INTERNATIONAL STANDARD

ISO 12764

First edition
2017-08

Measurement of fluid flow in closed conduits — Flowrate measurement by means of vortex shedding flowmeters inserted in circular cross-section conduits running full

Mesurage du débit de fluide dans les conduites fermées — Mesurage du débit par débitmètres à effet vortex insérés dans les conduites de section circulaire remplies au droit

Reference number
ISO 12764:2017(E)

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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).

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For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 5, *Velocity and mass methods.*

This first edition of ISO 12764 cancels and replaces ISO/TR 12764:1997. In general this document reflects the current state of vortex shedding flow meter methodology, with advancements that have occurred since the original TR was published. In particular:

— the terms “systematic measurement error” and “measurement uncertainty” are more clearly defined;

— the terms “rangeability”, “lowest local pressure”, “response time” and “fade” have been removed;

— 6.1.1.4 and 6.1.2 have been added;

— Clause 8 and Clause 9 have been revised;

— Annex A has been revised;

— a new Annex B has replaced the previous version;

— Annex C has been incorporated into 7.2 and updated.

Introduction

This document is one of the series of International Standards and Technical Reports covering a variety of devices that measure the flow of fluids in closed conduits.

The term “vortex shedding flowmeter”, commonly referred to as a “vortex meter”, covers a large family of devices with varying proprietary designs. These devices have in common the shedding of vortices from an obstruction (called a bluff body) which has been deliberately placed in the flow path in the meter. The natural laws of physics relate the shedding frequency of the vortices (f) to the fluid velocity and hence the volumetric flowrate (q_V) of the fluid in the conduit. The vortices can be counted over a given period of time to obtain total flow.

The vortex shedding phenomenon has become an accepted basis for fluid flow measurement. Meters are available for measuring the flow of fluids from cryogenic liquids to steam and high pressure gases. Many vortex shedding flowmeter designs are proprietary and, therefore, their design details cannot be covered in this document.

Insufficient data have been collected and analysed to be able to state, in this document, an expected uncertainty band for this type of vortex-shedding flowmeter.

Measurement of fluid flow in closed conduits — Flowrate measurement by means of vortex shedding flowmeters inserted in circular cross-section conduits running full

1 Scope

This document

a) describes the use of vortex shedding flow meters for liquids, gases, and steam, including a glossary and a set of engineering equations used for specifying performance,

b) provides technical information to assist the user in selecting, specifying and applying vortex shedding flowmeters, including influence effects,

c) describes typical construction and provides recommendations for inspection, certification, and material traceability,

d) describes availability of diagnostics associated with vortex shedding flowmeters,

e) provides calibration guidance,

f) does not apply to insertion type vortex shedding flowmeters,

g) applies only to closed conduits running full,

h) applies only to fluid flow that is steady or varies only slowly with time, and

i) applies to fluids considered to be single-phase.

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 4006, *Measurement of fluid flow in closed conduits — Vocabulary and symbols*

ISO/IEC Guide 99:2007 (JCGM 200:2012), *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4006 and ISO/IEC Guide 99:2007 (JCGM 200:2012) and the following apply.

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

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

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

3.1 Definitions specific to this vortex flowmeter standard

3.1.1
***K*-factor**
ratio of the meter output in number of pulses to the corresponding total volume of fluid passing through the meter during a measured period

Note 1 to entry: The variations in the *K*-factor can be presented as a function of either the pipe Reynolds number or flowrate at a specific set of thermodynamic conditions. The mean *K*-factor is commonly used and is defined by the following formula:

$$K_{\text{mean}} = \frac{K_{\text{max}} + K_{\text{min}}}{2}$$

where

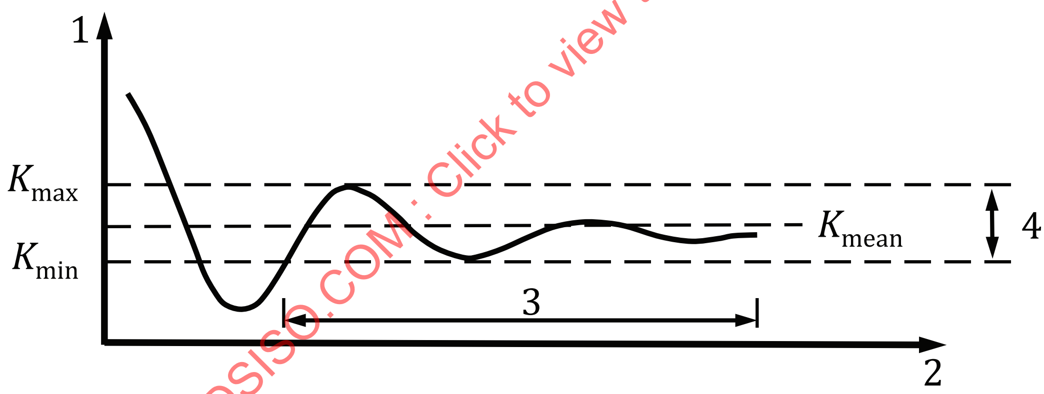
K_{max} is the maximum *K*-factor over a designated range;

K_{min} is the minimum *K*-factor over the same range.

Alternatively, the average of several values of *K*-factor taken over the whole flow range of a meter can be calculated. The *K*-factor can change with pressure and thermal effects on the body of the meter; see Clause 11. The manufacturer of the meter should be consulted concerning the difference, if any, of the *K*-factor between liquid and gas and due to differences between pipe schedules of the adjacent pipe.

Note 2 to entry: It is expressed in pulses per unit volume.

Note 3 to entry: See Figure 1.



Key
1 *K*-factor
2 pipe Reynolds number
3 designated linear range
4 linearity (%)

Figure 1 — Typical shape of a *K*-factor curve

3.1.2
linearity
constancy of the *K-factor* (3.1.1) over a specified range defined either by the pipe Reynolds number or flowrate

Note 1 to entry: The upper and lower limits of the linear range are specified by the manufacturer.

Note 2 to entry: See Figure 1.

3.1.3
cavitation
phenomenon following flashing, in which the pressure recovers above the vapour pressure and the vapour bubble collapses (implodes)

Note 1 to entry: Cavitation can result in measurement error as well as mechanical damage to the meter.

3.1.4
flashing
formation of vapour bubbles

Note 1 to entry: Flashing occurs when the pressure falls below the vapour pressure of the liquid.

3.2 Definitions related to measurement of fluid flow in closed conduits

3.2.1
pressure loss
irrecoverable pressure loss caused by the presence of a primary device in the conduit

3.2.2
Strouhal number
dimensionless parameter relating the vortex shedding frequency, *f*, generated by a characteristic dimension, *l*, to the fluid velocity, *v*, given by the following formula:

$$Sr = \frac{f \cdot l}{v}$$

where

f is vortex shedding frequency;

l is a characteristic length of the system in which the flow occurs;

v is the fluid velocity.

3.2.3
Reynolds number
dimensionless parameter expressing the ratio between the inertia and viscous forces given by the following formula:

$$Re = \frac{U \cdot l}{\nu}$$

where

U is the mean axial fluid velocity across a defined area;

l is a characteristic length of the system in which the flow occurs;

ν nu (Greek alphabet) is the kinematic viscosity of the fluid.

Note 1 to entry: For pipe flows and closed pipe flow measurement, Reynolds number is usually based on the diameter of the pipe.

3.3 Definitions related to the vocabulary used in metrology

3.3.1
systematic measurement error
systematic error of measurement
systematic error
component of measurement error that, in replicate measurements, remains constant or varies in a predictable manner

Note 1 to entry: A reference quantity value for a systematic measurement error is a true quantity value, or a measured quantity value of a measurement standard of negligible measurement uncertainty, or a conventional quantity value.

Note 2 to entry: Systematic measurement error, and its causes, can be known or unknown. A correction can be applied to compensate for a known systematic measurement error.

Note 3 to entry: Systematic measurement error equals measurement error minus random measurement error.

3.3.2
measurement uncertainty
uncertainty of 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: Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of measurement standards, as well as the definitional uncertainty. Sometimes estimated systematic effects are not corrected for but, instead, associated measurement uncertainty components are incorporated.

Note 2 to entry: The parameter can be, for example, a standard deviation called standard measurement uncertainty (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.

Note 3 to entry: Measurement uncertainty comprises, in general, many components. Some of these can be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from a series of measurements and can be characterized by standard deviations. The other components, which can be evaluated by Type B evaluation of measurement uncertainty, can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information.

Note 4 to entry: In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quantity value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty.

4 Symbols and subscripts

4.1 Symbols

Symbol	Quantity	Dimensions	SI units
A	effective area	L^2	m^2
A_p	manufacturer supplied constant	L^2	m^2
c_1, c_2	empirical constant	dimensionless	
D	diameter of meter bore	L	m
f	frequency of vortex shedding	T^{-1}	Hz
K	K-factor, meter factor = $1/K$	L^{-3}	m^{-3}
l	characteristic length	L	m
N	number of pulses	dimensionless	
NOTE Fundamental dimensions: M = mass, L = length, T = time, θ = temperature			

Symbol	Quantity	Dimensions	SI units
n	number of period measurements	dimensionless	
p	pressure	$ML^{-1}T^{-2}$	Pa
$p_{d,min}$	minimum downstream pressure limit	$ML^{-1}T^{-2}$	Pa
p_p	permanent pressure loss	$ML^{-1}T^{-2}$	Pa
Δp	overall pressure drop	$ML^{-1}T^{-2}$	Pa
p_{vap}	liquid vapour pressure at the flowing temperature	$ML^{-1}T^{-2}$	Pa
Q_V	totalized volume flow at actual flowing conditions	L^3	m^3
Q_m	totalized mass	M	kg
q_V	volume flowrate at actual flowing conditions	L^3T^{-1}	m^3/s
q_m	mass flowrate	MT^{-1}	kg/s
Re	Reynolds number	dimensionless	
Sr	Strouhal number	dimensionless	
T	temperature	θ	K
t	two-tailed Student's at 95 % confidence	dimensionless	
U	average fluid velocity in meter bore	LT^{-1}	m/s
v	fluid velocity	LT^{-1}	m/s
α	coefficient of linear expansion of material	θ^{-1}	K^{-1}
δ	% error in the average period	dimensionless	
μ	absolute viscosity (dynamic)	$ML^{-1}T^{-1}$	Pa · s
ν (nu)	kinematic viscosity	M^2/s	m^2/s
ρ	fluid density	ML^{-3}	kg/m^3
σ	estimate of standard deviation of the average period	T	s
τ	average period of vortex shedding	T	s
NOTE Fundamental dimensions: M = mass, L = length, T = time, θ = temperature			

4.2 Subscripts

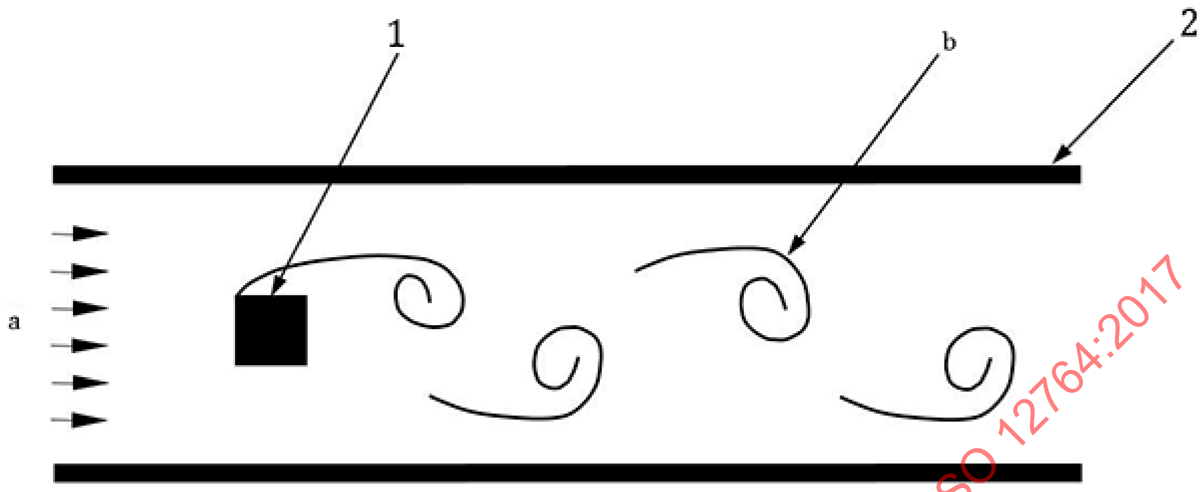
Subscript	Description
b	base conditions
m	mass unit
V	volume units, flowing conditions
mean	average of extreme values
max	maximum value
min	minimum value
i	the i^{th} measurement
d	downstream

5 Principle

5.1 Bluff body

When a bluff body, sometimes referred to as shedder bar, is placed in a pipe in which fluid is flowing, a boundary layer forms and grows along the surface of the bluff body. Due to insufficient momentum and an adverse pressure gradient, separation occurs and an inherently unstable shear layer is formed. Eventually, this shear layer rolls up into vortices that shed alternately from the sides of the body and propagate downstream. This series of vortices is called a Von Karman-like vortex street (See Figure 2).

The frequency at which pairs of vortices are shed is directly proportional to the fluid velocity. Since the shedding process is repeatable, it can be used to measure the flow.



Key

1 bluff body

2 conduit

a Flow.

b Vortex.

Figure 2 — Principle of Von Karman-like vortex street

5.2 Shedding vortices detection/sensors

Sensors are used to detect shedding vortices, i.e. to convert the pressure or velocity variations associated with the vortices to electrical signals. Vortex shedding sensor technology varies and is typically based on force, pressure, or velocity.

5.3 Strouhal number

The Strouhal number, *Sr*, relates the frequency, *f*, of generated vortices, the bluff body characteristic dimension, *l*, and the fluid velocity, *U*, as shown in Formula (1).

$$Sr = \frac{f \cdot l}{U} \tag{1}$$

remains essentially constant within a large range of Reynolds number. This means that the Strouhal number is independent of density, pressure, viscosity and other physical parameters. Given this situation, the flow velocity is directly proportional to the frequency at which the vortices are being shed, i.e. the vortex pulse rate [see Formula (2)].

$$U = \xi \cdot f \tag{2}$$

where ξ is a constant equal to l/Sr and q_V, the volumetric flowrate at flowing conditions, i.e. the volume flowrate, is given by Formula (3):

$$q_V = A \cdot U = \left[\frac{(A \cdot l)}{Sr} \right] \cdot f \tag{3}$$

where A is defined by the effective area of attack for the flow of the considered pipe/flowmeter configuration. The K-factor for a vortex shedding flowmeter is defined by Formulae (4) and (5)

$$K = \frac{\mathrm{Sr}}{(A \cdot l)} = \frac{f}{q_V} \tag{4}$$

hence,

$$q_V = \frac{f}{K} \tag{5}$$

To obtain a mass flowrate [see Formula (6)] or volumetric flowrate at base conditions [see Formula (7)], i.e. standard volume flowrate, the density at flowing temperature and pressure is needed.

$$q_m = \rho \cdot \frac{f}{K} \tag{6}$$

$$q_{V,\mathrm{b}} = \left(\frac{\rho}{\rho_\mathrm{b}} \right) \cdot \frac{f}{K} \tag{7}$$

The total amount of fluid that has flowed through a meter over a specified time interval is given by Formulae (8), (9), and (10).

$$Q_V = \frac{N}{K} \tag{8}$$

$$Q_m = \rho \cdot \frac{N}{K} \tag{9}$$

$$Q_{V,\mathrm{b}} = \left(\frac{\rho}{\rho_\mathrm{b}} \right) \cdot \frac{N}{K} \tag{10}$$

where

N is the total number of vortices shed, i.e. total number of vortex pulses, over that time interval.

6 Flowmeter description

6.1 Physical components

The vortex shedding flowmeter consists of two elements: the flow tube (sometimes referred to as the primary device or Primary) and the output device (sometimes referred to as the secondary device or Secondary).

6.1.1 Flow tube

The flow tube, which is an integral part of the piping system, is made up of the meter body, the bluff body(s), and the sensor.

6.1.1.1 Meter body

The meter body is usually available in two styles: a flanged version which bolts directly to the flanges on the pipeline and a wafer version, without flanges, that is clamped between the two adjacent pipeline flanges via bolts.

Since in many cases a properly sized vortex meter is one, and sometimes two, sizes smaller than the pipeline (see 7.1), some manufacturers offer reduced bore meters which take the reduction within the meter body. The manufacturer shall provide guidance on the installation and pressure compensation for reduced bore devices.

6.1.1.2 Bluff body

The bluff body(s) is a structural element positioned in the cross-section of the meter body. Its shape and dimensions and its ratio in relation to the open area in the meter body cross-section influence the linearity of the *K*-factor. An ideal bluff body shape is not known. Figure 2 shows it as a square, but this is not intended to imply a preferred, or even practical, shape.

6.1.1.3 Sensor

The sensor detects the passage of the shedding vortices. Sensor location and principle vary among the various vortex shedding flowmeter manufacturers.

6.1.1.4 Integrated temperature and pressure sensors

Some manufacturers provide temperature and/ or pressure sensors integrated into the meter body for calculating inferred outputs (e.g. mass flow, energy flow, compensated volume flow, etc.).

6.1.2 System output

The system output can be one or more of the following:

a) analogue 4 mA to 20 mA direct current;

b) analogue 4 mA to 20 mA direct current with communications (e.g. with Highway Addressable Remote Transducer or HART);

c) a digital output (e.g. communication buses, wired or wireless);

d) raw vortex frequency (shedding frequency);

e) scaled frequency data output (user inputs an upper range frequency);

f) a pulse output (user inputs value/pulse);

g) an alarm/status output.

Examples for output are

1) volume flow,

2) mass flow (inferred),

3) corrected volume flow (inferred),

4) energy/heat flow (inferred),

5) totalizer values of the above, and

6) process temperature and/or pressure (multivariable devices).

6.2 Marking

Vortex shedding flowmeters shall be marked to identify the manufacturer, serial number, pressure rating, direction of flow (preferably on both sides of the meter body) and hazardous location certification, if any.

6.3 Safety issues

6.3.1 Pressure and fluid-wetted parts

All pressure-containing and process-fluid-wetted parts of the vortex shedding flowmeter shall satisfy local codes and standards that apply to the particular installation.

6.3.2 In-line instrumentation, testing

Since vortex meters are an integral part of the process piping (in-line instrumentation), it is essential that the instrument shall be subjected to similar inspection and testing procedures to those applied to other in-line equipment.

6.3.3 Materials

The manufacturer should be contacted for any required certification of materials used in construction, hydrostatic tests, etc.

7 Application

7.1 Sizing

Care shall be taken to size the vortex shedding flowmeter to keep the flowrate between the maximum and minimum flowrates for the required uncertainty. Since the linearity and flow range are Reynolds-number-dependent, the Reynolds number of the flowing fluid shall be within the limits specified.

The calibration curve of a vortex shedding flowmeter may be presented as a function of volumetric flowrate or Reynolds number with limits for a specified uncertainty. The operating conditions shall be kept within those limits to stay within the uncertainty specified for the meter (see Figure 1). These limits define the linear range of the meter.

The minimum volumetric flowrate depends on the Reynolds number and is therefore dependent on the density and viscosity of the flowing fluid. The minimum volumetric flowrate may also be limited by the sensitivity of the sensor(s).

Maximum and minimum flowrates may also be limited by the vortex sensing means. For example, in designs that use pressure sensing, the maximum and minimum volumetric flowrates may depend on fluid density.

Where available, the manufacturer's sizing tools should be used.

7.2 Pressure loss and cavitation

There will be a loss of pressure as the fluid passes through the meter. The manufacturer will provide a formula to calculate the permanent pressure loss with a general form as shown in Formula (11).

$$p_p = \frac{A_p \rho q_V^2}{D^4} \quad (11)$$

where

p_p is the permanent pressure loss (this formula only);

A_p is the manufacturer supplied constant;

ρ is the fluid density at operating conditions;

q_V is the volumetric flowrate;

D is the vortex shedding flowmeter bore diameter.

Based on the permanent pressure loss, the manufacturer shall provide guidance for avoiding cavitation. Cavitation can cause errors in the flow reading and, in extreme cases, damage to the meter.

Since the vortex shedding phenomena are based on the constancy of the separation of vortices from the bluff body(s), any condition that causes a change in the fluid characteristics will affect the uncertainty of the flow measurement.

Reduced flow area at the bluff body(s) causes a local increased fluid velocity and therefore a local reduced pressure. In a liquid system, flashing and cavitation may be caused by the reduction of the local pressure to or below the vapour pressure of the liquid. This will cause the formation of bubbles and therefore a change in the fluid characteristics. Consequently, it may cause an irregularity in the triggering of the separation of the vortices, and this may produce errors.

The accepted criterion is the minimum downstream pressure limit, $p_{d,min}$, which can be calculated based on Formula (12).

$$p_{d,min} = (c_1 \cdot \Delta p) + (c_2 \cdot p_{vap}) \quad (12)$$

where

$p_{d,min}$ is the downstream minimum pressure limit;

p_{vap} is the vapour pressure of the liquid at the flowing temperature;

c_1, c_2 are empirically determined by the manufacturer for each design and size.

Since this pressure reduction is dependent on the construction of the meter, the manufacturer should be contacted for guidance in calculating minimum downstream pressure.

Where available, the manufacturer's sizing tools should be used.

7.3 Swirl and undeveloped profile

A vortex meter is sensitive to abnormal velocity profiles and swirl. Meters should be installed to the manufacturer recommendations but when a particular meter installation is expected to deviate from the manufacturer's recommendations, the user may desire to perform an *in situ* calibration. Flow conditioners can also be used to reduce the effect of abnormalities in the flow.

NOTE Various flow conditioner designs can be effective in reducing anomalies in the distribution of axial velocity in the pipe or in reducing swirl, or both. Thus, they can be effective in improving meter performance where installation conditions are not in accordance with the manufacturer's recommendations.

7.4 Flow stability

The fluid stream should be steady or varying only slowly.

7.5 Vibration

Vibration of the vortex meter and associated piping should be within the levels recommended by the manufacturer.

8 Installation

8.1 General

Care should be taken to follow the manufacturer's instructions for installation. The following is supplementary advice.

8.2 Installation location

The following general precautions should be observed in determining the installation location for the vortex shedding flowmeter:

— common mode electrical noise may interfere with the measurement. RFI (radio frequency interference), EMI (electromagnetic interference), improper grounding (earthing), and insufficient signal shielding may also interfere with the measurement. In some cases, it may not be possible to check the noise in the output signal with no flow. The manufacturer should be contacted for advice if it is suspected that any of these noise levels is high enough to cause an error;

— care shall be exercised to observe the manufacturer's specified temperature limits, vibration limits, and corrosive atmosphere and humidity limits;

— select a location that allows for regular inspection and maintenance.

8.3 Piping

The following factors should be considered when preparing pipework for the installation of vortex shedding flowmeters and associated devices.

8.3.1 Straight sections

Straight unobstructed pipe sections of the recommended lengths should be installed upstream and downstream of the vortex shedding flowmeter to obtain the specified uncertainty at operating conditions. There are many vortex meter manufacturers with some of them supplying multiple designs vortex shedding flowmeters. The overall upstream recommended lengths are generally between 5 and 20 times the nominal diameter of the pipe. The overall downstream lengths are generally between 3 and 10 times the nominal diameter of the pipe. These straight pipe lengths should comply with the conditions outlined from 8.3.2 to 8.3.12. The recommendations for upstream and downstream piping by manufacturers should be treated as a minimum.

8.3.2 Mating pipe

The ideal geometry is with the inside diameter of the connecting pipe being of the same nominal diameter as the meter. Moreover, the inside diameter of the pipe used for the calibration of the meter should be the same nominal diameter. A sudden change in internal diameter between the meter and its connecting pipes can cause a change in performance of the meter. The manufacturer should be contacted for information regarding such effects.

8.3.3 Position of valves

There should be no valves or bypass piping immediately upstream of or downstream of the meter. If a valve is foreseen to be mounted upstream, the manufacturer should be consulted concerning any possible effect on the meter performance. The resulting pressure drop of many valve types, [e.g. Pressure Reducing Valves (PRV)], should be taken into account. For example, phase change could occur downstream of a PRV.

8.3.4 Dual phase flow

Dual phase flow, for example gas bubbles in liquids or liquid content in gases, should be avoided for the best performance. When entrained gas bubbles are included in a liquid and/or a dirty fluid is to be measured, a gas separator and/or a strainer may be required. To avoid entrained liquids in gas or steam flow, steam traps and separators should be considered. They should be installed upstream of the straight lengths of pipe.

8.3.5 Bypass

It may be desirable to install a bypass for maintenance, inspection and cleaning of the vortex shedding flowmeter. If this is the case, the necessary "tee" joints (T-joints) should be upstream of the upstream straight length of the pipe or flow conditioner and downstream of the downstream straight section.

8.3.6 Additional process measurements for compensation

Additional process measurements, such as pressure, temperature or density, may be made (e.g. in order to calculate mass flow or corrected volume). These measurements should be made as close as possible to the location of the flow measurement and in piping having the same nominal diameter as the vortex shedding flowmeter. The manufacturer's literature should be followed concerning the ideal location for these measurements (see Figure 3).

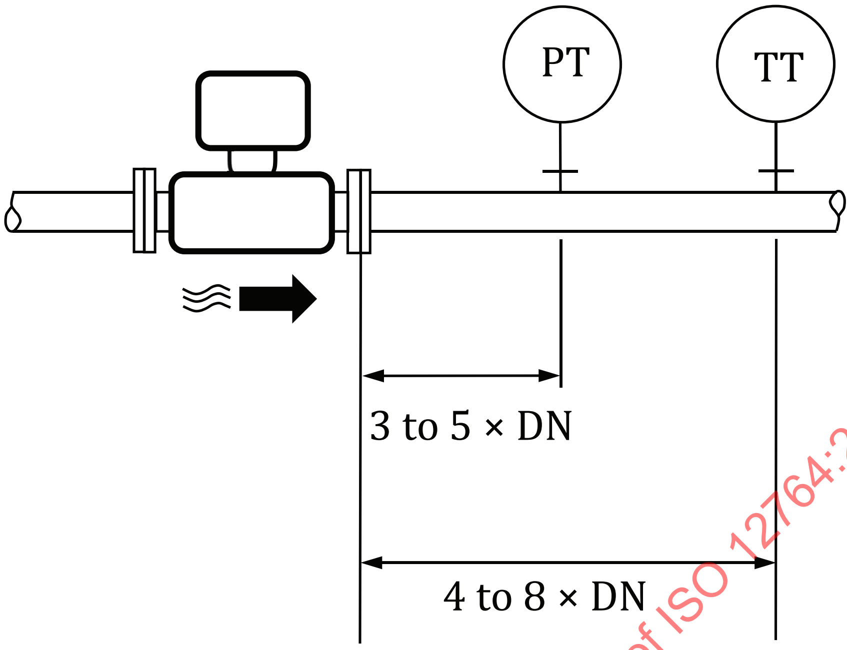


Figure 3 — Additional process measurement

8.3.7 Installation orientation, electronics

In a horizontal pipeline, it is preferable to mount the meter such that the electronics are not directly above the piping for very hot processes to avoid over-heating the electronics, and not directly below for cryogenic (very cold) processes to prevent condensation damage.

In general, when insulation is used on piping it is best to keep the electronics outside the insulation.

8.3.8 Bluff body orientation

In a horizontal pipeline, it is recommended to consider mounting the bluff body in the horizontal plane in order to prevent the collection of material on the bottom of the bluff body and the sensor. Since designs do vary, it is advised to review the specific product installation instructions for recommendations regarding orientation for different types of fluids (i.e. gases, liquids, steam).

8.3.9 Full pipe condition

In liquid flow measurement, the pipe shall be flowing full. One method to ensure this is to install the meter in a vertical pipe with the flow direction upwards.

8.3.10 Condensable gas

If the fluid is a condensable gas (e.g. steam), the expected meter measurement capabilities may be substantially changed in wet steam, and the manufacturer should be consulted for recommendations concerning possible physical damage to the meter. See also Annex B.

8.3.11 Extreme conditions

The manufacturer should be contacted for advice if the vortex shedding flowmeter is expected to withstand extreme conditions such as water hammer for liquids, slugs of liquid in gas measurement, over ranging, etc.

8.3.12 New installations

New installations require that the line be cleaned to remove any collection of welding beads, rust particles or other pipeline debris. It is usually good practice to remove the complete meter before the cleaning and initial pressure-testing.

9 Operation

9.1 Operating limits

Vortex shedding flowmeters should be operated within their operating limits as specified in the manufacturer's literature sheet. Operating limits include flowrates, Reynold's numbers, pressures and temperatures. Operation outside these limits may cause increased uncertainty and/ or may cause damage to the vortex meter. See 7.1 for guidance in proper sizing of flowmeters to help prevent operation outside of the necessary limits of flowrate and Reynolds number.

9.2 Start-up procedure

As with any vortex shedding flowmeter, caution should be taken during start up to prevent over-ranging, water hammer, etc. to avoid damage to the internals of the meter.

9.3 Shift of calibration

The manufacturer's recommendations should be followed when repairing or replacing sensors in order to prevent a shift in the calibration of the vortex shedding meter. The manufacturer's literature should also be consulted for guidance on likely shifts due to excessive wear of the bluff body. See also Annex A.

9.4 Maintenance

Meters should be maintained in accordance with the manufacturer's recommendations and with due consideration to any additional maintenance requirements associated with the specific application or product measured.

10 Performance characteristics

10.1 Reynolds number range

Within the stated Reynolds number range and its associated flow measurement uncertainty, vortex meters can measure the actual volume of the fluid passing through the flowtube regardless of the fluid properties, i.e. density, or viscosity (see 5.3 for mass and standard volume flow measurement). If used outside the specified Reynolds number range, the manufacturer should be consulted regarding correction factors and the expected magnitude of the measurement uncertainty.

10.2 P-T conditions

Process temperatures and pressures which differ significantly from those during calibration can affect the geometry of the flow tube, and hence the *K*-factor of the meter. The manufacturer should be consulted for relevant correction factors.

10.3 Performance disturbing influences

Performance can be affected by phenomena that influence the vortex shedding process, such as velocity profile, two-phase flow, pump noise, pulsation effects, inlet throttling noise, flashing, and cavitation. These phenomena can adversely affect vortex detection, as well as shift the *K*-factor. Such influences can be reduced or eliminated by careful selection and placement of flow system components and proper piping arrangement. The meter manufacturer should be consulted concerning ways of dealing with these issues.

11 Calibration (*K*-factor determination)

11.1 Mean *K*-factor

The meter manufacturer should state the meter's mean *K*-factor and the expected uncertainty under specified conditions. This factor may be derived from dimensional measurements, but is more commonly only obtained by wet flow calibrations. Since the performance of a vortex meter is not sensitive to Reynolds number, the calibration can be performed using any suitable fluid, but it is necessary to keep the vortex shedding frequency and the Reynolds number within the limits of the instrument. The calibration method employed shall be stated. Annex A describes the effects of period jitter on flow calibration and how to determine the number of cycles of vortex shedding required to get a stable mean value of vortex shedding frequency.

11.2 *In situ* calibration

Where possible, measurement uncertainty may be improved by *in situ* calibration. (This calibration should be done in accordance with relevant International Standards). For gas flows, the reference flow measurement device is usually either a transfer device, volumetric tank with pressure and temperature corrections, or critical-flow nozzles. For liquid flows, transfer, weighing, or volumetric techniques are used.

Annex A
(informative)

Period jitter and its effects on calibration

The frequency of vortex shedding has some natural level of frequency and amplitude modulation. This modulation is often referred to as jitter, period jitter, or frequency jitter. The cause of this jitter in vortex shedding is an unsteady flow phenomenon that, when used in flow measurement applications, is operating in the turbulent flow regime. Over time this unsteadiness averages out to a very repeatable flow measurement. This informative annex addresses the calculations one should take to ensure that this unsteadiness does not impact calibration results.

A determination of the period for a number of pulses would provide an average period, τ, and a standard deviation, σ, for that average. If a sufficiently large number of period measurements are obtained, increasing that number would no longer significantly affect the standard deviation.

NOTE Period jitter, and the associated frequency jitter, is of no concern for most applications. During calibration, it can be useful to understand the effect of jitter on the minimum volume needed to ensure the best calibration results.

The random uncertainty (component of uncertainty associated with a random error) of the average period to 95 % confidence would then be given by Formula (A.1).

$$\delta = \frac{100 \times t \cdot \sigma}{\tau \cdot n^{0,5}} \tag{A.1}$$

where

n is the number of period measurements;

t is the Student's t with n – 1 degrees of freedom for a 95 % confidence level (equal to 2,0 for 30 or more measurements);

δ is the uncertainty in the average period in percent;

σ is the estimate of standard deviation $\sigma = \left[\sum \frac{(\tau_i - \tau)^2}{(n-1)} \right]^{0.5}$;

τ is the average period of vortex shedding $\tau = \sum \frac{\tau_i}{n}$;

i is the i^{th} period measurement.

Once σ has been determined, the number of pulses, N, that should be counted to determine a flowrate to within a preassigned uncertainty of +δ %, is given by Formula (A.2).

$$N = \left[\frac{100 \times t \cdot \sigma}{\delta \cdot \tau}\right]^2 \quad \text{(A.2)}$$

Often in calibration, the variable available to be changed is the total volume being used as a standard. To determine the necessary volume for calibration, estimate a K-factor, K (generally, K-factors are consistent for a particular design within at least ±5 %), and multiply this by N, as shown in Formula (A.3).

$$V = N \cdot K \quad \text{(A.3)}$$

This volume can be used to size calibration equipment or determine the length of time needed for a calibration run. Since the K-factor is related to the diameter of the vortex shedding flowmeter by the inverse of the diameter cubed, this calculation will more often be required with vortex shedding flowmeters for larger-size lines, where large volumes and longer times will be required to obtain a good calibration.

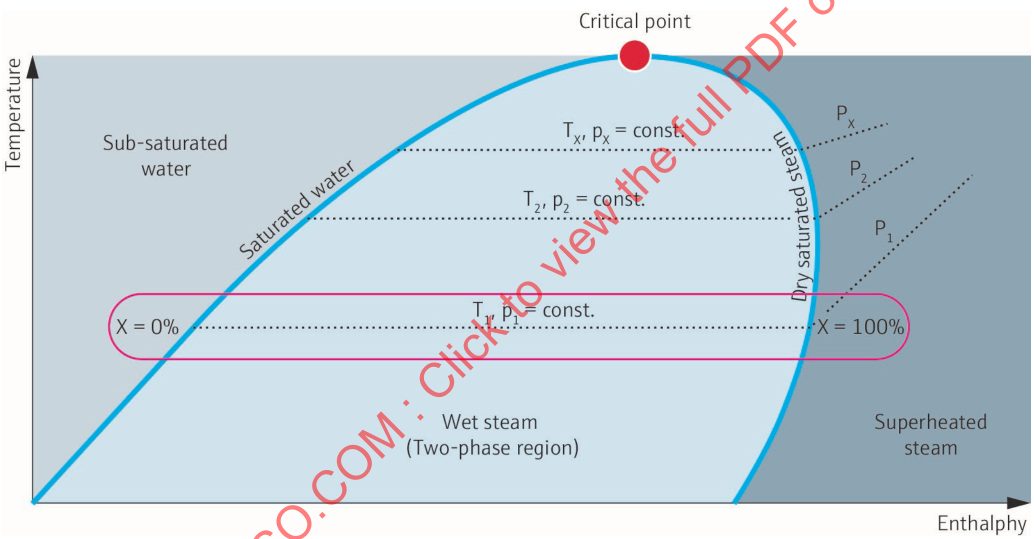
Annex B
(informative)

Special considerations for steam

B.1 Types of steam

B.1.1 General

The state of flowing steam is determined by pressure, temperature, and energy. Meters rarely operate in fixed operational process design conditions. The dry saturated steam line is infinitesimally narrow; meters will be in either the wet steam or the superheated steam regions, often moving continuously between all three states. The dryness fraction, density, mass flow, and useful steam energy are dependent on the steam state, which is determined by steam distribution system entry conditions and meter upstream installation effects e.g. from valves, bends, and pipework condition.



NOTE Water can exist as a liquid, wet steam (liquid and vapour co-exist at different dryness fractions x), dry saturated steam (100 % dryness fraction) and superheated steam.

Figure B.1 — Types of steam - Mollier chart (T-h type) for water

B.1.2 Wet steam

Wet steam is a liquid and vapour mixture, the ratios of which are indicated by the wet steam dryness fraction, sometimes referred to as the steam quality. The dryness fraction in flowing systems is the fraction of wet steam mass flowrate which, if separated out, would consist of only saturated steam vapour compared to the combined total of the saturated steam vapour mass and the saturated liquid mass. The pressure, temperature and dryness fraction together define the state of the wet steam and its energy content (the higher the dryness fraction, the higher the energy content of the steam is).

B.1.3 Saturated steam

Saturated steam, sometimes referred to as dry saturated steam, is pure vapour that lies on an infinitesimally narrow phase line between wet steam and superheated steam. It is considered most useful in process applications because of the high content of latent heat. Absorbing additional heat

