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Vortex meters used in measuring systems for fluids

Compteurs à vortex utilisés dans les ensembles de mesurage de fluides

Organisation Internationale
de Métrologie Légale

International Organization
of Legal Metrology

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Foreword

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VORTEX METERS USED IN MEASURING SYSTEMS FOR FLUIDS

1 Scope

This International Document describes the general metrological characteristics and performances attainable by measuring systems for fluids fitted with vortex meters and specifies the installation and testing conditions which should be fulfilled for these performances to be actually obtained.

Safety matters are not subject to metrological control and are therefore not dealt with in this Document.

2 Terminology

The general terms used in this Document are in accordance with the *International vocabulary of basic and general terms in metrology* (VIM, 1993 edition) and the *Vocabulary of legal metrology* (VML, 1978 edition).

For other terms used in this Document, please refer to ISO/CD12764 *Measurement of fluid flow in closed conduits - Flowrate measurement by means of vortex shedding flowmeters inserted in circular cross section conduits running full.*

2.1 Vortex meter

A vortex meter operates by sensing vortices shed from alternative sides of a bluff body located in the flowing fluid. The frequency of vortex shedding is dependant on the Reynolds number of the fluid.

A vortex meter consists of four basic components as shown in Figure 1.

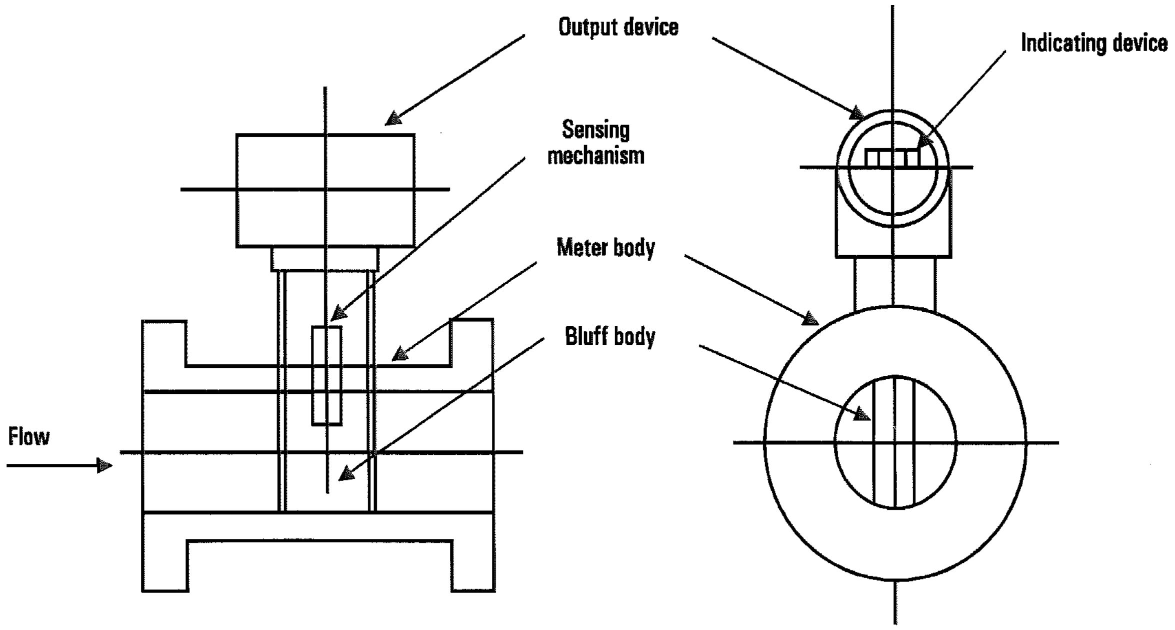

Figure 1 Vortex meter

Typical arrangement of a measuring system fitted with a vortex meter is shown in Figure 2.

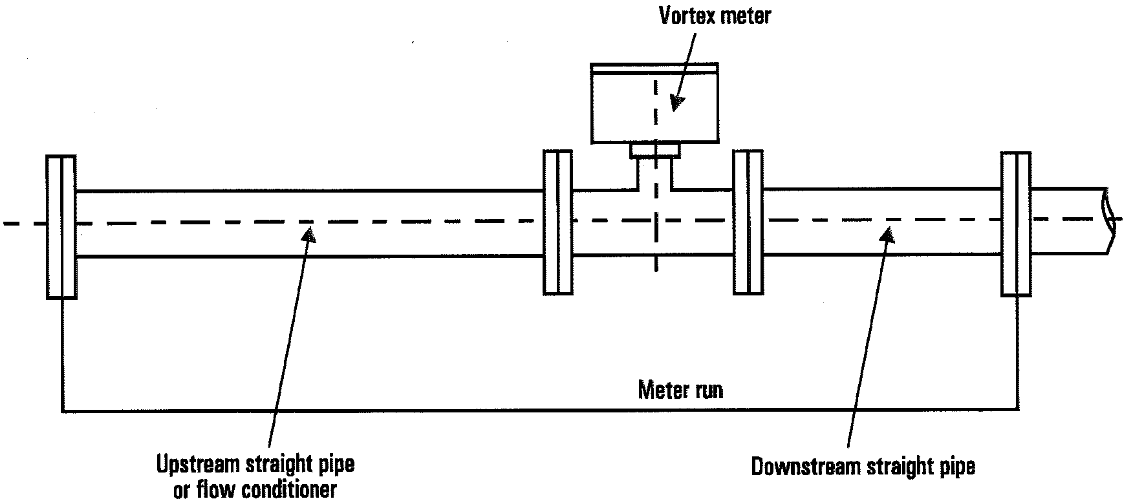

Figure 2 Typical arrangement with a vortex meter

2.2 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 the measuring period.

The variations in the K-factor may be presented as a function of either the pipe Reynolds number or of the flowrate under a specific set of thermodynamic conditions (see Figure 3).

The mean K-factor is commonly used and defined by:

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

where:

K_{max} is the maximum K-factor over a designated linear range, and
K_{min} is the minimum K-factor over the same linear range.

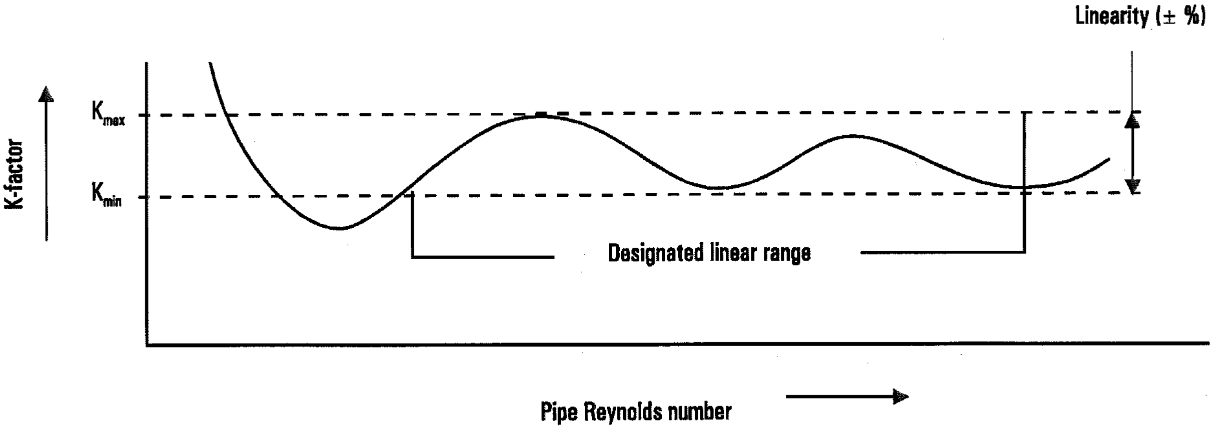

Figure 3 Typical shape of a K-factor curve

The K-factor may change in line with pressure and thermal effects on the body of the meter (see 4.5).

The manufacturer of the meter should be consulted on the difference, if any, of the K-factor between liquid and gas, and between pipe schedules of the adjacent pipe.

Note: The K-factor is the function of the Reynolds number. In this Document all the characteristics are given in relation to the Reynolds number. However, in legal metrology the characteristics are normally given in relation to the flowrate, which can be obtained from the Reynolds number.

2.3 Linearity

Linearity, L, refers to the constancy of the K-factor over a specific range, either defined by the pipe Reynolds number or by the flowrate (see Figure 3).

This linear range is usually specified by a band defined by maximum and minimum K-factors, within which the K-factor is assumed to be equal to K_{mean}.

In equation form, linearity is defined as:

$$L = \pm \frac{K_{max} - K_{min}}{2 \times K_{mean}} \times 100\ \%$$

The upper and lower limits of this range can be specified by the manufacturer either as a maximum and minimum Reynolds number range or as a flowrate range of a specified fluid and other meter design limitations such as fluid velocity profile, viscosity, density, pressure, temperature or installation effects (see clause 5).

2.4 Meter accuracy

When a complete meter is tested as one unit the following formula applies:

for the complete meter: $$E_{meter} = \frac{I - V}{V} \times 100\ \%$$

When the test is divided into separate transducer and calculator/indicator tests, the following formulae apply:

for the transducer: $$K_{tran} = \frac{N}{V}$$

for the calculator/indicator: $$K_{calc} = \frac{N}{I}$$

for the meter: $$E_{meter} = \left(\frac{K_{tran}}{K_{calc}} - 1 \right) \times 100\ \%$$

where:

I is the meter reading in terms of volume,
V is the reading of volumetric measure (volume swept through the transducer),
N is the number of factored pulses transmitted from the transducer,
K_{tran} is the calibration constant for the transducer,
K_{calc} is the calibration constant for the calculator/indicator, and
E_{meter} is the error of the meter.

2.5 Rangeability

Flowmeter rangeability is the ratio of the maximum to minimum flowrate or Reynolds number in the range over which the meter is linear as defined in 2.3.

Under certain conditions the meter is, or can be made, usable outside the linear range.

As the Reynolds number decreases below the linear limit, the shedding and detection can become increasingly difficult and eventually the shedding can cease.

2.6 Reynolds number

The pipe Reynolds number is a dimensionless ratio of inertia to viscous forces which is used as a correlating parameter combining the effects of viscosity, density and pipe line velocity. It is defined as:

$$Re = D \times (U/\nu) = D \times U \times (\rho/\mu)$$

where:
D is the meter bore size,
U is the average fluid velocity in the meter,
ν is the kinematic viscosity,
ρ is the fluid density, and
μ is the absolute (dynamic) viscosity.

2.7 Strouhal number

The Strouhal number is a dimensionless parameter that is relevant to the separated flow past the bluff body(ies). It relates the measured vortex shedding frequency to the fluid velocity and the bluff body characteristic dimension. In practice the K-factor, which is not dimensionless, replaces the Strouhal number as the significant parameter.

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

It is given by:

$$St = f \times (b/U), \text{ or } f = St \times (U/b)$$

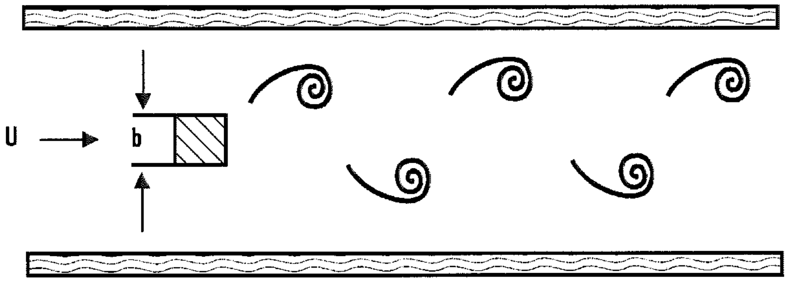

Figure 4 Principle

3 Metrological characteristics

3.1 Attainable accuracy

3.1.1 Accuracy of ± 1 %

A meter accuracy of ± 1 % of indicated value can be achieved under the following conditions:

1) Minimum flowrate is determined with reference to the lower limit of the Reynolds number and to the sensitivity of the sensor to be used.

2) Maximum flowrate is determined in order not to produce excessive differential pressure and cavitation.

3) The meter is appropriately installed under the conditions mentioned in clause 5.

3.1.2 Accuracy of ± 0.5 %

A meter accuracy of ± 0.5 % of indicated value can be achieved under the following additional conditions:

1) The rate between the minimum flowrate and the maximum flowrate is limited within the following range:

   a) 1 to 5 with a constant K-factor, or

   b) 1 to 10 with a temperature compensated K-factor as specified in 4.5, or

   c) 1 to 10 at any constant temperature within the limits specified for the flowrate, or

   d) wider than 1 to 5 in the case of a calculator which can utilize frequency dependant K-factors.

2) The meter is calibrated using a fluid to be actually measured or alternatively a fluid having a similar Reynolds number.

3.2 Minimum measured quantity (MMQ)

In determining the MMQ, the following conditions should be taken into consideration:

1) lower limit of the frequency of generated vortices,
2) lower limit of the Reynolds number,
3) minimum scale interval of the indicating device to be connected,
4) attainable accuracy.

4 Evaluation of the metrological performance of vortex meters

4.1 The K-factor or meter accuracy shall be determined by meter calibration. The meter calibration should be conducted considering the conditions described in 3.1.

4.2 In the calibration rig, the meter to be tested shall be connected with an upstream straight pipe section (with a flow conditioner if needed) and a downstream straight pipe section considering the conditions described in clause 5.

4.3 Calibration should be carried out at at least six flowrates (including the maximum and minimum flowrates) and the number of test runs at each flowrate should be at least three in order to estimate the repeatability. At each flowrate, the K-factor is determined as the mean value of the test runs.

4.4 The volume of each test run should correspond to at least 1000 times the scale interval of the indicating device. It is recommended to take a considerably larger volume than 1000 times the scale interval at each test run, as the frequency of vortex shedding may fluctuate in line with flow noise.

4.5 The K-factor depends on geometric changes in the meter body which are caused by temperature and pressure effects on the meter material.

When the bluff body and the meter body are made of the same material, a typical change to the K-factor due to the temperature effect on the meter and bluff body is estimated by:

$$K = K_0 [1 - 3 \alpha (t_f - t_0)]$$

or, when the bluff body and the meter body materials have different thermal expansion factors, by:

$$K = K_0 [1 - (2 \alpha_1 + \alpha_2) (t_f - t_0)]$$

where:
K_0 is the K-factor obtained at the initial calibration,
t_f is the temperature at the operating condition,
t_0 is the temperature at the initial calibration,
α is the linear thermal expansion coefficient of the meter and bluff bodies material,
α_1 is the linear thermal expansion coefficient of the meter body material,
and
α_2 is the linear thermal expansion coefficient of the bluff body material.

At present, there is no way of estimating the effect of pressure changes on the K-factor. Therefore, it is recommended to determine the K-factor by calibration under the operating pressure. Alternatively, manufacturers should make available test results showing pressure influences of less than 20 % of the rated K-factor accuracy over the pressure range of the meter.

Note: A change in temperature of the fluid may also cause its viscosity and density to change.

5 Installation conditions

Care should be taken to follow the manufacturer's installation instructions. The following are also of note.

5.1 Installation location

The following general precautions should be observed when determining the installation location for the meter:

1) 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.

2) Care must be exercised to observe the manufacturer's specified temperature limits, vibration limits and corrosive atmosphere and humidity limits.
3) A location should be chosen which allows for regular inspection and maintenance as well as piping and wiring.

5.2 Piping

The following factors should be considered when performing piping work for the installation of flowmeters and ancillary devices.

5.2.1 Straight and unobstructed pipe sections of the required length must be installed up- and down-stream of the flowmeter in order to obtain the specified accuracy under operating conditions. Ensure that:

a) the pipes have the same bore diameter and circular cross sections as the flowmeter;

b) the flowmeter is mounted concentric with the pipes;

c) gaskets do not protrude inside the pipe.

5.2.2 Avoid untolerated flow distortion and pulsating flow due to incorrectly installed ancillary devices.

a) Shut off and control valves shall be installed down-stream of the outlet pipe.

b) Bypass piping tees shall be installed ahead of and beyond the recommended inlet and outlet pipe section.

5.2.3 The required straight length of the inlet pipe can be reduced by an appropriate flow conditioner.

5.2.4 In the event that entrained gas bubbles are present in the liquid flow and/or dirty fluids, a gas separator and/or a strainer shall be installed up-stream of the inlet pipe.

5.2.5 The meter shall be protected from excessive piping stress.

Note: The straight pipe lengths differ depending on the nature of the up- and down-stream disturbances and on flowmeter construction. Therefore the manufacturer should be consulted for recommendation.

5.3 Flow 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 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 size and its location relative to the meter.

6 Application notes (advantage and disadvantage)

6.1 The fluid pressure at the lowest point must be high enough to avoid flashing or cavitation, and the fluid must not be gas/liquid multi-phase, e.g. wet steam.

6.2 The manufacturer should be consulted for recommendations to avoid flashing and cavitation. These recommendations may be in the form of equations which include the vapor pressure for the fluid being measured and the lowest local pressure in the flowmeter. They may include recommendations to increase the back pressure by a down-stream valve.

6.3 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 wish to perform an in-situ calibration or contact for known effects. Flow conditioners can also be used to correct this condition (see 5.3).

6.4 The fluid stream should be steady (without pulsating flowrate or pressure).

6.5 The fluid temperature and the ambient temperature must be within the limits specified for the flowmeter.

6.6 The watertightness and hazardous area certification should be suitable for the intended installation.

6.7 If relying on intrinsic safety the entire circuit must be considered.

6.8 To ensure the fidelity and security of the vortex meter output pulse signal, ISO 6551 should be referred to.

Note: Examples have been reported in: *Twin detection system in an output device* and *System with two meters constantly compared in the computer*, OIML Bulletin N° 107, June 1987.

ANNEX A
(Informative)

EXPERIMENTAL DATA

According to vortex meter experiments carried out in Japan, the relation between the Strouhal number and the Reynolds number for a meter was established as shown in Figure 5.

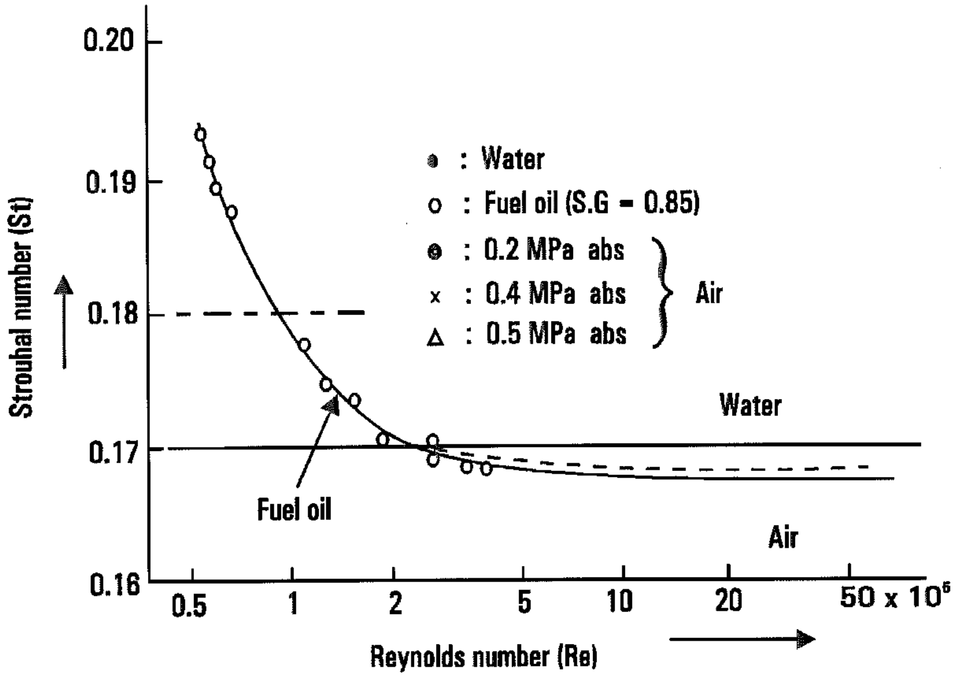

Figure 5 Relation between Strouhal number and Reynolds number for a vortex meter

Taking the linearity range of the Strouhal number in Figure 5, the K-factor of the vortex meter was calibrated using the Reynolds number ranged from 2×10^4 to 2.8×10^6, of which the viscosity range is between 0.5 mPa · s to 15 mPa · s; and as a result, under the flow condition, it was proved that meter accuracy could be determined within ± 1 % of the indicated value and within ± 0.2 % of repeatability as shown in Figure 6.

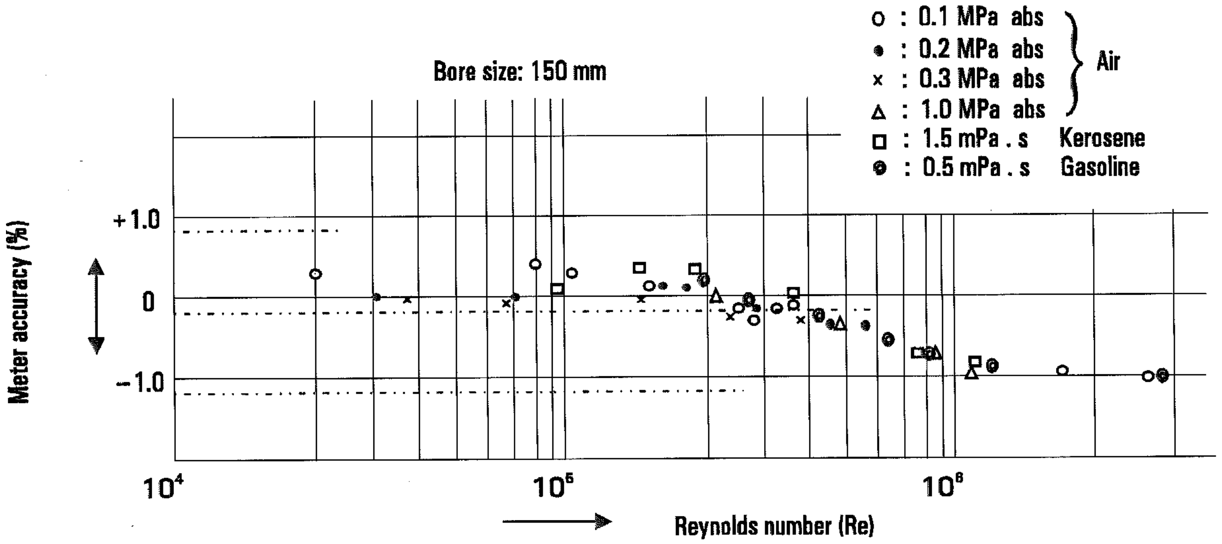

Figure 6 Meter accuracy versus Reynolds number