ASME MFC-6M–1998

MEASUREMENT OF FLUID FLOW IN PIPES USING VORTEX FLOWMETERS

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The American Society of Mechanical Engineers

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A N   A M E R I C A N   N A T I O N A L   S T A N D A R D

MEASUREMENT OF FLUID FLOW IN PIPES USING VORTEX FLOWMETERS

ASME MFC-6M-1998

Date of Issuance: July 4, 1998

This Standard will be revised when the Society approves the issuance of a new edition. There will be no addenda or written interpretations of the requirements of this Standard issued to this edition.

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

FOREWORD

(This Foreword is not a part of ASME MFC-6M-1998.)

This Standard has been prepared by ASME/MFCC/SC16 — Vortex Shedding Flowmeters. 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. Meters 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 document. However, these devices have in common the shedding of alternating pairs of vortices from some obstruction in the meter. The natural laws of physics relate the shedding frequency, f, to the volumetric flowrate, q_v, of the fluid in the conduit. The vortex pairs can be counted over a given period of time to obtain total flow.

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

This Standard was approved by the American National Standards Institute on February 20, 1998.

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Measurement of Fluid Flow in Closed Conduits

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MEASUREMENT OF FLUID FLOW IN PIPES USING VORTEX FLOWMETERS

1 SCOPE

This Standard:

(a) describes vortex shedding flowmeters in which alternating vortices are shed from one or more bluff bodies installed in a closed circular conduit;

(b) describes how the frequency of the vortex pairs is a measure of the fluid velocity; how volume, mass, and standard volume flowrate is determined; and how the total fluid that has flowed through the meter in a specified time interval can be measured;

(c) applies only to fluid flow that is steady or varies only slowly with time, is considered single-phased, and when the closed conduit is full;

(d) provides only generic information on vortex shedding flowmeters, including a glossary and a set of engineering equations useful in specifying performance;

(e) describes the physical components of vortex shedding flowmeters and identifies the need for inspection, certification, and material traceability;

(f) addresses phenomena that may negatively affect vortex detection, as well as shift the K factor, and describes guidelines for reducing or eliminating their influences; and

(g) provides calibration guidance.

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
ASME MFC-2M, Measurement Uncertainty for Fluid Flow in Closed Conduits
ASME MFC-7M, Measurement of Gas Flow by Means of Critical Flow Venturi Nozzles
ASME MFC-9M, Measurement of Liquid Flow in Closed Conduits by Weighing Method
ASME MFC-10M, Method for Establishing Installation Effects on Flowmeters
Publisher: The American Society of Mechanical Engineers (ASME), Three Park Avenue, New York, NY 10016-5990

ISO 4006, Measurement of Fluid Flow in Closed Conduits — Vocabulary and Symbols
ISO 4185, Measurement of Fluid Flow in Closed Conduits — Weighing Method
ISO 5168, Measurement of Fluid Flow — Evaluation of Uncertainty
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 8316, Measurement of Liquid Flow in Closed Conduits — Method by Collection of the Liquid in a Volumetric Tank
ISO DIS 9368, Installations for Flowrate Measurement by the Weighing Method — Test Methods — Part 1: Static Weighing Systems
ISO TR 12764, Measurement of Fluid Flow in Closed Conduits — Flowrate Measurement by Means of Vortex Shedding Flowmeters Inserted in Circular Cross-Section Conduits Running Full
ISO DTR 12765, Measurement of Fluid Flow in Closed Conduits — Flowrate Measurement by Means of Ultrasonic Flowmeters
Publisher: International Organization for Standardization (ISO), 1 rue de Varembé, Case postale 56, CH-1211 Genevé 20, Switzerland

IEC PUB 359, Expressions of the Functional Performance of Electronic Measuring Equipment
IEC PUB 381-1 d.c., Current Transmission
IEC PUB 381-2 d.c., Voltage Transmission
IEC PUB 529, Ingress Protection Classification and Testing Procedures
Publisher: International Electrotechnical Commission (IEC), 3 rue de Varembé, Case postale 131, CH-1211 Genevé 20, Switzerland

3 DEFINITIONS (See Table 1 for Symbols)

For the purposes of this Standard, the following definitions are particularly useful in describing the

TABLE 1
SYMBOLS

Symbol	Quantity	Dimensions	SI Units
a	Averaging Time	T	s
D	Diameter of meter bore	L	m
A	Cross-sectional area of meter bore	L^2	
f	Frequency of vortex shedding	T^{-1}	Hz
d	Width of bluff body normal to the flow	L	m
K	K factor	L^{-3}	m^{-3}
N	Number of vortex pulses	dimensionless	
q_v	Volume flowrate	$L^3 T^{-1}$	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 vapor pressure at the flowing temperature	$ML^{-1} T^{-2}$	Pa

GENERAL NOTES:

(a) Fundamental dimensions: M = mass, L = length, T = time, θ = temperature

(b) Subscript:

- b = base conditions
- $flow$ = flowing fluid conditions
- D = unobstructed diameter of meter bore, see above
- m = mass unit
- O = 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 ith measurement
- d_{min} = minimum downstrean value

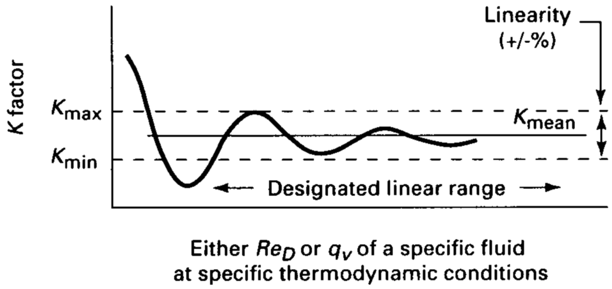

FIG. 1 EXAMPLE OF A *K* FACTOR CURVE

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. ISO 7066-1 and ISO 7066-2 provide additional definitions, statistical techniques, and analytical concepts pertaining to measurement uncertainty.

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: the *K* factor, in pulses per unit volume, is 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 of the flowrate of a specific fluid at a specific set of thermodynamic conditions (see Fig. 1).

In practice, the *K* factor that is commonly used is the mean *K* factor, which is defined by:

$$K_{mean} = \frac{K_{\max} + K_{\min}}{2} \quad (1)$$

where

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

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

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. 1). In equation form it is defined as:

$$\%\ Linearity = \frac{K_{\max} - K_{\min}}{2 \times K_{mean}} \times 100 \quad (2)$$

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

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

$$Re_D = \frac{DU\rho}{\mu} \quad (3)$$

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

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

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.

random uncertainty: 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 flowrates or Reynolds number in the range over which the meter meets a specified uncertainty (accuracy).

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

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

$$St = \frac{f \times d}{U} \quad (4)$$

In practice the *K* factor, which is not dimensionless,

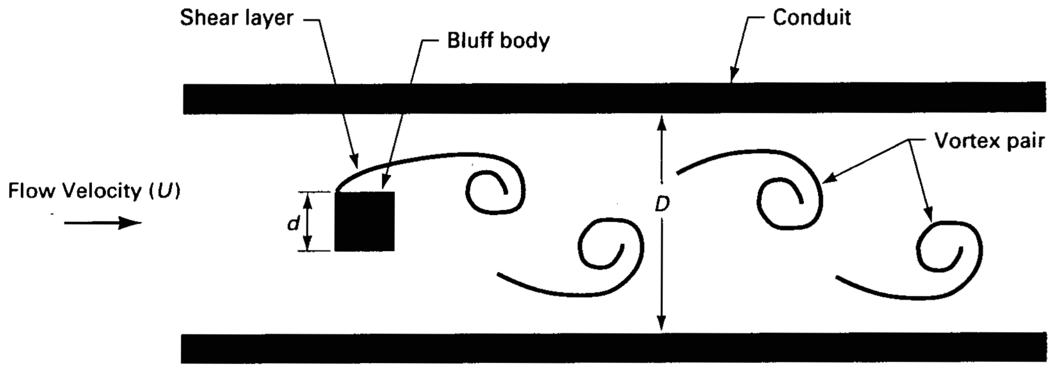

FIG. 2 VORTEX FORMATION

replaces the Strouhal number as the significant parameter.

systematic error: a 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.

systematic uncertainty: a component of uncertainty associated with a systematic error. Its effect cannot be reduced by taking many measurements.

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

Note: Uncertainty is also referred to as accuracy.

4 PRINCIPLE OF MEASUREMENT

If 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 street (see Fig. 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.

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

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

$$U = \frac{f \times d}{St} \tag{5}$$

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 vortex pairs are being shed; i.e., the vortex pulse rate,

$$U = \xi \times f \tag{6}$$

where ξ is a constant equal to $d/_{St}$, and the volumetric flowrate at flowing conditions, i.e., the volume flowrate, is given by:

$$q_v = A \times U = \left[\frac{(A \times d)}{St}\right] \times f \tag{7}$$

The K Factor for a vortex shedding flowmeter is related to the Strouhal number by:

$$K = \frac{St}{(A \times d)} = \frac{f}{q_v} \tag{8}$$

Hence,

$$q_v = \frac{f}{K} \tag{9}$$

When the density at flowing temperature and pressure is known, the mass flowrate (see Eq. 10) and the volumetric flowrate at base conditions, i.e., standard volume flowrate (see Eq. 11), can be determined.

$$q_m = \rho_f \times \frac{f}{K} \tag{10}$$

$$q_v = \left(\frac{\rho_f}{\rho_b}\right) \times \frac{f}{K} \tag{11}$$

Assume that the flowrate can be considered constant over the time it takes a vortex pair to shed, i.e., over one cycle of period τ. In this case, the amount of fluid volume that flows through the meter during one cycle is:

$$q_v \times \tau = \frac{f \times \tau}{K} = \frac{1}{K} \tag{12}$$

Since K is a constant independent of the flowrate and, hence, frequency, the total flow over N cycles is:

$$Q_v = \frac{N}{K} \tag{13}$$

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

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

$$Q_m = \rho_{flow} \times \frac{N}{K} \tag{14}$$

and

$$Q_v = \left(\frac{\rho_{flow}}{\rho_b}\right) \times \frac{N}{K}$$

5 FLOWMETER DESCRIPTION

5.1 Physical Components

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

5.1.1 Flowtube. The flowtube is made up of the meter body, the bluff body(s), 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 2 shows it as a square cross-section bluff body, but this 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. The transmitter converts sensed signals to one or more of the following:

(a) a digital flowrate readout;
(b) a digital total flow readout;
(c) a pulse or scaled pulse signal; or
(d) a current proportional to flowrate.

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 flowrate falls between the maximum and minimum flowrates within the required uncertainty.

6.1.1 Maximum Flow. The maximum flow for a vortex meter is usually limited by the structural integrity of the device. These limits vary by manufacturer.

Pressure loss increases with flowrate but is usually not the limiting factor in sizing a vortex flowmeter, except possibly in low pressure applications. However, pressure loss resulting from the flowmeter and the associated connections must be considered in system design.

6.1.2 Minimum Flow. The minimum volumetric flowrate depends on the Reynolds number (see Fig. 1). If used outside the stated Reynolds number range, the manufacturer should be consulted for details regarding correction procedures and the expected magnitude of the measurement uncertainty.

The minimum volumetric flowrate may also be limited by the sensor(s). As the volumetric flowrate is reduced below a certain value for a given fluid density, the vortex shedding weakens to the point at which the sensor can no longer distinguish between the vortex signal and noise due to flow or vibration. To handle this situation, many designs may employ a low flow cutoff point where the meter output is automatically set to zero regardless of whether there is flow in the pipe or not.

6.2 Process Influences

6.2.1 Temperature and Pressure

6.2.1.1 Affect on Uncertainty. Measurement accuracy is directly related to K factor uncertainty. Process temperatures that differ significantly from those during calibration can affect the geometry of the flowtube, and hence, affect 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:

$$K = K_0 \times [1 - 3\alpha \times (T_f - T_0)] \tag{15}$$

When the bluff body and the meter body are made of different materials, the change in K factor for a given change in temperature is estimated by:

$$K = K_0 \times [1 - (2\alpha_1 + \alpha_2) \times (T_f - T_0)] \tag{16}$$

where

α_1 = the thermal expansion coefficient of the meter body material

α_2 = the thermal expansion coefficient of the bluff body material

Process pressure effects on the K factor are generally negligible.

The manufacturer should be consulted for information and relevant correction procedures regarding a specific flowmeter.

6.2.1.2 Affect on Range. The range of a vortex meter depends in general on the following parameters: the K factor, fluid density, and Reynolds number. The K factor, as described in para. 6.2.1.1, depends from a practical viewpoint 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.

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

6.2.3 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 and/or cavitation is beyond the scope of this Standard.

Note: Flashing and cavitation can lead to measurement errors and/or structural damage.

To avoid flashing and cavitation, the downstream pressure after recovery must be equal to or greater than P_{dmin} as given by:

$$P_{dmin} = c_1 \times \Delta P + c_2 \times P_{vap} \tag{17}$$

where

P_{dmin} = minimum allowable downstream pressure after recovery

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

ΔP = overall pressure drop

c_1, c_2 = empirical constants for each design and size

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

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 (NDE), etc. are the responsibility of the user.

6.3.2 Electrical. The watertightness and hazardous area certification shall be suitable for the intended location. See IEC PUB 529 (Ingress Protection).

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. The following are some of the factors to be considered.

7.1 Adjacent Piping

A vortex meter is sensitive to distorted or undeveloped velocity profiles and swirl caused by changes in pipe size or schedule and flow through pipe fittings, valves, and other process 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 must be mounted concentric with the pipe according to the manufacturer's recommendations.

(c) Gaskets must 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, 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 known correction factors, an appropriate flow conditioner or acceptance of higher uncertainties. The meter manufacturer should be consulted regarding the use of flow conditioners. This includes the type of flow conditioner, its sizing and its location relative to the flowmeter.

(g) The location of additional process measurements, such as pressure, temperature, or density, may impact the performance of a vortex flowmeter. The flowmeter manufacturer's literature should be consulted for recommendations.

(h) In order to satisfy the minimum measureable 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 and/or uncertainty must be made.

(i) In some applications it may be desirable to periodically inspect and/or clean the flowmeter. If a bypass is installed to facilitate this, the fittings must 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.

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 upwards.

7.3 Flowmeter Location

The flowmeter shall be properly supported to reduce any effects of vibration and pipe stress.

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.

7.4 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 flowmeter 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 startup procedures should be followed to avoid damage to the bluff body(s) or sensor(s) by overrange, water hammer, etc.

9 *K* FACTOR DETERMINATION

The meter manufacturer shall supply the meter's mean K factor and the expected uncertainty under stated reference conditions and provide a certificate of calibration on request. The following considerations apply:

(a) The mean *K* factor is usually established by flow calibrations with a suitable fluid. It is possible, but at reduced accuracy, to derive the factor from dimensional measurements. The method employed must be stated.

(b) Where possible, measurement uncertainty can be improved by in situ calibration.

(c) 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.

(d) The *K* factor depends upon geometric changes in the meter body produced by temperature and pressure on the meter material (see para. 6.2).

APPENDIX A — PERIOD JITTER AND ITS EFFECT ON CALIBRATION

(This Appendix is not a part of ASME MFC-6M–1998 and is included for information purposes only.)

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 time (i.e., period) between vortices to vary in a manner called "period jitter."

Note: Period jitter and the associated frequency jitter is of no concern for most applications.

There are several influences that affect 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 principle of vortex shedding.

Regarding period jitter,[1] 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:

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

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

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 $\pm$ δ%, is given by:

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

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

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

or equivalently

$$a = \frac{N}{K \times q_v}$$

where

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

[1] 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 that it causes concern about these phenomena.

K = mean K factor
q_v = volumetric flowrate
a = averaging time

It can therefore be seen that if St does not vary with flowrate (not necessarily a good assumption), the averaging 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:

$$\frac{100 \times \sigma}{\tau} = 1.5\%$$

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:

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

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

TABLE A-1
TIME, *a*, NEEDED FOR A FLOWRATE UNCERTAINTY OF 0.25%

Flow Velocity, m/s	Meter Size	
	D = 25 mm	D = 145 mm
0.31	13.0	76.0
3.1	1.3	7.6
6.35	0.51	3.0
63.5	0.051	0.30

GENERAL NOTE: a = sec

$$a = \frac{\left(\frac{2}{0.25} \times 1.5\right)^2 \times d}{0.24 \times U} = 600 \times \frac{d}{U} = 160 \times \frac{D}{U}$$

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

Thus, the averaging time 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 $100 \times \sigma/\tau = 3\%$, the times in the above table must be multiplied by 4.

The manufacturer should be consulted for details regarding the effect of this phenomena on his/her meter.

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ISBN 0-7918-2524-8
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K11798