TECHNICAL REPORT

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

Mesure de débits des fluides dans les conduites fermées — Mesure de débit par débitmètres à effet vortex insérés dans les conduites de section circulaire remplies au droit

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Contents

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Foreword

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

The main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid.

ISO/TR 12764, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits.*

This document is being issued in the technical report (type 2) series of publications (according to subclause G.3.2.2 of part 1 of the IEC/ISO Directives) as a “prospective standard for provisional application” in the field of flow measurement using vortex flowmeters, because there is an urgent need for guidance on how standards in this field should be used to meet an identified need.

This document is not to be regarded as an “International Standard”. It is proposed for provisional application so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to the Secretary of ISO/TC 30, via the ISO Central Secretariat.

A review of this technical report (type 2) will be carried out not later than three years after its publication with the options of: extension for another three years; conversion into an International Standard; or withdrawal.

Annexes A, B and C of this Technical Report are for information only.

Introduction

ISO/TR 12764 is one of a 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 deliberatley placed in the flow path in the meter. The natural laws of physics relate the shedding frequency of the vortices (f) to 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 analyzed to be able to state, in this document, an expected uncertainty band for this type of 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 Technical Report provides generic information on vortex shedding flowmeters, including a glossary and a set of engineering equations useful in specifying performance. It describes the typical construction of vortex shedding flowmeters and identifies the need for inspection, certification, and material traceability. It also provides technical information to assist the user in selecting and applying vortex shedding flowmeters, and provides calibration guidance. It explains the relevant terminology and describes test procedures, together with a list of specifications, application notes, and equations with which to determine the expected performance characteristics.

This Technical Report describes how the frequency of the vortices is a measure of the fluid velocity; how volume, mass, and standard volume flowrate are determined; and how the total fluid that has flowed through the meter in a specified time interval can be measured.

This Technical Report applies only to full-bore flowmeters (not insertion types) and applies only to fluid flow that is steady or varies only slowly with time, and is considered to be single-phased, with the closed conduit running full.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 5167-1, *Measurement of fluid flow by means of pressure differential devices — Part 1: Orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full*

ISO 5168, *Measurement of fluid flow — Estimation of uncertainty of a flowrate measurement*

ISO 7066-1, *Assessment of uncertainty in the calibration and use of flow measurement devices — Part 1: Linear calibration relationships*

ISO 7066-2, *Assessment of uncertainty in the calibration and use of flow measurement devices — Part 2: Non-linear calibration relationships*

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

IEC 60381-1, *Analogue signals for process controls systems — Part 1: Direct current signals*

IEC 60381-2, *Analogue signals for process controls systems — Part 2: Direct voltage signals*

IEC 60359, *Expressions of the functional performance of electronic measuring equipment*

IEC 60529, *Degrees of protection provided by enclosures (IP code)*

3 Terms and definitions

For the purposes of this Technical Report, the terms and definitions given in ISO 4006, ISO 5168, ISO 7066-1 and ISO 7066-2, and the following definitions apply.

3.1
random error
component of the error of measurement which, in the course of a number of measurements of the same measurand, varies in an unpredictable way

NOTE It is not possible to correct for random error.

3.2
systematic error
component of the error of measurement which, in the course of a number of measurements of the same measurand, remains constant or varies in a predictable way

NOTE Systematic errors and their causes may be known or unknown.

3.3
uncertainty
estimate characterizing the range of values within which the true value of a measurement lies

3.4
random uncertainty
component of uncertainty associated with a random error

NOTE Its effect on mean values can be reduced by taking many measurements.

3.5
systematic uncertainty
component of uncertainty associated with a systematic error

NOTE Its effect cannot be reduced by taking many measurements.

3.6
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

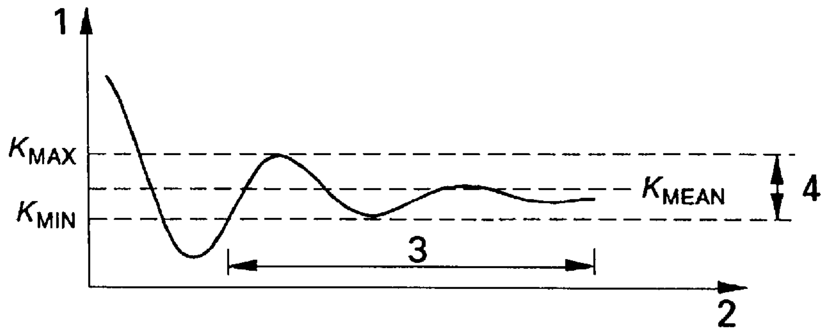
See Figure 1.

NOTE 1 The variations in the K-factor may 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:

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

where: K_{max} is the maximum K-factor over a designated range, and 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 may 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 It is expressed in pulses per unit volume.



Key:

1 K-factor

2 Pipe Reynold's number

3 Designated linear range

4 Linearity (± %)

Figure 1 — Typical shape of a K-factor curve

3.7
linearity
constancy of the K-factor over a specified range defined either by the pipe Reynolds number or flowrate

See Figure 1.

NOTE The upper and lower limits of the linear range are specified by the manufacturer.

3.8
rangeability
ratio of the maximum to minimum flowrates or Reynolds numbers in the range over which the meter meets a specified accuracy (uncertainty)

3.9
Reynolds number
Re
<pipe> dimensionless ratio of inertial to viscous forces which is used as a correlating parameter that combines the effects of viscosity, density and pipeline velocity

3.10
Strouhal number
St
dimensionless parameter that relates the measured vortex shedding frequency to the fluid velocity and the bluff body characteristic dimension

NOTE In practice the K-factor, which is not dimensionless, replaces the Strouhal number as the significant parameter.

3.11
lowest local pressure
lowest pressure found in the meter

NOTE This is the pressure of concern regarding flashing and cavitation. Some of the pressure is recovered downstream of the meter.

3.12
pressure loss
difference between the upstream pressure and the pressure downstream of the meter after recovery

3.13
flashing
formation of vapour bubbles

NOTE Flashing occurs when the pressure falls below the vapour pressure of the liquid.

3.14
cavitation
phenomenon following flashing, in which the pressure recovers above the vapour pressure and the vapour bubble collapses (implodes)

NOTE Cavitation can result in measurement error as well as mechanical damage to the meter.

3.15
response time
time needed for the indicated flowrate to differ from the true flowrate by a prescribed amount (for example, 10%), in response to a step change in flowrate

3.16
fade
failure of a vortex shedding flowmeter to shed or detect vortices

4 Symbols and subscripts

4.1 Symbols

Symbol	Quantity	Dimensions	SI units
a	Response Time	T	s
D	Diameter of meter bore	L	m
f	Frequency of vortex shedding	T^{-1}	Hz
d	Width of bluff body normal to the flow	L	m
K	K-factor, meter factor=1/K	L^{-3}	m^{-3}
N	Number of pulses	dimensionless	
q_v	Volume flowrate	L^3T^{-1}	m^3/s
q_m	Mass flowrate	$M\,T^{-1}$	kg/s
Q_v	Totalized volume flow	L^3	m^3
Q_m	Totalized mass flow	M	kg
Re	Reynolds number	dimensionless	
St	Strouhal number	dimensionless	
U	Average fluid velocity in meter bore	LT^{-1}	m/s

α	Coefficient of linear expansion of material	θ^{-1}	K^{-1}
μ	Absolute viscosity(dynamic)	$ML^{-1} T^{-1}$	Pa•s
ρ	Fluid density	ML^{-3}	kg/m^3
T	Temperature	θ	K
δ	% error in the average period	dimensionless	
t	Two-tailed Student's t at 95% confidence	dimensionless	
σ	Estimate of standard deviation of the average period	T	s
τ	Average period of vortex shedding	T	s
n	Number of period measurements	dimensionless	
P	Pressure	$ML^{-1}T^{-2}$	Pa
P_{dmin}	Minimum downstream pressure limit	$ML^{-1}T^{-2}$	Pa
c_1, c_2	Empirical constant	dimensionless	
ΔP	Overall pressure drop	$ML^{-1}T^{-2}$	Pa
P_{vap}	Liquid vapour pressure at the flowing temperature	$ML^{-1}T^{-2}$	Pa

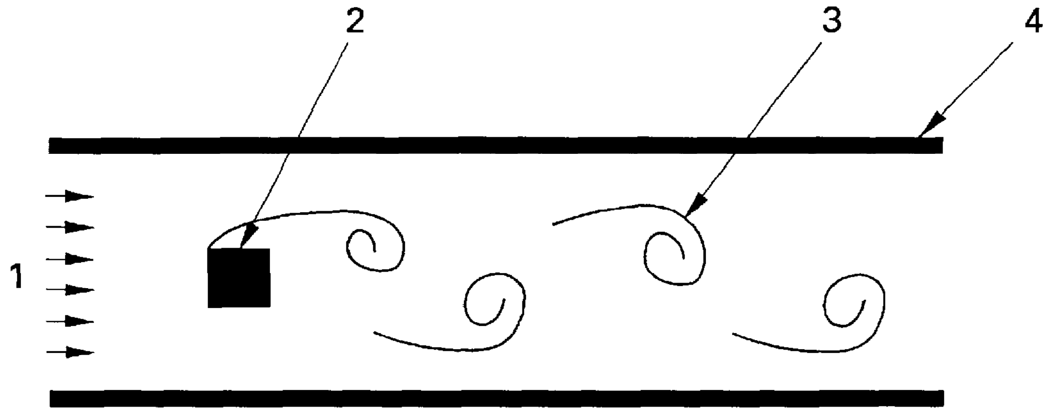
NOTE Fundamental dimensions: M=mass, L=length, T=time, θ =temperature

4.2 Subscripts

Subscript	**Description**
b	base conditions
flow	flowing fluid conditions
D	unobstructed diameter of meter bore, see above
m	mass unit
0	refers to reference condition
V	volume units, reference conditions
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 When a bluff body 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 flow.



Key:

1 Flow

2 Bluff body

3 Vortex

4 Conduit

Figure 2 — Principle

5.2 Sensors are used to detect shedding vortices , i.e. to convert the pressure or velocity variations associated with the vortices to electrical signals.

5.3 The Strouhal number, *St*, relates the frequency *f* of generated vortices, the bluff body characteristic dimension *d* and the fluid velocity *U*.

$$U = \frac{f \times d}{St}$$

5.4 For certain bluff body shapes, the Strouhal number 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,

$$U = \xi \times f$$

where ξ is a constant equal to d/St,

and the volumetric flowrate at flowing conditions, i.e. the volume flowrate, is given by

$$q_V = A \times U = \left[\frac{(A \times d)}{St}\right] \times f$$

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

$$K = \frac{St}{(A \times d)} = \frac{f}{q_v}$$

hence,

$$q_v = \frac{f}{K}$$

To obtain mass flowrate or volumetric flowrate at base conditions, i.e. standard volume flowrate, the density at flowing temperature and pressure is needed.

Mass flowrate: $q_m = \rho_f \times \frac{f}{K}$

Volume flowrate at base conditions: $q_{vb} = \left(\frac{\rho_f}{\rho_b}\right) \times \frac{f}{K}$

The total amount of fluid that has flowed through a meter over a specified time interval is given by

$$Q_v = \frac{N}{K},\ Q_m = \rho_f \times \frac{N}{K}, \text{ or } Q_v = \left(\frac{\rho_f}{\rho_b}\right) \times \frac{N}{K}$$

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 flowtube (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 Flowtube

The flowtube, 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 The meter body is normally 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.

6.1.1.2. 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 The sensor detects the passage of the shedding vortices. Sensor location and principle varies among the various flowmeter designs. (See Annex B)

6.1.2 Output device

The output device converts sensed signals to a digital flowrate readout, digital total flow readout, a pulse of scaled pulse signal, and/or a standardized analog output (see IEC 60381)

6.2 Equipment markings

6.2.1 Meters shall be marked to identify the manufacturer, serial number, pressure rating, mean K-factor, or Meter factor, and hazardous location certification, if any.

6.2.2 The direction of flow shall be permanently indicated on the meter body, preferably on both sides.

6.3 Safety issues

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

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

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

7 Application notes

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 error or calibration curve of a vortex 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).

7.2 Process hydrodynamics

7.2.1 Fluid pressure

The fluid pressure at the lowest point shall be high enough to avoid flashing or cavitation, and the fluid shall not be gas/liquid multiphase, e.g. wet steam.

7.2.2 Cavitation

The manufacturer should be consulted for recommendations to avoid flashing and cavitation. These recommendations may be in the form of equations that include vapour pressure for the fluid being measured and the lowest local pressure in the flowmeter. They may include recommendations to increase the back-pressure with a downstream valve. See Annex C.

7.2.3 Swirl and undeveloped profile

A vortex meter is sensitive to abnormal velocity profiles and swirl. When a particular meter installation is expected to deviate from the manufacturer's recommendations, the user may desire to perform an *in situ* calibration or contact the manufacturer for known effects (see 10.3). Flow conditioners can also be used to correct abnormalities in the flow (see 8.3).

7.2.4 Flow stability

The fluid stream should be steady or varying only slowly in relation to the response time of the meter. Pulsations in flowrate or pressure may affect performance

7.3 Vibration

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

7.4 Safety

The watertightness and hazardous area certification shall be suitable for the intended installation. See IEC 60529 (Ingress Protection).

8 Installation

Care should be taken to follow the manufacturer's instructions for installation. In the absence of such recommendations, adopt the requirements for orifice plates in ISO 5167-1. The following is supplementary advice.

8.1 Installation location

The following general precautions should be observed in determining the installation location for the flowmeter.

a) 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.

b) Care shall be exercised to observe the manufacturer's specified temperature limits, vibration limits, and corrosive atmosphere and humidity limits (see also 10.2).

c) Select a location that conveniently allows for regular inspection and maintenance as well as piping and wiring.

8.2 Piping

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

8.2.1 Straight unobstructed pipe sections of the required lengths should be installed upstream and downstream of the flowmeter in order to obtain the specified accuracy at operating conditions. These straight pipe lengths should comply with the conditions outlined in 8.2.2 to 8.2.15. Note that straight pipe section lengths may differ depending on flowmeter construction and the nature of the upstream disturbances.

8.2.2 The ideal geometry is with the inside diameter of the connecting pipe being of the same nominal diameter as the meter. Also, the inside diameter of the pipe used for the calibration of the meter should be the same. A sudden change in internal diameter betwen 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.

8.2.3 The flowmeter should be mounted concentric with the pipe; and gaskets should not protrude inside the pipe.

8.2.4 If more than one piece of pipe is used, the overall length should be straight, with minimal misalignment.

8.2.5 There should be no valves or bypass piping immediately ahead of or downstream of the meter. If a valve must be upstream, the manufacturer should be consulted concerning any possible effect on the meter performance.

8.2.6 The required length of straight pipe may be reduced through the use of an appropriate flow conditioner (see 8.3).

8.2.7 When entrained gas bubbles may be included in a liquid, and/or a dirty fluid is to be measured, a gas separator and/or a strainer may be required. They should be installed upstream of the straight lengths of pipe or conditioner.

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

8.2.9 The flowmeter should be protected from excessive pressures which may result from thermal expansion of the fluid when both the upstream and downstream valves are closed at the same time.

8.2.10 Additional process measurements, such as pressure, temperature or density may be made. However for some vortex meters the locations of the sensors for these measurements may be critical and the manufacturer should be asked for instructions.

8.2.11 Flowmeters should be installed within the orientations recommended by the manufacturer.

8.2.12 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.

8.2.13 The flowmeter should be protected from excessive piping stress.

8.2.14 If the fluid is a condensable gas (e.g. steam), the manufacturer should be consulted for recommendations.

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

8.3 Conditioners

Various flow conditioner designs may be effective in reducing anomalies in the distribution of axial velocity in the pipe or in reducing swirl, or both. Thus they may be effective in improving meter performance where installation conditions are not in accordance with the manufacturer's recommendations. The meter manufacturer should be consulted regarding installation conditions and/or the use of flow conditioners. This includes the type of flow conditioner, its sizing and its location relative to the meter.

9 Operation

9.1 Flowmeters should be operated within the manufacturer's recommended operating limits to produce the specified uncertainty and achieve normal service life. Key considerations in operation are proper sizing, proper installation and operation and maintenance procedures.

9.2 New installations require that the line be cleaned to remove any collection of welding beads, rust particles or other pipeline debris. It is normally good practice to remove the bluff body(s) and sensor(s), or even the complete meter, before the cleaning, and, replace them before pressure-testing for leaks.

9.3 The manufacturer's recommended startup procedures should be followed to avoid damage to the bluff body(s) or sensor(s) by overrange, water hammer, etc.

9.4 In order to avoid causing a shift in the K-factor, the manufacturer should be consulted for advice about precautions to be taken whilst repairing or replacing sensors, and also about the effects of wear on the bluff body.

10 Performance characteristics

10.1 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 5.4 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 Process temperatures and pressures which differ significantly from those during calibration can affect the geometry of the flowtube, and hence the K-factor of the meter. The manufacture should be consulted for relevant correction factors.

10.3 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 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 The meter manufacturer should state the meter's mean K-factor and the expected uncertainty under specified reference 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.

11.2 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.

11.3 The manufacturer should be contacted for any required certification of calibration or performance.

Annex A
(informative)

Period jitter and its effect on calibration

Period jitter (fluctuation of period) and the associated frequency jitter is normally of concern only during calibration.

NOTE All methods of on-line measurement of fluid flow are affected more or less by the fluctuations associated with turbulent flow (often referred to as 'flow noise'). In the case of vortex measurement this 'noise' causes the period between sensor signals to vary in a manner called 'period jitter'.

There are several influences affecting the vortex shedding characteristics of flowmeters. They range from the physical phenomena on which the measurement depends to the electronic signal processing techniques used to process the basic measurement. The following discussion is confined to the physical phenomenon of vortex shedding.

Regarding period jitter (see note below), it is generally known that small, random variations may occur in the vortex shedding period from one cycle to another, even though the flowrate is held constant. As a result, a determination of the period would invariably lead to an average period (τ) and a standard deviation (σ) for that average. If a sufficiently large number of period measurements is obtained, increasing that number would no longer significantly affect the standard deviation.

The random uncertainty of the average period to 95% confidence would then be given by:

$$\delta = \frac{100\ t\ \sigma}{\tau\ (n)^{0.5}}$$

where:

$$\tau = \frac{\sum \tau_i}{n}$$

t = Student's t with $n-1$ degrees of freedom for a 95% confidence level (equal to 2,0 for 30 or more measurements)

n = the number of period measurements

$$\sigma = \left[\frac{\sum (\tau_i - \tau)^2}{n-1}\right]^{0.5}$$

τ_i = ith period measurement

δ = error in the average period in percent

NOTE It is known that the strength and relative positions of successive vortices can differ from their mean values. These changes are associated with the nature of the turbulent flow phenomena and can cause frequency jitter and amplitude variations in the output of a detector. Frequency jitter can affect the response time of a meter. Amplitude variations, if severe, can affect the performance of a meter, particularly at low flowrates, by causing dropped counts or pulses. The meter manufacturer should be contacted if the turbulence level is such as to cause concern about these phenomena.

Once σ has been determined, N, the number of pulses that must be counted in order to determine a flowrate to within a pre-assigned uncertainty of ± δ %, is given by:

$$N = \left(\frac{100\, t\, \sigma}{\delta\, \tau} \right)^2$$

The time required to obtain this average, $a = N\,\tau$, is related to the flowrate by:

$$a = \frac{N \times d}{St \times U}$$

or equivalently, $$a = \frac{N}{K \times q_v}$$

where:

$St = \dfrac{f\, d}{U}$ = Strouhal number

f = vortex shedding frequency

U = flow velocity in the meter bore

d = width of the face of the bluff body(s) normal to the flow

K = mean K-factor

q_v = volumetric flowrate

a = response time

It can therefore be seen that if St does not vary with flowrate (not necessarily a good assumption), the response time of the meter associated with only the period uncertainty of vortex shedding is inversely proportional to the fluid velocity or the volumetric flowrate.

For example, if a meter has a Strouhal number of 0,24 and if the standard deviation for period measurements is given by:

$$\frac{100\, \sigma}{\tau} = 1{,}5\%$$

and if d/D = 0,27, then the time a required to obtain an average flowrate with an uncertainty of 0,25% is given by:

$$a = \frac{N \times d}{St \times U} = \frac{\left(\frac{100\, t\, \sigma}{\delta\, \tau} \right)^2 d}{St \times U}$$

which, upon substituting the above-mentioned values and assuming N is large, becomes:

$$a = \frac{\left(\frac{2}{0{,}25} \times 1{,}5 \right)^2 d}{0{,}24\, U} = 600 \frac{d}{U} = 160 \frac{D}{U}$$

The calculated response times for 25 mm and 145 mm meters having these characteristics are given in Table A.1:

Table A.1 — Time, *a*, needed for a flowrate uncertainty of 0,25%

Flow velocity m/s	***a*** s Meter size D = 25mm	D = 145 mm
0,31	13,0	76,0
3,1	1,3	7,6
6,35	0,51	3,9
63,5	0,051	0,30

Thus, the time constants for low velocity flows in large conduits is large enough to require a considerable integration time to obtain high accuracy after upsets in the flowrate. Note that, if $100\sigma/\tau$ = 3 %, the times in the above table shall be multiplied by 4.

The manufacturer should be consulted for details regarding the effects of these phenomena on his meter.

Annex B
(informative)

Vortex sensors

A wide variety of sensor techniques are available for detecting vortex shedding. The most important feature of the sensing element is for it to be sensitive to the full effect to be measured and to be insensitive to other influences such as temperature, pressure pulsations, vibration, etc. Velocity and pressure fluctuations in the vortex shedding area may cause different effects which can be detected by the following selected examples of vortex sensors.

a) Mechanical stress movement of the bluff body, detected by:-

- — piezoelectric strain sensor
- — strain gauge sensor
- — capacitive strain sensor
- — optical sensor
- — etc.

b) Change of differential pressure laterally across the bluff body:

- — piezoelectric pressure sensor
- — capacitive pressure sensor
- — oscillating ball, tongue, tail
- — variable inductance type of pressure sensor
- — etc.

c) Change of velocity around the bluff body:

- — thermistor sensor
- — hot-wire anemometer
- — ultrasonic sensor
- — etc.

The sensors can be mounted inside or outside of the bluff body, or can be located outside of the meter body.

The density of the fluid affects the performance of the vortex sensor(s). A low density fluid may, because of the relatively lower energy level of the vortices, limit the low flow performance. A high density fluid may limit the upper flowrate performance by causing damage to sensitive sensors because of the relatively greater energy of the vortices.

Other items of consideration may include:

- — viscosity effects
- — liquid cavitation

— dimensional changes due to temperature

— vibration of process piping

— process pressure fluctuations

— installation effects (see clause 8)

Annex C
(informative)

Calculation of pressure limit to avoid cavitation

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 accuracy 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_{dmin} which can be calculated as:

$$P_{dmin} = (c_1 \times \Delta P) + (c_2 \times P_{vap})$$

where:

P_{dmin} = downstream minimum pressure limit;

P_{vap} = vapour pressure of the liquid at the flowing temperature;

ΔP = overall pressure drop;

c_1, c_2 = empirically determined constants for each design and size.

Since this pressure reduction is dependent on the construction of the meter, the manufacturer should be contacted for the values of c_1 and c_2.

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Descriptors: liquid flow, pipe flow, flow measurement, flowmeters, installation, inspection, marking.

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