Vortex Shedding Flowmeter for Measurement of Hydrocarbon Fluids

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Vortex Shedding Flowmeter for Measurement of Hydrocarbon Fluids

1 Introduction

This document describes the design, installation and operation of vortex shedding flowmeters for the measurement of fluid flows, especially hydrocarbon flow measurement. It is being issued initially as a draft standard in order for the industry to obtain more experience with the technology, as well as to determine where this technology may best be applied within the industry. It will have a term of 3 years, at which time it will either be dropped or considered as a standard in *MPMS*. One particular area where additional experience is needed prior to converting this to a custody transfer standard is in the area of proving. However, this document may provide guidance for non-custody applications where the technology provides benefit.

Vortex shedding flowmeters are inferential meters that derive flow rate by measuring the shedding frequency of vortices which are with a few exceptions proportional to flow rate. The vortices which are sensed electronically are generated by placing a bluff body in the fluid path. Numerical computational techniques are then used to compute the fluid velocity and flow rate at line conditions.

Vortex shedding flowmeters may be utilized to measure the flow rate of liquids, gases and steam.

2 Scope

This document:

a. provides information on vortex shedding flowmeters, operation and terminology;
b. provides sets of engineering equations useful in specifying performance;
c. describes how the vortex shedding frequency is used to determine the velocity in order to infer the volume, mass, and energy flow rate and how the total fluid flow through the meter over a specific time interval can be measured;
d. describes the physical components of vortex shedding flowmeters and identifies need for inspection, certification, and material traceability;
e. provides guidance on application and installation design;
f. addresses the effect of fluid properties, installation, and process conditions that may affect vortex shedding accuracy, and describes guidelines for reducing or eliminating their influences;
g. defines the method for calculating uncertainty of the flow rate measurement;
h. defines the meter output requirements and necessary information pertaining to the meter output for the purpose of fiscal measurement of hydrocarbon fluids; and
i. provides calibration and/or performance verification guidance.

3 Field of Application

This document applies to:

a. single phase Newtonian fluids including steam and most hydrocarbon liquids and gases running full in a closed conduit; and
b. fluid flows that are steady or that vary slowly in time.

3.1 GENERAL CHARACTERISTICS OF THE VORTEX FLOW MEASUREMENT TECHNOLOGY

- The vortex flowmeter is a field-proven technology with many installed meters operating worldwide. It is applicable to single phase fluids (i.e., liquids or gases including dry steam). The response of the primary element is linearly proportional to the actual volumetric flow rate through the device. Vortex shedding is primarily considered a flowmeter for "clean" fluids. Details of the meter sizing, selection, and application are presented in Sections (7, 8 and 9) of this document.
- Vortex shedding flowmeters are available in sizes $^1/_2$ in. – 16 in., depending on manufacturer. However, application and proving considerations may limit applicable sizes (see Section 6).
- The shedding frequency of the vortex flowmeter is independent of changes in viscosity or density of the flowing fluid within specified limits.
- The volumetric K factor may be utilized to infer mass flow rate or volume flow rate at base or standard conditions using applicable compensation methods or computed from known fluid properties.
- Vortex meters have no moving parts and the primary element, the vortex shedder, is not easily damaged during brief periods of mixed phase flow.

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- The vortex flowmeter can produce an analog or digital output and/or a scaled pulse output. The dual output capability allows independent signal for process control and direct pulse counting for flow totalization.

4 Definition, Symbols, and Variables

4.1 DEFINITIONS

The following definitions are useful in describing the characteristics of vortex shedding flowmeters.

4.1.1 accuracy: The ability of a measuring instrument to indicate values closely approximating the true value of the quantity measured.

4.1.2 cavitation: The implosion of vapor bubbles formed after flashing when the local pressure rises above the vapor pressure of the liquid. See also **flashing** (4.1.4).

4.1.3 fade or pulse drop-off: Under certain flowing conditions (i.e., below the minimum Reynolds number), vortex meters fail to shed or will shed vortices of insufficient strength to be detected by the meter electronics a phenomenon referred to as fade. The likelihood of this phenomenon occurring may be reduced through proper sizing and installation. The sensitivity varies with design of the detectors or struts/shedder, piping configuration, and other installation features. The meter manufacturer should be consulted for specific recommendations.

4.1.4 flashing: The formation of vapor bubbles in a flowing liquid when the local pressure falls to or below the vapor pressure of the liquid, often due to local lowering of pressure, often because of an increase in the liquid velocity. See also **cavitation** (4.1.2).

4.1.5 frequency output or output in the form of frequency varies as a function of the applied measurand (e.g., angular speed, flow rate, etc.). In the case of a vortex meter, the rate in which vortices are generated off the shedder bar is sometimes referred to as raw frequency. Many designs offer manufactured pulses that are derived from the raw frequency but may be either higher or lower in value. In the case of raw and manufactured pulses, the frequency is directly proportional to the flow rate.

4.1.6 K factor is the ratio of the meter output in number of pulses to the corresponding volume of fluid passing through the meter. The variations in the K factor may be presented as a function of either pipe Reynolds number or flow rate (see Figure 4.1). The mean K factor is commonly used and is defined by:

$$K_{mean} = \frac{K_{max} + K_{min}}{2} \qquad \text{Equation 4.1}$$

where

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

K_{min} = minimum K factor over the specified linear range

The K factor may change with pressure and thermal effects on the body of the meter (see Section 8). The manufacturer of the meter should be consulted regarding changes in K factor, if any, that occur between liquid and gas, or between one pipe schedule (inside pipe diameter) and another.

4.1.7 laminar flow: A smooth flow of fluid in which no mixing occurs between adjacent stream lines.

4.1.8 linearity: The ideal accuracy curve of a volume meter is a straight line denoting a constant K factor. Meter linearity is expressed as the total range of deviation of the accuracy curve from such a straight line between the minimum and maximum recommended flow rates. The linearity of the meter is often defined as:

$$\text{Linearity} = \pm\frac{K_{max} - K_{min}}{K_{max} + K_{min}} \text{ (refer to Figure 4.1)} \qquad \text{Equation 4.2}$$

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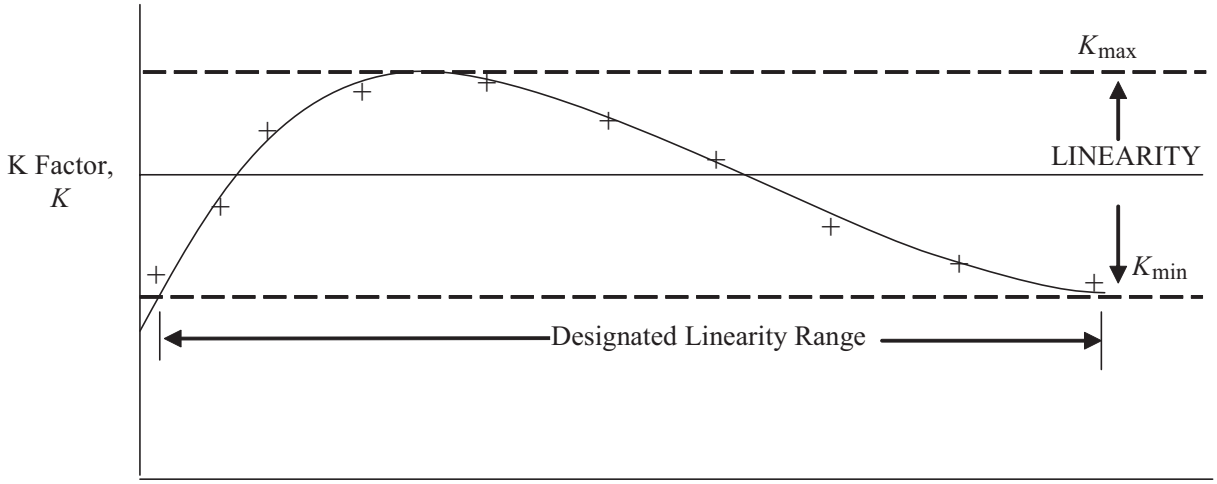


Figure 4.1—Typical Shape of a K Factor Curve

4.1.9 minimum response time: In the case of a pulse train type meter, response to a change in flow rate is a function of system design more than of the pulse-generating phenomenon, because the shedding frequency is typically given by:

$$\frac{f}{U} = \frac{\text{constant}}{d} \qquad \text{Equation 4.3}$$

Refer to the manufacturer for the constant for the particular meter. As the meter bore increases, the frequency reduces. Recovery from a flow velocity change will then generally be slower for larger pipes. The user should determine the minimum designed count rate for the process to achieve a desired resolution.

4.1.10 permanent pressure loss of the meter: The differential pressure between the inlet and downstream location of the meter after the pressure recovery. The pressure drop is a function of velocity through the meter, meter inside diameter and flowing fluid properties such as density and viscosity.

4.1.11 primary element: The portion of a flowmeter element that responds to the change in the variable that is being monitored. For a vortex meter, the primary element is the shedder bar in the flow tube.

4.1.12 rangeability: The capability of a meter or flow measuring device to operate between the minimum and maximum flow range within an acceptable tolerance. Rangeability is generally expressed as ratio of a maximum flow to the minimum flow.

4.1.13 repeatability: (a) For flowmetering—The range of results between successive measurements of the same quantity using a single measurement device over a short period of time. More specifically, the ability of a meter and prover system to repeat its registered volume during a series of consecutive proving runs under the same operating conditions. (b) Laboratory Test Method—The difference between successive test results obtained by the same operator, with the same apparatus, under certain operating conditions, on identical test material using the same test method.

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4.1.14 Reynolds number (*Re*): The ratio of inertial forces to viscous forces; a measure of turbulence. A parameter that correlates the actual flow profile with the fully developed flow profile established under steady flow of a homogeneous, Newtonian fluid. It is a dimensionless number defined as follows:

$$Re_D = \frac{U \cdot \rho \cdot D}{\mu} \qquad \text{Equation 4.4}$$

where, in compatible units

D = unobstructed bore diameter (m or ft)

U = average velocity of fluid in unobstructed meter bore (m/s or ft/sec)

ρ = fluid density (kg/m^3 or lb$_m$/ft^3)

μ = absolute (dynamic) viscosity of the fluid (kg/m/s or lb$_m$/ft/sec)

4.1.15 secondary element: The secondary instrumentation or/and transducer (sensor) that responds to the vortices shed by the primary element and conditions the signal for meter output.

4.1.16 Strouhal number (*St*): The Strouhal number is a dimensionless parameter that relates the measured vortex shedding frequency to the fluid velocity and the bluff body characteristic dimension and is given by:

$$St = \frac{f \cdot d}{U} \qquad \text{Equation 4.5}$$

where

f = vortex shedding frequency (1/s or 1/sec)

d = characteristic length scale of the bluff body, typically strut width (m or ft)

U = average velocity of fluid in unobstructed meter bore (m/s or ft/sec)

In this standard, Strouhal number is a dimensional parameter that is relevant to the separated flow past bluff bodies. It is the ratio between the vortex interval (i.e., space between successive vortices) and the shedder bar width. The vortex interval is a function of the width and shape of the shedder bar shape. In practice, the K factor replaces the Strouhal number as the significant parameter.

4.1.17 swirl: A qualitative term describing tangential motions of fluid flow in a pipe, tube, or tank.

4.1.18 systematic uncertainty: The uncertainty associated with systematic errors, those that cannot be reduced by increasing the number of measurements. Figure 4.1 shows a systematic error that may be different for each design of vortex flowmeters but, for each design, knowing the curve presents one possibility of correcting for it in the meter or associated equipment and thereby improving the overall accuracy. The uncertainty of the points on the curve must be considered as random errors.

4.1.19 transition flow: Characterized by Reynolds numbers between 2,300 and 4,000 and the flow intermittently change from laminar to turbulent flow characteristics and vice se versa.

4.1.20 turbulent flow: In turbulent flow, random flow patterns are superimposed upon the general flow progressing in a given direction. The transition from smooth uniform laminar flow to turbulent flow generally occurs as the Reynolds number increases from about 4,000 and higher.

4.1.21 wet gas flows: A predominate gas flow where particles of free liquid are transported generally as an aerosol mist.

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4.2 SYMBOLS

Table 1—Symbols and Dimensions

Symbol	Description	Dimensions (Note [1])	SI (Metric) Units	U.S. Customary Units
a	Response time	T	s	sec
c_1 & c_2	Empirical constant	dimensionless		
D	Unobstructed diameter of meter bore, thus, the effective inside pipe diameter	L	m	ft
d	Width of strut, normal to the flow	L	m	ft
f	Frequency	T^{-1}	Pulses/s	Pulses/sec
K	K factor	L^{-3}	Pulses/m^3	Pulses/ft^3
N or n	Number of pulses	dimensionless		
P	Pressure	$ML^{-1}T^{-2}$	Pa	$lb_f/in.^2$
P_{min}	Minimum upstream pressure	$ML^{-1}T^{-2}$	Pa	$lb_f/in.^2$
P_{d-min}	Minimum downstream pressure	$ML^{-1}T^{-2}$	Pa	$lb_f/in.^2$
$\triangle P$	Unrecoverable pressure drop	$ML^{-1}T^{-2}$	Pa	$lb_f/in.^2$
P_{vap}	Liquid vapor pressure at the flowing temperature	$ML^{-1}T^{-2}$	Pa	$lb_f/in.^2$
Q	Totalized flow	L^3 or M	m^3 or kg	ft^3 or lb_m
Q_m	Totalized mass flow	M	kg	lb_m
Q_v	Totalized volume flow	L^3	m^3	ft^3
q	Flow rate [volume or mass]	L^3T^{-1}, MT^{-1}	m^3/s, kg/s	ft^3/sec, lb_m/sec
q_m	Mass flow rate	MT^{-1}	kg/s	lb_m/sec
q_v	Volume flow rate	L^3T^{-1}	m^3/s	ft^3/sec
Re_D	Pipe Reynolds number	dimensionless		
St	Strouhal number	dimensionless		
T or θ	Temperature	θ	°C	°F
t	Two-tailed Student's t at 95% confidence	dimensionless		
U	Average fluid velocity through meter bore	LT^{-1}	M/s	ft/sec
α	Thermal expansion coefficient of meter material	θ^{-1}	mm/mm/°C	in./in./°F
δ	% error in the average period	dimensionless		
μ	Absolute viscosity (dynamic)	$ML^{-1}T^{-1}$	Pa s or g•cm/sec^2	centipoise or lb_f-sec/ft^2
τ	Average period of vortex shedding	T	s	sec
ρ	Fluid density	ML^{-3}	kg/m^3	lb_m/ft^3
σ	Estimate of standard deviation of the average period	T	s	sec

Note: [1] Fundamental dimensions: M = Mass; L = Length; T = Time; θ = Temperature

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4.3 SUBSCRIPTS

Subscript	Description
b	Base conditions of temperature, pressure, density and gas composition
D	Unobstructed diameter of meter bore, see above
d	Downstream
f	Flowing fluid conditions
i	The i-th measurement
m	Mass units
max	Maximum value
mean	Average of extreme values
min	Minimum value
o	Refers to reference condition
V	Volume units, reference conditions
v	Volume units, flowing conditions

4.4 ABBREVIATIONS

URV—Upper Range Value

URF—Upper Range Frequency

LFCI—Low Flow Cut–in

LFCO—Low Flow Cut-off

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6 System Description

The vortex shedding flowmeter can be described as having two major components, the flow tube and the transmitter. The response of the primary element is linearly proportional to the actual volumetric flow rate through the device.

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