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

**Part 5:
Cone meters**

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

Partie 5: Cônes de mesure



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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/SS F05, *Measuring instruments*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition of ISO 5167-5 cancels and replaces the first edition (ISO 5167-5:2016), which has been technically revised.

The main changes are as follows:

- this document is consistent with ISO/IEC Guide 98-3;
- errors in [Figure 2](#) and in [5.2.7](#) have been corrected;
- the expansibility uncertainty is given as a relative uncertainty for ease of use with ISO 5167-1 (the calculated flow rate uncertainty is unchanged).

A list of all parts in the ISO 5167 series can be found on the ISO website.

Introduction

ISO 5167, consisting of six parts, covers the geometry and method of use (installation and operating conditions) of orifice plates, nozzles, Venturi tubes, cone meters and wedge 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. ISO 5167 (all parts) also provides methodology for bespoke calibration of differential pressure meters.

ISO 5167 (all parts) 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 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, or alternatively they can be used across their calibrated range.

ISO 5167 (all parts) 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.

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 to facilitate the instrument readings are known as secondary devices, and the flow computer that receives these readings and performs the algorithms is known as a tertiary device. ISO 5167 (all parts) covers primary devices; secondary devices (see ISO 2186) and tertiary devices will be mentioned only occasionally.

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.

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

This document 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, Re . This document 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 document has one or more upstream pressure tapings 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 are referred to in the text in such a way that some or all of their content constitutes requirements of this document. 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, *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.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

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.

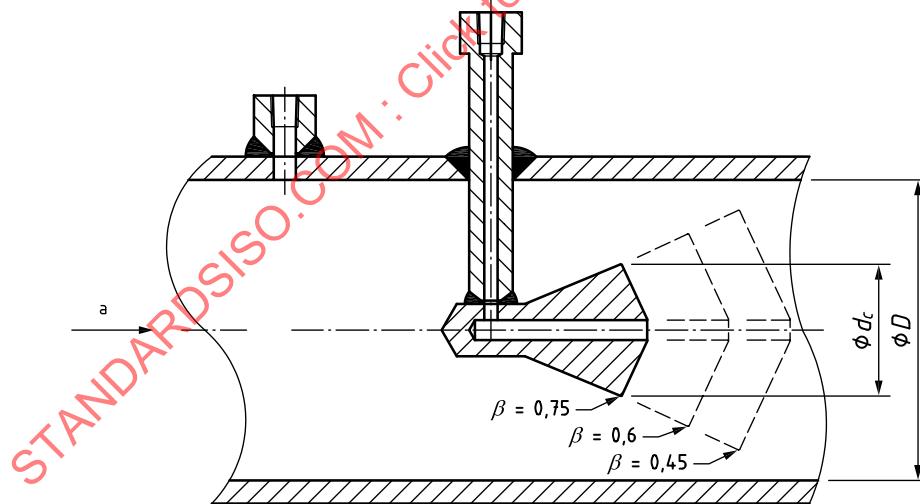
The mass flow rate can be determined by [Formulae \(1\)](#) and [\(2\)](#):

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

and

$$\beta = \sqrt{1 - \frac{d_c^2}{D^2}} \quad (2)$$

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.



a Direction of flow.

Figure 1 — Cone meter showing different values of β

The uncertainty can be calculated using the procedure given in ISO 5167-1:2022, Clause 8.

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

$$q_V = \frac{q_m}{\rho} \quad (3)$$

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 \(4\)](#) 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 discharge coefficient, 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 5167-1:2022, 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.

5 Cone meters

5.1 Field of application

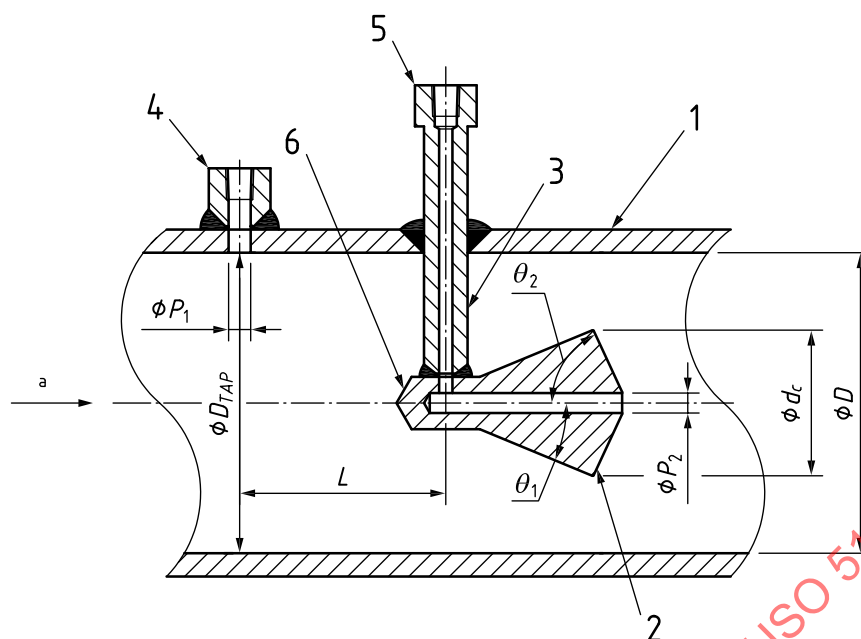
Uncalibrated cone meters can be used in pipes with diameters between 50 mm and 500 mm and with $0,45 \leq \beta \leq 0,75$. Cone meters with $\beta > 0,75$ shall be calibrated. Cone meters with values of $\beta < 0,45$ are not normally manufactured.

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 body pipe
- 2 cone element
- 3 support strut
- 4 high pressure tapping
- 5 low pressure tapping
- 6 cone nose
- a Direction of flow.

NOTE $50 \text{ mm} \leq L \leq 2D$, 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 example 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.

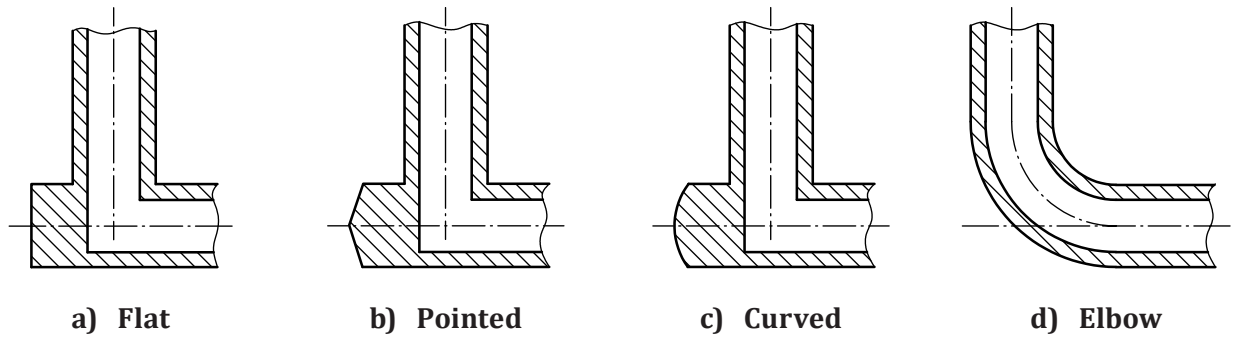
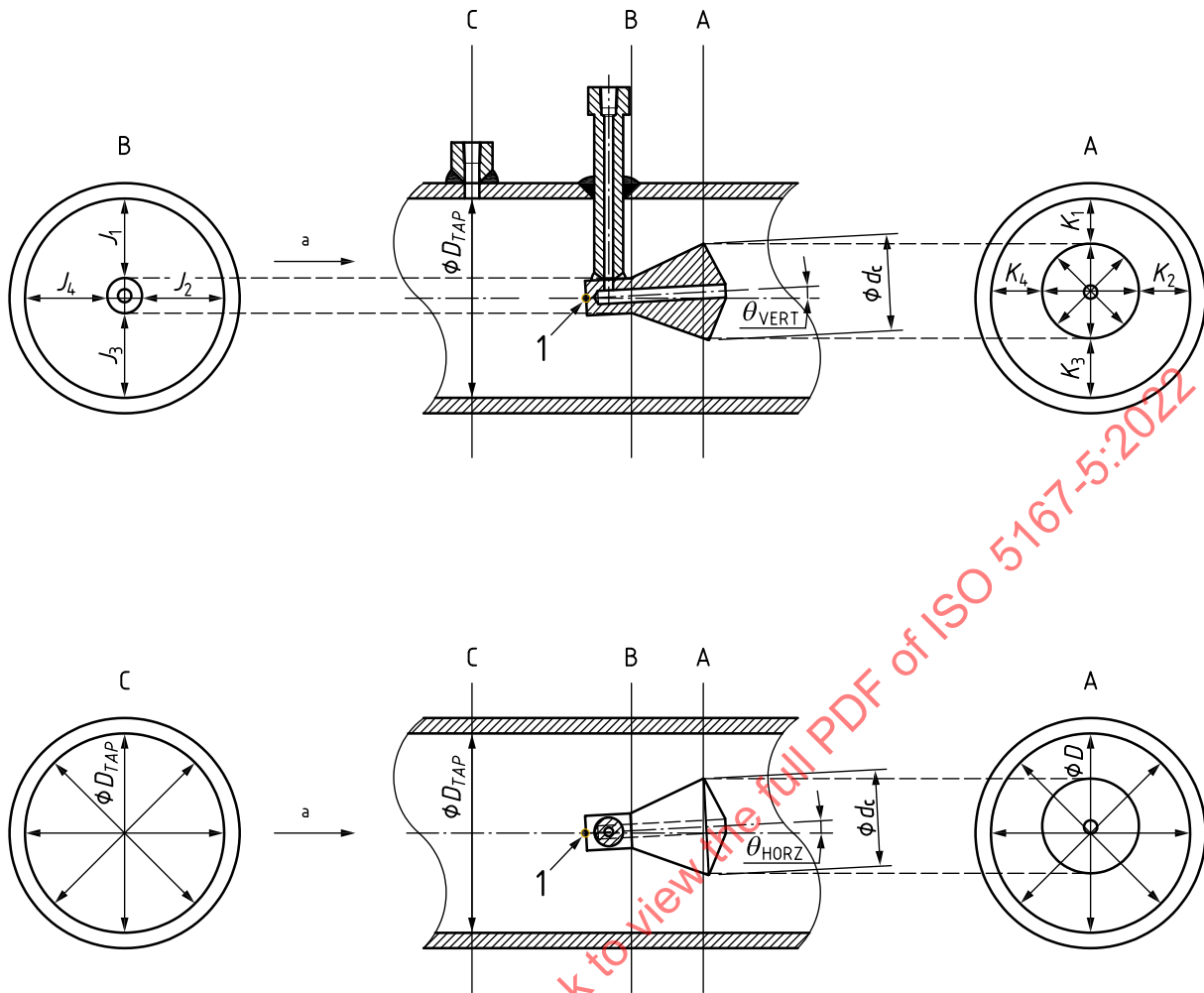


Figure 3 — Examples of different cone nose designs

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 tapplings (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 cone nose
- a Direction of flow.

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, R_a , 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 $22,5^\circ \pm 5^\circ$ to the centreline of the frusta. The downstream frustum shall have a single internal angle, θ_2 , of $64^\circ \pm 2,5^\circ$ 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 %.

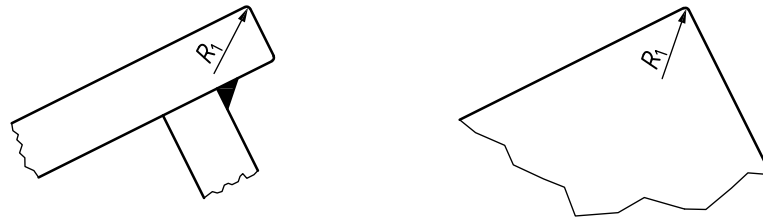


Figure 5 — Radius of curvature, R_1 , at the beta edge shown, as examples, for fabricated and machined cones

5.2.11 The cone surface shall be clean and smooth, and the roughness criterion, R_a , 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 $2,0^\circ$ 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 tapings

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 $0,1D$.

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 $2D$, 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 , Ra/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 document.

5.5.2 Discharge coefficient of the cone meter

Cone meters as per [Figure 2](#) can only be used in accordance with this document 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^[5] is

$$C = 0,82$$

5.6 Expansibility (expansion) factor, ε

The expansibility (expansion) factor, ε , is calculated by means of [Formula \(4\)](#).

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

[Formula \(4\)](#) was derived by Stewart et al.^[8]. Test results for determination of ε are only known for air. However, [Formula \(4\)](#) is generally applied to cone meters for gases and vapours for which the isentropic exponent is known.

However, [Formula \(4\)](#) 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 [Annex A](#).

5.7 Uncertainty of the discharge coefficient, C

The uncertainty of an uncalibrated cone meter, as given below, is relatively high when compared with 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](#).

U'_C , the relative expanded uncertainty of the value of C as given in [5.5.2](#)^[5] at $k = 2$ (approximately 95 % confidence level), is equal to 5 %, expressed at a 95 % confidence level.

For cone meters with values of $\beta > 0,75$, the relative uncertainty of the uncalibrated discharge coefficient at $k = 2$ (approximately 95 % confidence level) has been found to be greater than 5 %.

5.8 Uncertainty of the expansibility (expansion) factor, ε

From available data, U'_ε , the relative expanded uncertainty of the value of ε at $k = 2$ (approximately 95 % confidence level), is given by [Formula \(5\)](#):

$$9,6 \frac{\Delta p}{\kappa p_1 \varepsilon} \% \quad (5)$$

5.9 Pressure loss

The pressure loss, $\Delta\varpi$, for the cone meter described in this document is approximately related to the differential pressure, Δp , by [Formula \(6\)](#).

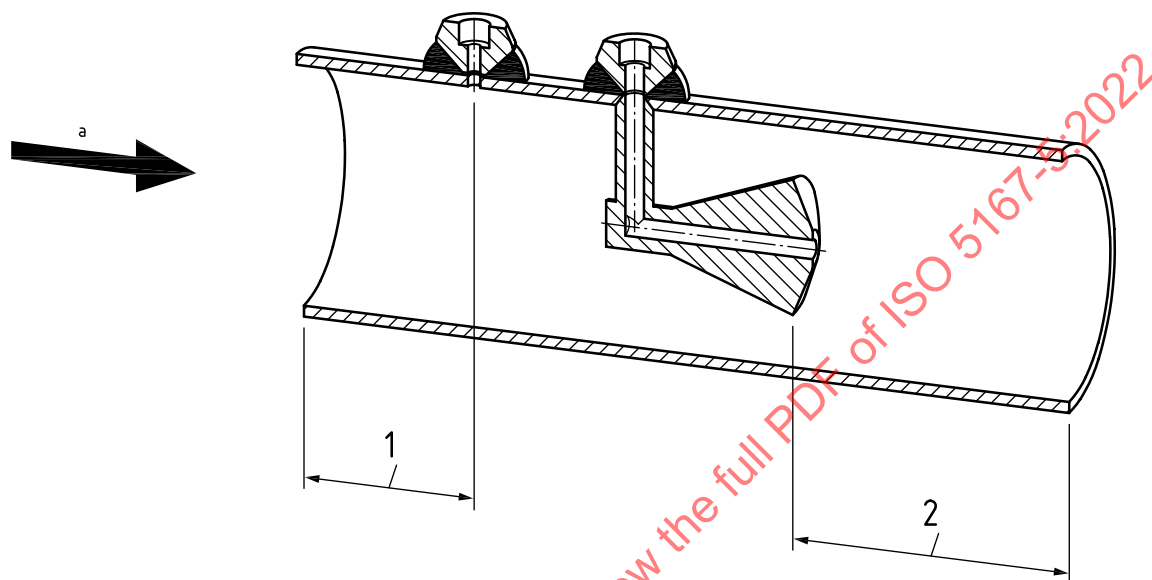
$$\Delta\varpi = (1,09 - 0,813\beta)\Delta p \quad (6)$$

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).

6 Installation requirements

6.1 General

General installation requirements for pressure differential devices are contained in ISO 5167-1:2022, 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 5167-1:2022, 7.3. The requirements for use of a flow conditioner are given in ISO 5167-1:2022, 7.4; however, flow conditioners are generally not required for cone meters.



Key

- 1 upstream straight length
- 2 downstream straight length
- a Direction of flow.

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 [6][7].

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 $2D$ downstream of the cone meter introduce no additional errors.

6.2.2 Single 90° bend

For $0,45 \leq \beta < 0,6$, a minimum of $3D$ upstream straight length is required. For $0,6 \leq \beta \leq 0,75$, a minimum of $6D$ upstream straight length is required.

6.2.3 Two 90° bends in perpendicular planes

For $0,45 \leq \beta < 0,6$, a minimum of $3D$ upstream straight length is required. For $0,6 \leq \beta \leq 0,75$, 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 relative expanded 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 cylindricity of the pipe

6.3.1.1 The pipe shall be cylindrical over an upstream length of at least $6D$ measured from the plane of the centreline of the upstream pressure tapping(s), or up to the first fitting if permitted to be closer. 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 pipe 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 Ra 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.