INTERNATIONAL STANDARD

ISO 5167-5

First edition
2016-03-01

Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full —

Part 5:
Cone meters

Mesure de débit des fluides au moyen d'appareils déprimogènes insérés dans des conduites en charge de section circulaire —

Partie 5: Cônes de mesure

Reference number
ISO 5167-5:2016(E)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 2, *Pressure differential devices*.

The first edition of ISO 5167-5 is complementary to ISO 5167-1, ISO 5167-2, ISO 5167-3, and ISO 5167-4.

ISO 5167 consists of the following parts, under the general title *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full*:

— *Part 1: General principles and requirements*

— *Part 2: Orifice plates*

— *Part 3: Nozzles and Venturi nozzles*

— *Part 4: Venturi tubes*

— *Part 5: Cone meters*

Introduction

This International Standard, divided into five parts, covers the geometry and method of use (installation and operating conditions) of orifice plates, nozzles, Venturi tubes, and cone meters when they are inserted in a conduit running full to determine the flow rate of the fluid in the conduit. It also gives necessary information for calculating the flow rate and its associated uncertainty.

This International Standard is applicable only to pressure differential devices in which the flow remains subsonic throughout the measuring section and where the fluid can be considered as single-phase, but it is not applicable to the measurement of pulsating flow. Furthermore, each of these devices can only be used within specified limits of pipe size and Reynolds number.

This International Standard deals with devices for which direct calibration experiments have been made sufficient in number, spread, and quality to enable coherent systems of application to be based on their results and coefficients to be given with certain predictable limits of uncertainty. However, for cone meters calibrated in accordance with Clause 7, a wider range of pipe size, β, and Reynolds number may be considered.

The devices introduced into the pipe are called “primary devices”. The term primary device also includes the pressure tappings. All other instruments or devices required for the measurement are known as “secondary devices”. This International Standard covers primary devices; secondary devices[1][5] will be mentioned only occasionally.

This International Standard is divided into the following five parts:

a) ISO 5167-1 gives general terms and definitions, symbols, principles, and requirements as well as methods of measurement and uncertainty that are to be used in conjunction with ISO 5167-1, ISO 5167-2, ISO 5167-3, ISO 5167-4, and ISO 5167-5.

b) ISO 5167-2 specifies requirements for orifice plates, which can be used with corner pressure tappings, D and $D/2$ pressure tappings[1], and flange pressure tappings.

c) ISO 5167-3 specifies requirements for ISA 1932 nozzles[2], long radius nozzles, and Venturi nozzles, which differ in shape and in the position of the pressure tappings.

d) ISO 5167-4 specifies requirements for classical Venturi tubes[3].

e) This part of ISO 5167 specifies requirements for cone meters and includes a section on calibration.

Aspects of safety are not dealt with in ISO 5167 (all parts). It is the responsibility of the user to ensure that the system meets applicable safety regulations.

1) Orifice plates with ‘vena contracta’ pressure tappings are not considered in ISO 5167 (all parts).

2) ISA is the abbreviation for the International Federation of the National Standardizing Associations, which was succeeded by ISO in 1946.

3) In the USA, the classical Venturi tube is sometimes called the Herschel Venturi tube.

Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full —

Part 5: Cone meters

1 Scope

This part of ISO 5167 specifies the geometry and method of use (installation and operating conditions) of cone meters when they are inserted in a conduit running full to determine the flow rate of the fluid flowing in the conduit.

As the uncertainty of an uncalibrated cone meter might be too high for a particular application, it might be deemed essential to calibrate the flow meter in accordance with Clause 7.

This part of ISO 5167 also provides background information for calculating the flow rate and is applicable in conjunction with the requirements given in ISO 5167-1.

This part of ISO 5167 is applicable only to cone meters in which the flow remains subsonic throughout the measuring section and where the fluid can be considered as single-phase. Uncalibrated cone meters can only be used within specified limits of pipe size, roughness, β, and Reynolds number. This part of ISO 5167 is not applicable to the measurement of pulsating flow. It does not cover the use of uncalibrated cone meters in pipes sized less than 50 mm or more than 500 mm, or where the pipe Reynolds numbers are below 8×10^4 or greater than $1,2 \times 10^7$.

A cone meter is a primary device which consists of a cone-shaped restriction held concentrically in the centre of the pipe with the nose of the cone upstream. The design of cone meter defined in this part of ISO 5167 has one or more upstream pressure tappings in the wall, and a downstream pressure tapping positioned in the back face of the cone with the connection to a differential pressure transmitter being a hole through the cone to the support bar, and then up through the support bar.

Alternative designs of cone meters are available; however, at the time of writing, there is insufficient data to fully characterize these devices, and therefore, these meters shall be calibrated in accordance with Clause 7.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 5167-1:2003, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4006, ISO 5167-1, and the following apply.

3.1
beta edge
maximum circumference of the cone

4 Principles of the method of measurement and computation

The principle of the method of measurement is based on the installation of the cone meter into a pipeline in which a fluid is running full. Flow through a cone meter produces a differential pressure between the upstream and downstream tappings.

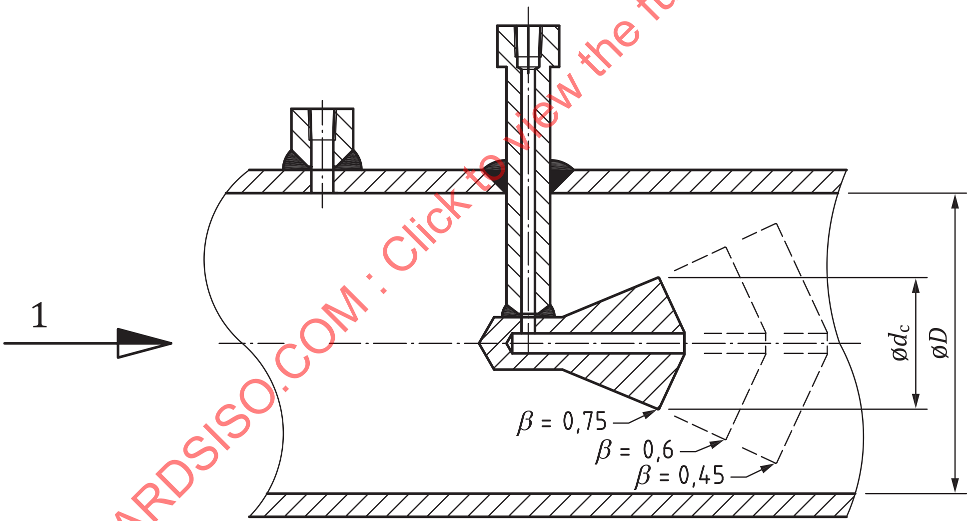
The mass flow rate can be determined by Formulae (1) and (2):

$$q_m = \frac{C}{\sqrt{1-\beta^4}} \varepsilon \frac{\pi}{4} (D\beta)^2 \sqrt{2\Delta p \rho_1} \tag{1}$$

and

$$\beta = \sqrt{1 - \frac{d_c^2}{D^2}} \tag{2}$$

where d_c is the diameter of the cone in the plane of the beta edge. This assumes that the diameter of the pipe at the upstream tapping, D_{TAP}, is equal to the diameter of the pipe at the beta edge, D. Figure 1 shows that as the cone diameter increases, β decreases.



Key
1 flow

Figure 1 — Cone meter showing different values of β

The uncertainty limits can be calculated using the procedure given in ISO 5167-1:2003, Clause 8, except that Formula (3) should be used instead of ISO 5167-1:2003, Formula (3)

$$\frac{\delta q_m}{q_m} = \left[\left(\frac{\delta C}{C}\right)^2 + \left(\frac{\delta \varepsilon}{\varepsilon}\right)^2 + \left(\frac{2(1+\beta^2+\beta^4)}{\beta^2(1+\beta^2)}\right)^2 \left(\frac{\delta D}{D}\right)^2 + \left(\frac{2}{\beta^2(1+\beta^2)}\right)^2 \left(\frac{\delta d_c}{d_c}\right)^2 + \frac{1}{4}\left(\frac{\delta \Delta p}{\Delta p}\right)^2 + \frac{1}{4}\left(\frac{\delta \rho_1}{\rho_1}\right)^2\right]^{1/2} \tag{3}$$

Similarly, the value of the volume flow rate can be calculated since

$$q_V = \frac{q_m}{\rho} \tag{4}$$

where ρ is the fluid density at the temperature and pressure for which the volume is stated.

Computation of the flow rate, which is a purely arithmetic process, is performed by replacing the different items on the right-hand side of Formula (1) by their numerical values. Formula (5) in 5.6 (or the computed values in Table A.1) gives cone meter expansibility factors (ε). The values in Table A.1 are not intended for precise interpolation. Extrapolation is not permitted. However, the coefficient of discharge, C, is generally dependent on the Reynolds number, Re, which is itself dependent on q_m, and has to be obtained by iteration (see ISO 5167-1:2003, Annex A for guidance regarding the choice of iteration procedure and initial estimates).

The diameters, d_c and D, mentioned in Formulae (1) and (2) are the values of the diameters at working conditions. Measurements taken at any other conditions should be corrected for any possible expansion or contraction of the primary device and the pipe due to the values of the temperature and pressure of the fluid during the measurement.

As the cone meter flow rate calculation is particularly sensitive to the pipe and cone diameter values used, the user shall ensure that these are correctly entered into the flow computation calculations. For example, care shall be taken to use the measured internal diameter rather than a nominal value.

It is necessary to know the density and the viscosity of the fluid at working conditions. In the case of a compressible fluid, it is also necessary to know the isentropic exponent of the fluid at working conditions.

NOTE The turndown of all differential pressure flow meters is dependent upon the differential pressure range. Typically, a 10:1 turndown in flow rate (equivalent to 100:1 turndown in differential pressure) can be achieved.

5 Cone meters

5.1 Field of application

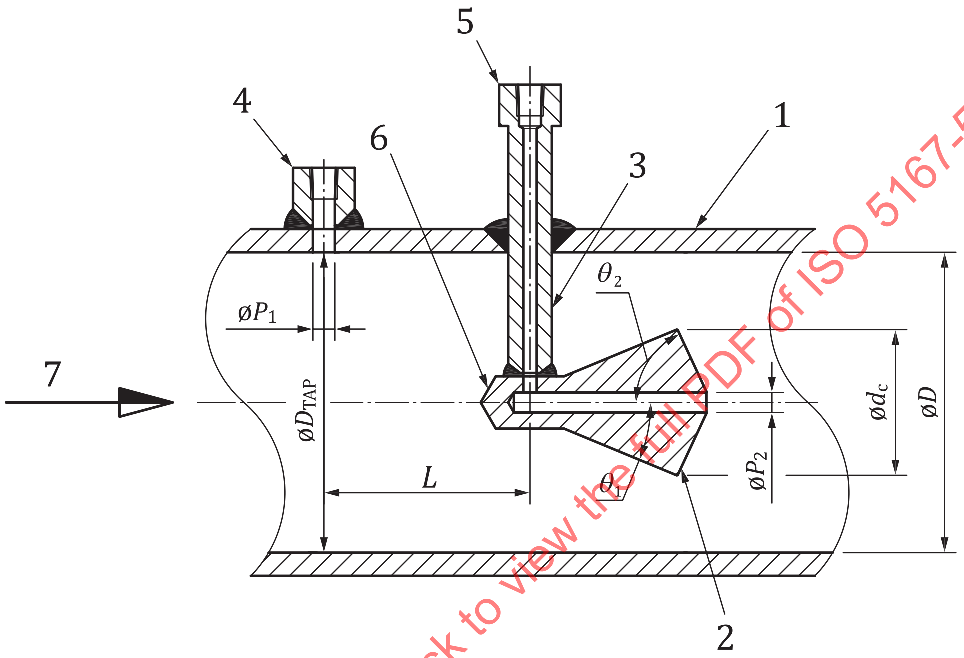
Uncalibrated cone meters can be used in pipes with diameters between 50 mm and 500 mm and with $0{,}45 \leq \beta \leq 0{,}75$. Cone meters with $\beta > 0{,}75$ shall be calibrated. Cone meters with values of $\beta < 0{,}45$ are not normally manufactured.

There are limits to the roughness and Reynolds number which shall be addressed.

5.2 General shape

5.2.1 Figure 2 shows a section through the centreline of a cone meter. Figure 4 shows other sections through the meter to aid in the metrology of the cone meter. The letters used in the text refer to those shown in Figure 2 and Figure 4.

The cone meter is made up of a pipe section of diameter, D, which houses the cone assembly with cone diameter, d_c, the support structure for the cone, and the tappings for differential pressure measurement. The cone assembly is installed such that the cone centreline is concentric to the centreline of the pipe section, as per 5.2.13.



Key

1 flow

2 body pipe

3 cone element

4 support strut

5 high pressure tapping

6 low pressure tapping

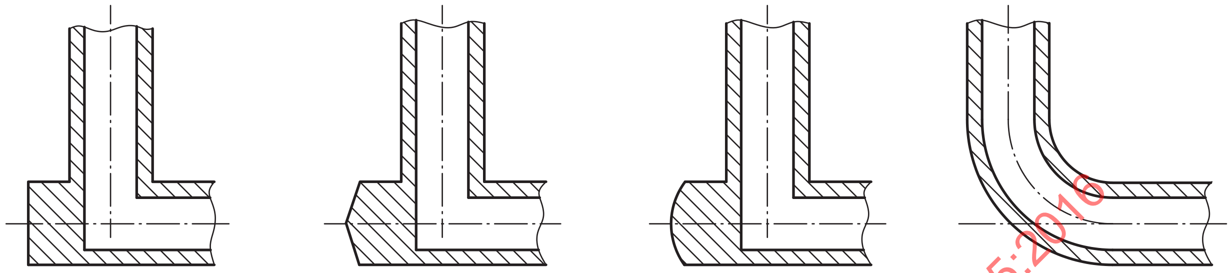
7 cone nose

NOTE 50 mm ≤ L ≤ $2D$, as defined in 5.4.7.

Figure 2 — Geometric profile of cone meter

5.2.2 The design of the nose of the cone (for examples, see Figure 3) can be constructed as a machined component or from an elbow. The nose shall be downstream of the plane of the centreline of the upstream tapping(s). It is recommended that the nose be as short as practicable.

These designs shown in Figure 3 should not be considered exclusive.



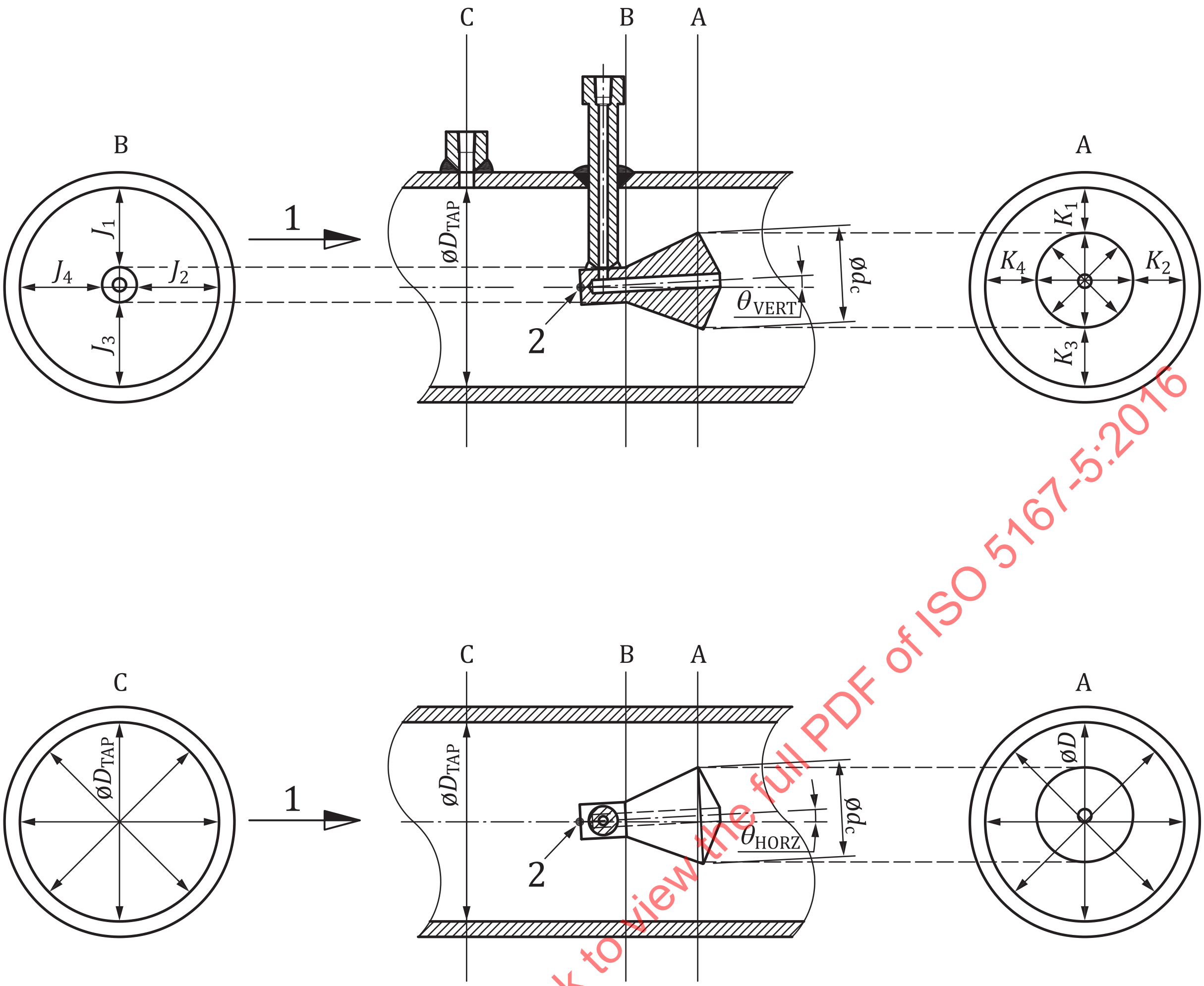
a) Flat b) Pointed c) Curved d) Elbow

Figure 3 — Examples of different cone nose designs

5.2.3 The pipe diameter, D, shall be measured at plane A of Figure 4. The number of measurements shall be a minimum of four equally spaced around the pipe internal circumference. The arithmetic mean value of these measurements shall be taken as the value of D in the calculations.

5.2.4 The pipe diameter shall also be measured at plane C of Figure 4 (shown as D_{TAP} in Figure 2). The number of measurements at this plane shall be at least equal to the number of pressure tappings (with a minimum of four).

5.2.5 No diameter at any point between plane C and 1D downstream of plane A from Figure 4 shall differ from the pipe diameter, D, by more than 1,0 %.



Key

1 flow

2 cone nose

Figure 4 — Metrology data for a cone meter

5.2.6 The internal surface of the pipe section from plane C to plane A from Figure 4 shall be clean and smooth, and the roughness criterion, *Ra*, should be as small as possible and shall be less than $10^{-3}D$.

5.2.7 The cone assembly shall generally consist of a circular bifrustum (two truncated cones joined at their widest points). The upstream frustum shall have a single internal angle, θ_1, of 26° ± 5° to the centreline of the frusta. The downstream frustum shall have a single internal angle, θ_2, of 67,5° ± 2,5° to the centreline of the frusta.

5.2.8 The cone diameter, d_c, shall be measured at plane A of Figure 4. There shall be a minimum of four measurements equally spaced around the cone external circumference.

The arithmetic mean value of these measurements shall be taken as the value of d_c in the calculations. No diameter shall differ by more than 0,1 % from the value of the mean diameter. This requirement is satisfied when the difference in length of any of the measured diameters conforms to the said requirement with respect to the mean of the measured diameters.

5.2.9 The beta edge shall not be sharp. The radius of curvature, R_1, at the beta edge as shown in Figure 5, shall be less than the smaller of 0,2 mm and 0,000 5 d_c.

5.2.10 The cone shall be such that two diameters situated on the same plane perpendicular to the axis of revolution do not differ from the mean diameter by more than 0,1 %.

Figure 5 — Radius of curvature, R_1, at the beta edge shown, as examples, for fabricated and machined cones

5.2.11 The cone surface shall be clean and smooth, and the roughness criterion, *Ra*, shall be as small as possible and shall always be less than $5 \times 10^{-4}\ d_c$.

5.2.12 The supporting structure for the cone shall present as small a restriction to the flow as practical, whilst ensuring that the structural integrity of the cone meter is not impaired over the range of conditions anticipated. The cone assembly may optionally include gussets that provide additional mechanical support.

5.2.13 The lateral and angular deviations of the cone from the centreline of the pipe section shall be measured.

The distance between the widest part of the cone and the adjacent pipe internal wall shall be measured (see plane A of Figure 4, labelled K_1, K_2, K_3, K_4). There shall be a minimum of four measurements equally spaced around the external circumference of the cone. The difference between each measurement and the mean of those measurements shall be no greater than 5,0 %.

The distance between the cone nose and the adjacent pipe internal wall shall also be measured (see plane B of Figure 4, labelled J_1, J_2, J_3, J_4). There shall be a minimum of four measurements equally spaced around the external circumference of the cone. The difference between each measurement and the mean of those measurements shall be no greater than 5,0 %.

The angular deviation of the cone shall be measured and should be no greater than 2,0° in either the horizontal (θ_{HORZ}) or vertical (θ_{VERT}) from the pipe centreline at the cone nose, as shown in Figure 4.

The lateral deviation of the cone shall be measured and should be no greater than $0{,}01D$ in either the horizontal or vertical from the pipe centreline at the cone nose, as shown in Figure 4.

5.2.14 Consideration shall be taken in the design of the cone meter and its installation to ensure that the effects of pressure, temperature, and resonance over the entire range of conditions that the flow meter may see over its operational life do not result in mechanical failure.

In applications where flow conditions produce significant vibration, the use of gussets is recommended.

5.3 Material and manufacture

5.3.1 The cone meter may be manufactured from any material, provided that the cone meter is in accordance with the foregoing description and will remain so during use.

5.3.2 For fabricated cones, the cone shall include pressure relief vent holes through the downstream face to ensure the structural stability of the cone under rapid pressure changes.

5.4 Pressure tappings

5.4.1 The upstream tapping shall be made in the form of a pipe wall pressure tapping.

5.4.2 The diameter of the upstream tapping shall be between 4 mm and 10 mm and moreover shall never be greater than 0,1*D*.

It is recommended that the upstream tapping be as small as compatible with the fluid (for example, with its viscosity and contaminants).

5.4.3 The centreline of the upstream tapping(s) shall meet the centreline of the pipe.

5.4.4 At the point of break-through, the hole of the pressure tapping shall be circular. The edges shall be flush with the pipe wall and free from burrs. The radius shall not exceed one-tenth of the diameter of the pressure tapping.

5.4.5 The upstream pressure tapping should be cylindrical over a length at least equal to the diameter of the tapping.

5.4.6 Conformity of the pressure tapping with the two foregoing requirements is assessed by visual inspection.

5.4.7 The spacing between the planes perpendicular to the pipe axis of the centrelines of the upstream pressure tapping(s) and the downstream tapping within the cone support, *L*, shall be a minimum of 50 mm and a maximum of 2*D*, as shown in Figure 2.

5.4.8 The downstream tapping through the cone shall be cylindrical, and shall have its centreline concentric to the centreline of the cone. The diameter of this tapping shall be between $0,1 \times d_c$ and $0,2 \times d_c$. The hole of the pressure tapping shall be circular and the edges shall be free from burrs.

5.5 Discharge coefficient, *C*

5.5.1 Limits of use

A simultaneous use of extreme values for D, β, and Re_D shall be avoided as otherwise the uncertainties given in 5.7 might increase.

For installations outside the limits defined in 5.5.2 for D, β, and Re_D, it is necessary to calibrate the discharge coefficient for each meter in accordance with Clause 7 over its entire Reynolds number range of operation.

The effects of Re_D, R_a/D, and β on C are not yet sufficiently known for it to be possible to give reliable values of C outside the limits defined in this part of ISO 5167.

5.5.2 Discharge coefficient of the cone meter

Cone meters as per Figure 2 can only be used in accordance with this part of ISO 5167 when

$$50 \text{ mm} \leq D \leq 500 \text{ mm}$$

$$0,45 \leq \beta \leq 0,75$$

$$8 \times 10^4 \leq Re_D \leq 1,2 \times 10^7$$

Under these conditions, the value of the discharge coefficient, C, for an uncalibrated meter is

$$C = 0,82$$

5.6 Expansibility (expansion) factor, ε

The expansibility (expansion) factor, ε, is calculated by means of Formula (5).

$$\varepsilon = 1 - (0,649 + 0,696\beta^4)\frac{\Delta p}{\kappa p_1} \quad (5)$$

Formula (5) was derived by Stewart et al.[10] Test results for determination of ε are only known for air. However, Formula (5) is generally applied to cone meters for gases and vapours for which the isentropic exponent is known.

However, the Formula (5) is only applicable if $p_2/p_1 \geq 0,75$.

Values of the expansibility (expansion) factor for a range of isentropic exponents, pressure ratios, and β are given for convenience in Table A.1.

5.7 Uncertainty of the discharge coefficient, C

The uncertainty of an uncalibrated cone meter, as given below, is relatively high when compared to other ISO 5167 differential pressure devices. However, if a flow calibration is carried out as per Clause 7, the uncertainty in discharge coefficient is comparable to that of these other devices. Therefore, for applications requiring higher accuracy, it is recommended that every cone meter is calibrated over the full operational range of Reynolds number as is specified in Clause 7.

The relative uncertainty of the discharge coefficient as given in 5.5.2 is equal to 5 %, expressed at a 95 % confidence level.

For a given flowrate, the uncertainty of the discharge coefficient and that of the predicted differential pressure are directly linked. Consequently, care shall be taken with determining β such that the maximum differential pressure does not exceed the upper range limit of the transmitter.

For cone meters with values of $\beta > 0,75$, the uncertainty in the uncalibrated discharge coefficient has been found to be greater than 5 %.

5.8 Uncertainty of the expansibility (expansion) factor, ε

From available data, the absolute uncertainty of ε is estimated (expressed at a 95 % confidence level) to be

$$0,096\frac{\Delta p}{\kappa p_1} \quad (6)$$

5.9 Pressure loss

The pressure loss, $\Delta\omega$, for the cone meter described in this part of ISO 5167 is approximately related to the differential pressure, Δp, by Formula (7).

$$\Delta\omega = (1,09 - 0,813\beta)\Delta p \quad (7)$$

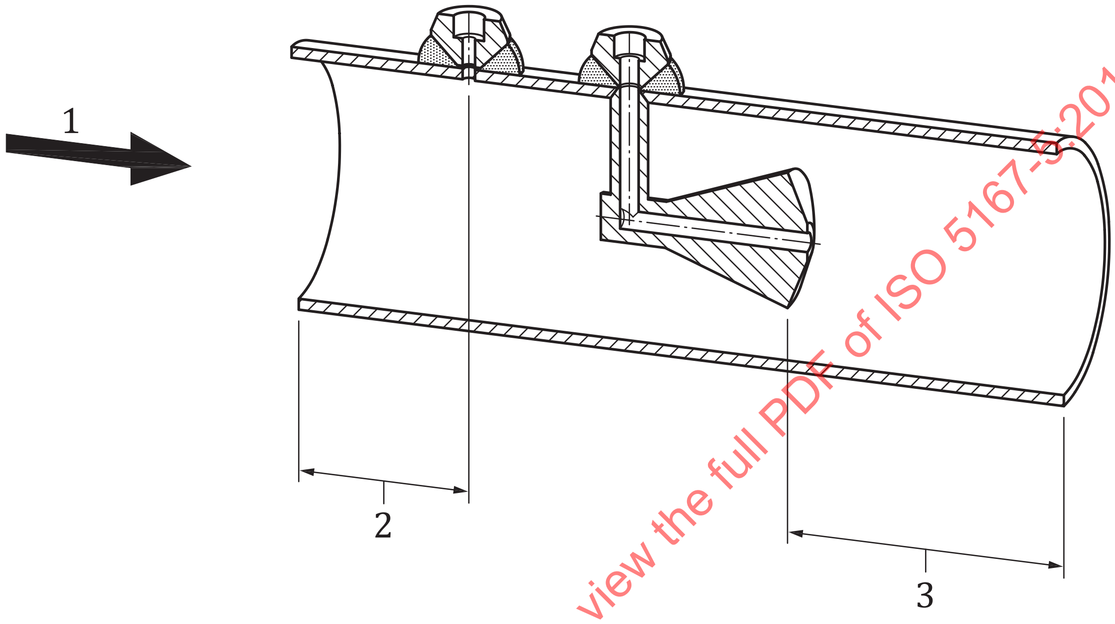
This pressure loss is the difference in static pressure between the pressure measured at the wall on the upstream side of the cone assembly, at a section where the influence of the approach impact pressure adjacent to the cone is still negligible (approximately D upstream of the nose of the cone), and that measured on the downstream side of the cone, where the static pressure recovery by expansion of the jet may be considered as just completed (approximately $6D$ downstream of the cone).

NOTE When comparing the permanent pressure loss of a cone meter with alternative differential pressure meter designs, it is important to compare meter designs that are sized to provide a similar range of differential pressure, rather than comparing the different meter designs with the same value of β.

6 Installation requirements

6.1 General

General installation requirements for pressure differential devices are contained in ISO 5167-1:2003, Clause 7 and should be followed in conjunction with the additional specific installation requirements for cone meters given in this Clause. The general requirements for flow conditions at the primary device are given in ISO 5167-1:2003, 7.3. The requirements for use of a flow conditioner are given in ISO 5167-1:2003, 7.4; however, flow conditioners are generally not required for cone meters.



Key

1 flow

2 upstream straight length

3 downstream straight length

Figure 6 — Straight lengths within cone meter

6.2 Minimum upstream and downstream straight lengths for installations between various fittings and the cone meter

6.2.1 General

Cone meters are relatively insensitive to common flow disturbances; however, the designer of the metering system should make reasonable efforts to minimize flow disturbances where possible.

Unless it is explicitly stated, the resistance to flow disturbances is assumed to be independent of the line size of the cone meter. The effect of an upstream disturber is relative to the meter's performance with no disturber installed.

Upstream straight lengths shall be measured from the downstream end of the curved portion of the nearest (or only) bend or the downstream end of the curved or conical portion of a reducer or expander to the plane of the centreline of the upstream tapping(s) of the cone meter, as shown in Figure 6.

Downstream straight lengths shall be measured from the plane of the beta edge, as shown in Figure 6, to the upstream end of the curved portion of the nearest (or only) bend or the upstream end of the curved or conical portion of a reducer or expander. Fittings at least 2*D* downstream of the cone meter introduce no additional errors.

6.2.2 Single 90° bend

For 0,45 ≤ β < 0,6, a minimum of 3D upstream straight length is required. For 0,6 ≤ β ≤ 0,75, a minimum of 6D upstream straight length is required.

6.2.3 Two 90° bends in perpendicular planes

For 0,45 ≤ β < 0,6, a minimum of 3D upstream straight length is required. For 0,6 ≤ β ≤ 0,75, a minimum of 6D upstream straight length is required.

6.2.4 Concentric expander

With a 0,75D to D concentric expander 3D upstream of a cone meter, an additional uncertainty in flow rate of up to 0,5 % can be expected.

A concentric reducer is a less significant flow disturber than a concentric expander.

6.2.5 Partially closed valves

A partially closed valve should not be installed within 10D upstream of a cone meter. Fully open, full-bore, isolation valves introduce no additional errors.

6.3 Additional specific installation requirements for cone meters

6.3.1 Circularity and cylindricality of the pipe

6.3.1.1 Over an upstream length of at least 6D measured from the plane of the centreline of the upstream pressure tapping(s), the pipe shall be cylindrical. The pipe is said to be cylindrical when no diameter in any plane differs by more than 2 % from the mean of the measured diameters of the pipe at that plane. The number of measurements in a plane shall be equal to a minimum of four. At least one axial plane shall be examined in addition to plane C from Figure 4.

6.3.1.2 Over a downstream length of at least 2D measured from the plane of the beta edge of the cone meter, the pipe shall be cylindrical. The pipe is said to be cylindrical when no diameter in any plane differs by more than 2 % from the mean of the measured diameters of the pipe at that plane. The number of measurements in a plane shall be equal to a minimum of four. At least one axial plane shall be examined in addition to plane A from Figure 4.

6.3.1.3 The mean diameter of pipe where it joins the cone meter shall be within 1 % of the cone meter diameter, D, as defined in 5.2.3.

6.3.2 Roughness of the upstream and downstream pipe

The upstream and downstream pipe roughness criterion R_a shall be less than $10^{-3}D$ over the lengths of 5D upstream and 2D downstream.

6.3.3 Positioning of a thermowell

If a thermowell is installed, it is recommended that its location be upstream of the straight length requirement. No correction for Joule-Thomson effect is necessary.

Where a thermowell is installed in the straight length requirement or between the plane of the centreline of the upstream pressure tapping(s) and the nose of the cone, the meter shall be calibrated with the thermowell installed. The thermowell shall not be installed in line with an upstream pressure tapping. No correction for Joule-Thomson effect is necessary.