ASME MFC-6–2013

[Revision and Redesignation of ASME MFC-6M–1998 (R2005)]

Measurement of Fluid Flow in Pipes Using Vortex Flowmeters

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Two Park Avenue • New York, NY • 10016 USA

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The American Society of Mechanical Engineers
Two Park Avenue, New York, NY 10016-5990

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FOREWORD

This Standard has been prepared by Subcommittee 6, Vortex Shedding Flowmeters, of the ASME Standards Committee for Measurement of Fluid Flow in Closed Conduits (MFC). It is one of a series of standards covering a variety of devices that measure the flow of fluids in closed conduits. The vortex shedding principle has become an accepted basis for fluid flow measurement. Flowmeters based on this principle are available for measuring the flow of fluids ranging from cryogenic liquids to steam and high-pressure gases. Vortex shedding flowmeters are also referred to as vortex meters. Their designs are proprietary, and therefore, their design details and associated uncertainty bands cannot be covered in this Standard. However, these devices have in common the shedding of alternating pairs of vortices from some obstruction in the meter.

This Standard contains the relevant terminology, test procedures, list of specifications, application notes, and equations with which to determine the expected performance characteristics.

This revision was approved by the American National Standards Institute on February 19, 2013.

ASME MFC COMMITTEE
Measurement of Fluid Flow in Closed Conduits

CORRESPONDENCE WITH THE MFC COMMITTEE

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Secretary, MFC Standards Committee
The American Society of Mechanical Engineers
Two Park Avenue
New York, NY 10016-5990
http://go.asme.org/Inquiry

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The Committee welcomes proposals for revisions to this Standard. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

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Subject:	Cite the applicable paragraph number(s) and the topic of the inquiry.
Edition:	Cite the applicable edition of the Standard for which the interpretation is being requested.
Question:	Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. The inquirer may also include any plans or drawings that are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in this format will be rewritten in this format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

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MEASUREMENT OF FLUID FLOW IN PIPES USING VORTEX FLOWMETERS

1 SCOPE

This Standard

(a) describes the use of vortex flowmeters, including their physical components, principle of operation, installation, performance, influence factors, and calibration in a closed conduit running full for the measurement of volumetric flow rate and volume flow total of single-phase liquids or gases, including vapors such as steam

(b) describes the use of vortex flowmeters in combination with one or more other process measurements for the inferential measurement of mass flow rate, mass flow total, base volumetric flow rate, base volume total, and heat flow metering

(c) is limited to full-bore flowmeters and does not include the special case of insertion-type flowmeters

2 REFERENCES AND RELATED DOCUMENTS

Unless otherwise indicated, the latest issue of a referenced standard shall apply.

ASME MFC-1M, Glossary of Terms Used in the Measurement of Fluid Flow in Pipes

Publisher: The American Society of Mechanical Engineers (ASME), Two Park Avenue, New York, NY 10016-5990; Order Department: 22 Law Drive, P.O. Box 2900, Fairfield, NJ 07007-2900 (www.asme.org)

IEC 60529, Degrees of Protection Provided by Enclosures (IP Code)

Publisher: International Electrotechnical Commission (IEC), 3, rue de Varembé, Case Postale 131, CH-1211 Genève 20, Switzerland/Suisse (www.iec.ch)

3 TERMINOLOGY AND SYMBOLS

3.1 Definitions From ASME MFC-1M Used in This Standard

For the purposes of this Standard, the following definitions are particularly useful in describing the characteristics of vortex shedding flowmeters. ASME MFC-1M provides a more extensive collection of definitions and symbols pertaining to the measurement of fluid flow in closed conduits.

cavitation: the implosion of vapor bubbles formed after flashing when the local pressure rises above the vapor pressure of the liquid.

flashing: the formation of vapor bubbles in a liquid when the local pressure falls to or below the vapor pressure of the liquid, often due to local lowering of pressure because of an increase in the liquid velocity.

K factor: in pulses per unit volume, the ratio of the meter output in number of pulses to the corresponding total volume of fluid passing through the meter during a measured period. Variations in the *K* factor may be presented as a function of either the meter bore Reynolds number or the flow rate of a specific fluid at a specific set of thermodynamic conditions (see Fig. 9.2-1).

lowest local pressure: the lowest pressure found in the meter. This is the pressure of concern regarding flashing and cavitation. Some of the pressure is recovered downstream of the meter.

meter bore Reynolds number: a dimensionless ratio of inertial to viscous forces that is used as a correlating parameter that combines the effects of viscosity, density, and pipeline velocity. It is defined as

$$Re_D = \frac{DU\rho}{\mu}$$

meter factor: the reciprocal of the mean *K* factor.

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

random error: a component of the error of measurement that, 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.

random uncertainty: a component of uncertainty associated with a random error. Its effect on mean values can be reduced by taking many measurements.

rangeability: flowmeter rangeability is the ratio of the maximum to minimum flow rates or Reynolds number in the range over which the meter meets a specified uncertainty.

response time: for a step change in flow rate, response time is the time needed for the indicated flow rate to differ from the true flow rate by a prescribed amount (e.g., 10%).

systematic error: a component of the error of measurement that, 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.

systematic uncertainty: the error associated with systematic error, i.e., the error that cannot be reduced by increasing the number of measurements under identical conditions. Also known as bias.

3.2 Definitions Specific to This Standard

linearity: linearity relates to the variations of the *K* factor over a specified range, defined either by Re_D or q_v of a specific fluid at specific thermodynamic conditions (see Fig. 9.2-1). In equation form, it is defined as

$$\% \text{ linearity} = \frac{K_{\text{max}} - K_{\text{min}}}{2 \times K_{\text{mean}}} \times 100$$

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

Strouhal number: a dimensionless parameter that relates the measured vortex shedding frequency to the fluid velocity and the bluff body characteristic dimension. It is given by

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

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

uncertainty: an estimate characterizing the range of values within which the true value of a measurement lies.

3.3 Symbols Used in This Standard

See Tables 3.3-1 and 3.3-2.

4 PRINCIPLE OF MEASUREMENT

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. 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 sheet (see Fig. 4-1). The frequency at which vortices are shed is directly proportional to the fluid velocity. Since the shedding process is repeatable, it can be used to measure flow. Vortex shedding can be observed in the ripple of a flag downstream from a flagpole.

Sensors are used to detect shedding vortices, i.e., to convert the pressure or velocity variations associated with the vortices to electrical signals. One cycle of the shedding frequency corresponds to the generation of two vortices, one from one side of the bluff body, followed by another from the bluff body's other side. The electrical signal generated by a flowmeter's vortex sensor varies at the shedding frequency, *f*, one cycle of which corresponds to the shedding of a pair of vortices.

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

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

For certain bluff body shapes, the Strouhal number remains essentially constant within a large range of Reynolds numbers. 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.

$$U = \varepsilon \times f$$

The constant, ε, is equal to *d/St*, and the volumetric flow rate at flowing conditions, i.e., the volume flow rate, is given by

$$\begin{aligned} q_v &= A \times U \\ &= [(A \times d)/St] \times f \end{aligned}$$

The *K* factor for a vortex shedding flowmeter is related to the Strouhal number by

$$K = [St/(A \times d)] = f/q_v$$

Hence

$$q_v = f/K$$

When the density at flowing temperature and pressure is known, the mass flow rate, q_m [see eq. (1)], and the volumetric flow rate at base conditions, i.e., the standard volume flow rate, q_v [see eq. (2)], can be determined.

$$q_m = \rho_f \times (f/K) \tag{1}$$

$$q_v = (\rho_f/\rho_b) \times f/K \tag{2}$$

If it is assumed that the flow rate can be considered constant over the time it takes a vortex pair to shed, i.e., over one cycle of period τ, then the amount of fluid volume that flows through the meter during one cycle is

$$q_v \times \tau = (f \times \tau)/K = 1/K$$

and the total flow over *N* cycles is

$$Q_v = N/K$$

Table 3.3-1 Symbols

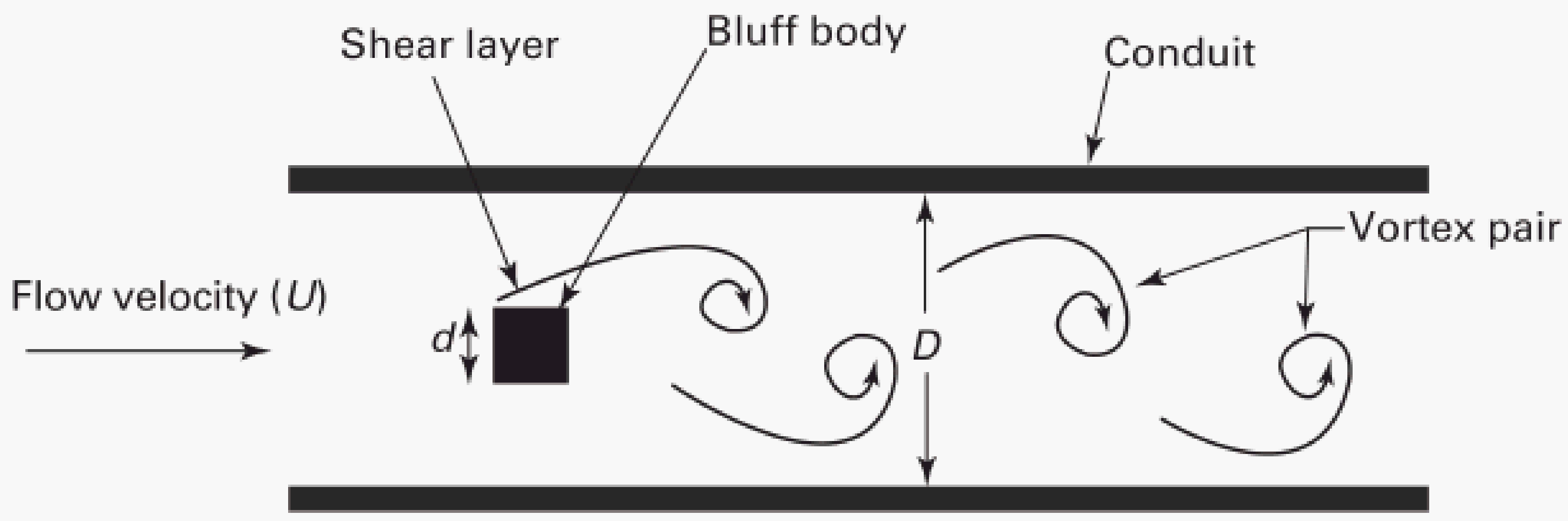
Symbol	Quantity	Dimension	SI Units
A	Cross-sectional area of meter bore	L^2	m^2
c_1, c_2	Empirical constant	Dimensionless	. . .
D	Diameter of meter body	L	m
d	Width of bluff body normal to the flow	L	m
f	Vortex shedding frequency (VSF)	T^{-1}	Hz
K	*K* factor	L^{-3}	m^{-3}
N	Number of vortex pulses	Dimensionless	. . .
Q_m	Totalized mass flow	M	kg
Q_v	Totalized volume flow	L^3	m^3
q_m	Mass flow rate	MT^{-1}	kg/s
q_v	Volume flow rate	L^3T^{-1}	m^3/s
P	Pressure	$ML^{-1}T^{-2}$	Pa
R_e	Reynolds number	Dimensionless	. . .
St	Strouhal number	Dimensionless	. . .
T	Temperature	θ	K
U	Average fluid velocity in meter bore	LT^{-1}	m/s
α	Linear thermal expansion	. . .	. . .
μ	Dynamic velocity of the fluid	$ML^{-1}T^{-1}$	Pa·s; N·s/m^2; or kg/(m·s)
ρ	Fluid density	ML^{-3}	kg/m^3

GENERAL NOTE: Fundamental dimensions: L = length; M = mass; T = time; θ = temperature.

Table 3.3-2 Subscripts

Subscript	Description
b	Base conditions
D	Unobstructed diameter of meter bore (see Table 3.3-1)
d_{min}	Minimum downstream value
f	Flowing conditions
flow	Flowing fluid conditions
i	The *i*th measurement
m	Mass unit
max	Maximum value
mean	Average of extreme values
min	Minimum value
V	Volume units, reference conditions
v	Volume units, flowing conditions

Fig. 4-1 Vortex Formation



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

Assuming further that the fluid density remains constant over the measurement time interval, then

$$Q_m = \rho_{\text{flow}} \times (N/K)$$

and

$$Q_v = (\rho_{\text{flow}}/\rho_b) \times (N/K)$$

5 FLOWMETER DESCRIPTIONS

5.1 Physical Components

The vortex shedding flowmeter consists of two elements: the flow tube and the transmitter.

5.1.1 Flow Tube. The flow tube is made up of the meter body, the bluff body(ies), and the sensor.

The meter body is normally available in two styles: a flanged version that bolts directly to the flanges on the pipeline, and a wafer version that is clamped between two adjacent pipeline flanges via bolts.

The bluff body is the shedding element positioned in the cross section of the meter body. Its shape and dimensions and the ratio of the frontal area in relation to the open area in the meter-body cross section influence the linearity of the K factor. Figure 4-1 shows it as a square cross-section bluff body, but it is not intended to imply a preferred shape.

The sensor detects the shedding vortices (see section 4). Sensor technology and location vary with flowmeter design.

5.1.2 Transmitter. There are three primary types of transmitters used on vortex shedding flowmeters: analog, digital (sometimes referred to as "smart"), and multivariable.

5.1.2.1 Analog Transmitters. Analog transmitters are comprised primarily of analog components and do not contain digital microprocessors. As such, they require the end user to configure them using discreet components such as potentiometers or switches. For this reason, they are the least flexible of the three transmitter types. They are typically used for simple applications that do not warrant the features provided by microprocessor-based transmitters. They are often preconfigured per the user's requirements by the manufacturer.

Analog transmitters typically provide an output range of 4 mA to 20 mA as well as a frequency output directly proportional to the vortex shedding frequency. If these two outputs are not available simultaneously, some means to select between them is provided. A scaled frequency output in which the maximum frequency represents the upper-range flow value (URFV) or a pulse output in which each pulse represents a specific quantity of fluid may also be provided. A digital or analog display of the flow rate may also be provided.

If a 4-mA to 20-mA signal proportional to the flow rate is to be utilized, the transmitter must be configured so that the 20-mA point equals the upper-range flow value. In an analog transmitter, this is typically accomplished by inputting a frequency equal to the shedding frequency that will be experienced at the upper-range flow value and adjusting a potentiometer until the output equals 20 mA. The vortex shedding frequency, f, that will be experienced at the upper-range flow value can be calculated from the equation

$$f = (URFV) \times (K)$$

Note that the K in the above equation represents the K factor at the operating temperature (see para. 6.2.1 for details).

A low-flow cutoff (LFC) may be included in the analog transmitter. The LFC is designed to hold the output at zero when the strength of the vortices is too low for an accurate measurement. In an analog transmitter, the LFC is typically set by adjusting a potentiometer at zero flow until the output reads zero or by selecting from a group of available LFC levels. As with digital transmitters, setting the LFC too high on an analog transmitter may result in cutting of flow indications within the desired flow measurement operating range, so care should be taken to set LFC at the minimum suitable value.

5.1.2.2 Digital Transmitters. Digital transmitters use one or more microprocessors to process raw input signals and provide output signals and a user interface. These transmitters are often referred to as smart transmitters. Their use of microprocessors provides several advantages over analog transmitters. Because the input signals are processed digitally, these transmitters can analyze the signals using mathematical algorithms to determine installation quality, external interference, and noise. Based on this analysis, the transmitters may be able to digitally filter out spurious signals. The use of microprocessors and digital processing minimizes the effect of component drift that may occur in analog transmitters. Digital transmitters may also be able to compensate for changes in the meter *K* factor caused by changes in process temperature and pressure.

Typical human interface is via a digital numeric or graphical display and buttons and optical or magnetic sensors to program parameters, or via a handheld communicator. Digital transmitters are programmable for range and other parameters in user-selectable units and languages. This configuration is stored on the transmitter and may also be uploaded via the communication protocol to other devices.

Digital transmitters may also include the ability to program a low-flow cutoff below which the instrument either emits an error signal or holds the output to zero. Alternatively, at no-flow conditions, the digital transmitter may determine the low-flow cutoff by differentiating between signal and noise, and adjust the measurement threshold accordingly.

Digital transmitters may be enabled with protocols that allow communication with other compatible instruments, communication devices, and control systems such as distributed control systems (DCS). Most digital transmitters include a programmable output range of 4 mA to 20 mA unless precluded by a communication protocol. They are also likely to include a programmable pulse or frequency output range.

5.1.2.3 Multivariable Transmitters. Multivariable transmitters are digital transmitters equipped with multiple inputs to the electronics to provide the temperature and pressure of the fluid that the meter is measuring. Multivariable transmitters perform a larger number of calculations than do typical digital transmitters. Vortex shedding flowmeters measure the volumetric flow rate. In many applications, the mass flow rate of the fluid is of interest. To calculate the mass flow rate from a vortex shedding meter's volumetric flow reading, the flowing density of the fluid must be determined. The flowing density can be calculated from the flowing temperature, pressure, and an equation of state for the specific fluid. There are exceptions to these requirements, and in the case of a liquid, the pressure effect is typically minimal and can be neglected. In the case of saturated steam, the density can be determined from knowledge of either the pressure or temperature; however, if the steam is superheated, then both pressure and temperature are required.

Multivariable transmitters may have built-in temperature and pressure sensors or may accept temperature- and, if required, pressure-measurement signals from external sensors.

The configuration of a multivariable transmitter is similar to that described for digital transmitters, but it requires additional steps to provide an accurate output. The inputs from the temperature and pressure sensors must be configured in the multivariable transmitter's electronics. The correct process fluid or equation of state must be selected in the electronics, and potentially more than one 4-mA to 20-mA output or other, digital output must be configured. It is extremely important that the right selection is made for the density compensation calculation.

The multivariable transmitter provides the temperature and, if applicable, pressure measurements to the end user via either a digital communications protocol or multiple 4-mA to 20-mA outputs. In addition, since the multivariable transmitter computes the density of the fluid, it can provide this value as well as a number of other computed fluid parameters to the user. Consult the manufacturer's literature to determine what variables the multivariable transmitter can calculate. The *K* factor is a nonlinear function of the Reynolds number (see Fig. 9.2-1), and the multivariable transmitter can compute the Reynolds number and correct the nonlinearity in the *K* factor. The flowing density of the fluid can be used to predict the expected strength of the vortices at a specific flow rate, allowing more accurate filtering algorithms in the transmitter to address signal interferences at low-flow rates.

5.2 Equipment Markings

Meters shall be marked by the manufacturer to identify the manufacturer, serial number, pressure rating, mean *K* factor, or meter factor, and hazardous location certification, if any. The direction of flow shall be permanently indicated by the manufacturer on the meter body.

6 APPLICATION CONSIDERATIONS

There are several considerations related to application of vortex meters, but the three primary ones are sizing, process influences, and safety.

6.1 Sizing

Size the meter according to the desired flow range rather than the nominal pipe size. The flowmeter size shall be selected such that the expected process flow rate falls between the maximum and minimum flow rates within the required uncertainty.

6.1.1 Maximum Flow. The maximum flow for a vortex meter can be determined by the structural limits of the meter, the pressure drop at the shedder bar, or the maximum accurate velocity as specified by the vendor.

Meter manufacturers provide a series of upper velocity limits. Manufacturers may specify an upper velocity limit as a function of process fluid density. This is usually for structural integrity reasons relating to the maximum stress due to vortex shedding that the sensor or meter body are able to withstand. For liquid flows, another limit is generally set due to pressure drop. Pressure loss increases with flow rate; as a result, the meter has a maximum velocity due to cavitation for any given process pressure. Also, most meters have a maximum velocity for which an analog current output may be obtained.

6.1.2 Minimum Flow. The minimum volumetric flow rate is determined by manufacturer-recommended limits. The manufacturer specifies recommended measurement limits based on the minimum measureable and minimum accurate flow rates. Minimum measureable flow rate may be useful for start-up operations. Minimum accurate flow rate is useful for operations where accuracy is important. The transmitter provides a means of configuring the low-flow cutoff for the meter based on these recommendations or specific application requirements.

Manufacturers generally provide sizing programs or published equations to calculate minimum measurable flow rate and minimum accurate flow rates.

6.1.2.1 Minimum Measurable Flow Rate. The minimum measureable flow rate, V_{min}, is the rate at which the force exerted on the sensor is too small to generate a signal strong enough for the meter to reliably differentiate between the flow signal and noise. The limit is a function of the fluid momentum and is therefore described by the following equation, where C is a manufacturer-specified value:

$$V_{\text{min}} = \frac{(C)^{1/2}}{\rho}$$

6.1.2.2 Minimum Accurate Flow Rate. The minimum accurate flow rate is the lowest flow rate at which the meter reads at the specified accuracy. This is generally expressed in terms of Reynolds number. Generally, the minimum accurate flow rate is near 20,000. A specific meter design and size may have accuracy limits above or below that number. Some manufacturers may have recommendations for ways to use the meter at lower Reynolds numbers.

6.1.2.3 Low-Flow Cutoff. The meter will have a low-flow cutoff. This is a configurable parameter that defines the velocity, or volumetric flow rate, below which the meter will read zero, regardless of the actual flow in the pipe. This value is generally configured to be at or above the minimum measurable flow rate. It can also be configured to the minimum accurate flow rate or, in a high-noise environment, to a higher flow rate that increases noise rejection. The meter manufacturer's literature should be consulted for the method by which the LFC is configured.

6.2 Process Influences

A number of process influences, e.g., temperature, pressure, density, and composition, may effect the vortex flowmeter measurement performance.

6.2.1 Effect of Thermal Expansion. Measurement accuracy is directly related to *K*-factor uncertainty. Process temperatures that differ significantly from those during calibration can affect the geometry of the flow tube and hence, the *K* factor of the meter.

When the bluff body and the meter body are made of the same material, the change in *K* factor for a given change in temperature is estimated by

$$K = K_0\,[1 - 3\alpha(T_f - T_0)]$$

where

K = flowing K factor
K_0 = K factor at calibration
T_0 = temperature during calibration
T_f = flowing temperature
α = linear thermal expansion coefficient of the meter material

Process pressure effects on the *K* factor due to expansion are generally negligible, except in high-pressure applications. The manufacturer should be consulted for information and relevant correction procedures for temperature and pressure effects.

6.2.2 Effect on Range. The range of a vortex meter depends in general on the following parameters: the *K* factor, fluid density, and Reynolds number. From a practical viewpoint, the *K* factor, as described in para. 6.2.1, depends only on the process temperature. The fluid density depends on the process temperature and pressure. The Reynolds number is a function of geometry, fluid density, and fluid viscosity, and hence, depends on temperature and pressure.

The manufacturer should be consulted for specific information regarding these effects.

6.2.3 Flow. The fluid stream should be steady or slowly varying. Pulsations in flow rate or pressure may affect flow measurement.

6.2.4 Flashing and Cavitation. Local lowering of pressure occurs when the fluid velocity is increased by the reduced cross section around the bluff body of the meter. In a liquid, this can lead to flashing and cavitation. Operation under conditions of flashing or cavitation, or both, is beyond the scope of this Standard.

NOTE: Flashing and cavitation can lead to measurement errors, structural damage, or both.

To avoid flashing and cavitation in low-vapor-pressure fluids, the downstream pressure after recovery must be equal to or greater than $P_{d\min}$ of eq. (3) or (4).

In the absence of manufacturer's recommendations, the numerical value of the minimum back pressure at the outlet of the meter may be calculated by eq. (3) or (4). This calculated back pressure has proven to be adequate to most applications, and it may be conservative for some applications.

$$P_{d\min} = 2 \times \Delta P + 1.25 \times P_{\text{vap}} \tag{3}$$

or

$$= (3 + P_{\text{vap}}) \text{ in bar} \tag{4}$$

whichever is less

where

$P_{d\min}$ = minimum allowable downstream pressure after recovery

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

ΔP = pressure drop through the meter at the maximum operating flow rate

6.3 Safety

6.3.1 Mechanical. Since vortex flowmeters are an integral part of the process piping (in-line instrumentation), it is essential that the instrument be designed and manufactured to meet or exceed industry standards for piping codes. Requirements for specific location, piping codes, material traceability, cleaning requirements, nondestructive evaluation, etc., shall be the responsibility of the user.

6.3.2 Electrical. The water tightness and hazardous area certification shall be suitable for the intended location. See IEC 60529.

7 INSTALLATION

Adjacent piping, fluid flow disturbances, flowmeter orientation, and location may affect flowmeter performance. The manufacturer's installation instructions should be consulted regarding installation effects. Paragraphs 7.1 through 7.4 discuss some of the factors to consider.

7.1 Adjacent Piping

A vortex meter is sensitive to distorted velocity profiles and swirl, including those caused by changes in pipe size or schedule and by flow through pipe fittings, valves, and other process instrumentation or control elements. Procedures for eliminating these effects are as follows:

(a) The diameter of the adjacent pipe should be the same nominal diameter as the flowmeter. Pipe schedule should be the same as that of the pipe used in calibration unless appropriate corrections are applied.

(b) The flowmeter shall be mounted concentric with the pipe according to the manufacturer's recommendations.

(c) Gaskets shall not protrude inside the pipe.

(d) The flowmeter should be mounted with straight runs of pipe upstream and downstream. The straight runs should be free of changes in pipe size or schedule, and of pipe fittings, valves, and other internal obstructions. The minimum lengths of straight pipe required to obtain the specified accuracy at operating conditions differ depending on flowmeter construction and the nature of the piping configuration.

(e) If more than one pipe section is used within the minimum length of straight pipe, the joined pipe should be straight, with minimal misalignment. Welding rings should be avoided within the required number of straight pipe lengths.

(f) The required length of straight pipe may be reduced through the use of an appropriate flow conditioner or acceptance of higher uncertainties. The meter manufacturer should be consulted regarding the use of flow conditioners or their effect on meter uncertainty. This includes the type of flow conditioner, its sizing, and its location relative to the flowmeter.

(g) The location of additional process measurements external to the meter, such as pressure, temperature, or density, may impact the performance of a vortex flowmeter, and hence, these measurement points should be located downstream from the flowmeter.

(h) To satisfy the minimum measurable flow requirement, a meter size smaller than the pipe size may have to be used. Pipe reducers may be used upstream and downstream to install such flowmeters. When pipe reducers are installed without sufficient straight length of pipe, adjustment of the K factor or the uncertainty, or both, shall be made.

(i) In some applications it may be desirable to periodically inspect or clean the flowmeter. If a bypass is installed to facilitate this, the fittings shall be ahead of the upstream straight length of pipe or flow conditioner and beyond the downstream straight section. The valve(s) used to shut off main flow should be positive closing.

(j) When a particular meter installation is expected to deviate from the manufacturer's recommendations, the user may desire to perform in situ calibration.

7.2 Flowmeter Orientation

Proper orientation of the flowmeter in the pipe may depend on the nature of the fluid. Flowmeters should be installed with the orientation recommended by the manufacturer. The orientation of the meter should take into consideration the temperature of the stream being measured and its effect on the transmitter.

In liquid flow measurement, the pipe must be flowing full. One way to ensure this is to install the meter in a vertical pipe with the flow upward. Review liquid flowmeter locations during design and avoid installation in horizontal lines that are the highest point in the piping, unless you are sure that the line will remain full of liquid at all times you need an accurate measurement.

7.3 Flowmeter Location

7.3.1 Proper Support. The flowmeter shall be properly supported to reduce any effects of vibration and pipe stress. Good pipe support is important to good vortex meter operation.

7.3.2 Noise Interference. Common mode electrical noise may interfere with the measurement. Radio frequency interference (RFI), electromagnetic interference (EMI), 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.

7.4 New Installations

For new installations, the pipeline shall be cleaned to remove any collection of welding beads, rust particles, or other pipeline debris. The flowmeter should be removed before cleaning and prior to pressure testing for leaks.

8 OPERATION

Flowmeters shall be operated within the manufacturer's recommended operating limits to achieve the stated uncertainty and normal service life.

The manufacturer's recommended start-up procedures should be followed to avoid damage to the bluff body(ies) or sensor(s) by over range, water hammer, etc.

9 CALIBRATION

The meter manufacturer shall calibrate the meter to determine the meter's mean *K* factor. The meter mean *K* factor shall be marked on the meter. The manufacturer shall provide expected meter uncertainty under stated reference conditions and a certificate of calibration on request. It is possible, at reduced accuracy, to derive an estimated mean *K* factor from dimensional measurements, which is sometimes referred to as "dry calibration."

9.1 Calibration Methods

The mean *K* factor is established by flow calibration with a suitable fluid. All calibrations should be performed according to acceptable standards (see section 2). For gas flows, the reference flow measurement device is usually a transfer device, volumetric tank with pressure and temperature corrections, or critical flow nozzles. For liquid flows, transfer, weighing, or volumetric techniques are used.

Vortex meter calibrations are characterized by the shedding cycles per unit volume. Because of the nature of vortex shedding, there is inherently some modulation in the period of the shedding cycles. This modulation can affect the uncertainty of the calibration. This modulation is often referred to as jitter. Nonmandatory Appendix A discusses a method for ensuring that jitter does not influence calibration results. This can be of particular importance when doing a calibration where the reference standard has a small volume, such as in a small-volume prover. As a guide, using the methods of Nonmandatory Appendix A, Table 9.1-1 provides the number of pulses needed to determine average shedding frequency within a 95% confidence interval.

To use Table 9.1-1, obtain the flowmeter standard deviation of the shedding cycle period from the manufacturer. Then, select the standard deviation column with the nearest value, and find the number of required pulses at the intersection of the selected column and the calibration uncertainty requirement.

The user should consult the meter manufacturer on the expected standard deviation of the meter's shedding cycles. In general, the standard deviation will be independent of flowing velocity.

9.2 Mean *K*-Factor Calculation

The meter is generally calibrated at a number of flow rates. A *K* factor for each flow rate is calculated. From these, the mean *K* factor is calculated as follows:

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

where

K_{max} = the maximum *K* factor over a designated range

K_{min} = the minimum *K* factor over the same range

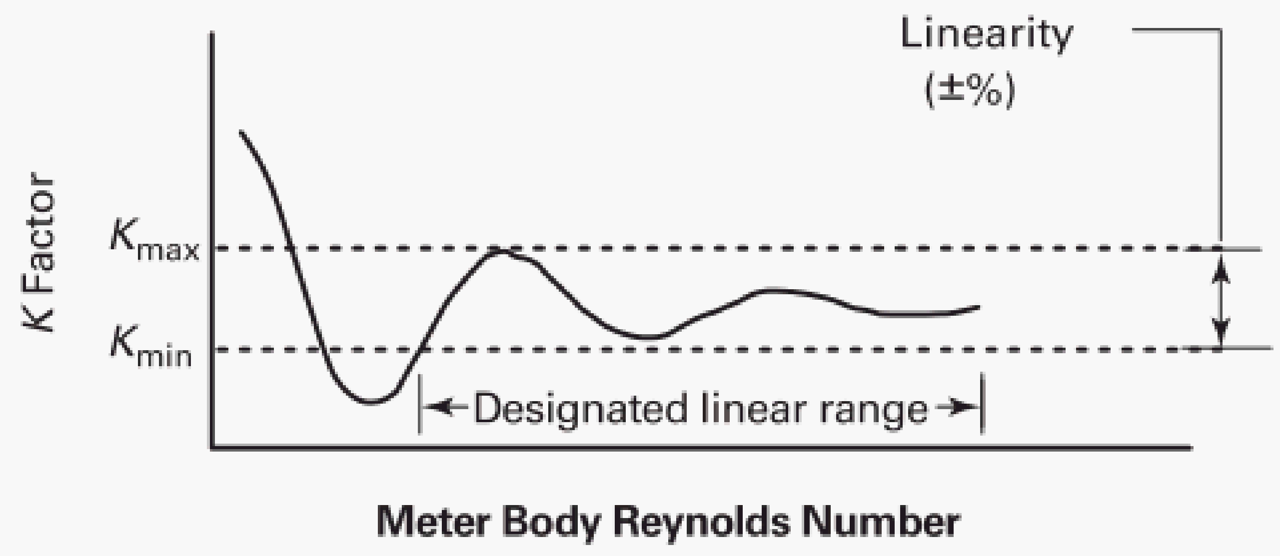
Figure 9.2-1 shows a *K*-factor curve.

Table 9.1-1 Number of Pulses Needed to Achieve a Given Calibration Uncertainty

Standard Uncertainty of Mean to 95%	Flowmeter Standard Deviation of the Shedding Cycle Period [Note (1)]				
	2%	4%	6%	8%	10%
0.10%	1,537	6,147	13,830	24,586	38,416
0.25%	246	983	2,213	3,934	6,147
0.50%	61	246	553	983	1,537

NOTE:
(1) This value is obtained from the manufacturer.

Fig. 9.2-1 Example of a *K*-Factor Curve



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NONMANDATORY APPENDIX A
PERIOD JITTER AND ITS EFFECT ON CALIBRATION

NOTE: Period jitter and the associated frequency jitter are 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 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 Nonmandatory Appendix addresses the calculations one must 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.

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

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

where

n = the number of period measurements
t = Student's t with $n - 1$ degrees of freedom for a 95% confidence level (equal to 2.0 for 30 or more measurements)
δ = error in the average period in percent
σ = $[\Sigma(\tau_i - \tau)^2 / (n-1)]^{0.5}$
τ = $\Sigma \tau_{i/n}$
τ_i = ith period measurement

Once σ has been determined, the number of pulses, N, that must be counted to determine a flow rate to within a preassigned uncertainty of +δ% is given by

$$N = \frac{[(100 \times t \times \sigma)]}{[(\delta \times t)]^2}$$

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.

$$V = N \times k$$

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 meter by the inverse of the diameter cubed, this calculation will more often be required with meters for larger-size lines, where large volumes and longer times will be required to obtain a good calibration.

NONMANDATORY APPENDIX B
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