temperature[b]	T1	°C	−163,5	−161,3	−159,8	−150,0	−146,0
	T2	°C	−161,5	−160,0	−158,5	−146,0	−152,2
Line pressure	P1	kPa	321	315	345	301	311
	P2	kPa	335	332	325	312	322
Density[c]	ρ1	kg/m³	466,02	462,98	460,93	446,93	441,02
	ρ2	kg/m³	463,28	461,20	459,10	441,03	450,14
Interconnected pipe	dMv	kg	−0,97	−0,63	−0,65	−2,09	3,22
[d]	δρ/δT	%/ °C	−0,29	−0,29	−0,30	−0,32	−0,33
[d]	dMv	kg	−0,95	−0,62	−0,63	−2,01	3,22
Reading CMF[e]	CMF1	kg	44,35	945,20	1 654,60	1 959,14	2 165,58
	CMF2	kg	779,29	1 440,35	1 938,14	2 139,98	2 239,15
	dCMF	kg	734,94	495,15	283,54	180,84	73,57
	MF	kg/h	26 121	1 7737	6 777,9	4 319,9	1 319,2
Reading weighing device[f]	Wt1	kg	10,342	23,456	31,451	8,934	18,295
	Wt2	kg	738,315	514,278	312,432	190,049	89,417
	dWt	kg	727,973	490,822	280,981	181,115	71,122

Table D.1 *(continued)*

	Par.	Unit	Run 1	Run 2	Run 3	Run 4	Run 5[a]
Reading gasmeter[g]	Wg1	kg	0,34	0,54	0,26	0,87	1,23
	Wg2	kg	10,111	5,743	3,095	2,528	1,924
	dWg	kg	9,771	5,203	2,835	1,658	0,694
Reference mass total	RM	kg	736,776	495,393	283,169	180,688	75,039
Meter error	e	%	−0,25	−0,05	0,13	0,08	−1,95

NOTE The interconnected pipe volume is 0,353 m^3. Index 1 and 2 represent the start and stop moment of the run, respectively.

[a] In this particular test run, the process conditions are near saturation. This can cause bubbling and instabilities, and probably affects the behaviour of the MUT. The impact of the interconnected pipe volume correction is around 1,5 % and is reverse proportional to the flow rates.

[b] Temperature that is representative for the liquid in the interconnected pipe volume.

[c] Density is based upon the equation of state. If this is not available, use the alternative method, see [d].

[d] The alternative calculation of change in the interconnected pipe liquid mass content based on the sensitivity coefficient as found in Table 4. The effect of the temperature change on the interconnected pipe geometry has been neglected.

[e] The electronically generated pulses can appear in bursts rather than perfectly synchronized with the real mass or volume flow rate. This can be a typical issue for short test times. Consult the manufacturer for details.

[f] The weighing device is corrected based on its calibration and other (possible) effects such as inclination, parasitic forces, etc.

[g] The release of evaporated LNG from the tank cannot be neglected. In the example, the impact of vapour release is around 1 % and depends on the batch magnitude, pressure and temperature of the gas.

Table D.2 — Example of the elaboration of measurement results for the determination of meter deviation in a master meter configuration

	Par.	Unit	Run 1	Run 2	Run 3	Run 4	Run 5
Time	t1	s	10,34	13,24	9,83	1,45	23,19
	t2	s	110,66	113,88	160,43	152,80	223,17
	dt	s	100,32	100,64	150,60	151,35	199,98
Temperature[a]	T1	°C	−163,5	−161,3	−159,8	−150	−150,3
	T2	°C	−161,5	−160	−158,5	−148,2	−152,2
Line pressure	P1	kPa	321	315	345	301	311
	P2	kPa	335	332	325	312	322
Density[b]	ρ1	kg/m^3	466,02	462,98	460,93	446,93	447,37
	ρ2	kg/m^3	463,28	461,20	459,10	444,29	450,14
Interconnected pipe	dMv	kg	−0,97	−0,63	−0,65	−0,93	0,98
Reading USM[c]	USM1	m^3	44,350	48,345	51,237	52,548	54,194
	USM2	m^3	46,083	49,484	52,430	53,216	54,366
	dUSM	m^3	1,733	1,139	1,1935	0,6676	0,1722
Volume flow rate	VF	m^3/h	62,2	40,7	28,5	15,9	3,10
Average temperature[d]	T_{avg}	°C	−162,5	−160,5	−159,3	−148,6	−151,2
Average pressure	P_{avg}	kPa	328,3	323,1	336,4	305,9	318,4
Average density[e]	ρ_{avg}	kg/m^3	464,65	461,88	460,23	444,88	448,69
Mass through USM	dMUSM	kg	805,4	525,9	549,26	296,98	77,29

