INTERNATIONAL STANDARD

ISO 5167-3

First edition
2003-03-01

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

Part 3:
Nozzles and Venturi nozzles

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

Partie 3: Tuyères et Venturi-tuyères

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 5167-2 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 2, *Pressure differential devices*.

This first edition of ISO 5167-3, together with the second edition of ISO 5167-1 and the first editions of ISO 5167-2 and ISO 5167-4, cancels and replaces the first edition of ISO 5167-1:1991, which has been technically revised, and ISO 5167-1:1991/Amd.1:1998.

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*

Introduction

ISO 5167, consisting of four parts, covers the geometry and method of use (installation and operating conditions) of orifice plates, nozzles and Venturi tubes when they are inserted in a conduit running full to determine the flowrate of the fluid flowing in the conduit. It also gives necessary information for calculating the flowrate and its associated uncertainty.

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.

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 for the measurement are known as "secondary devices". ISO 5167 (all parts) covers primary devices; secondary devices[1] will be mentioned only occasionally.

ISO 5167 consists of the following four 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 5167-2, ISO 5167-3 and ISO 5167-4.

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

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

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

Aspects of safety are not dealt with in Parts 1 to 4 of ISO 5167. It is the responsibility of the user to ensure that the system meets applicable safety regulations.

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1) See ISO 2186:1973, *Fluid flow in closed conduits — Connections for pressure signal transmissions between primary and secondary elements*.

2) Orifice plates with "vena contracta" pressure tappings are not considered in ISO 5167.

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

4) 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 3:
Nozzles and Venturi nozzles

1   Scope

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

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

This part of ISO 5167 is applicable to nozzles and Venturi nozzles in which the flow remains subsonic throughout the measuring section and where the fluid can be considered as single-phase. In addition, each of the devices can only be used within specified limits of pipe size and Reynolds number. It is not applicable to the measurement of pulsating flow. It does not cover the use of nozzles and Venturi nozzles in pipe sizes less than 50 mm or more than 630 mm, or where the pipe Reynolds numbers are below 10 000.

This part of ISO 5167 deals with

a)   two types of standard nozzles:

   1)   the ISA[5] 1932 nozzle;

   2)   the long radius nozzle[6];

b)   the Venturi nozzle.

The two types of standard nozzle are fundamentally different and are described separately in this part of ISO 5167. The Venturi nozzle has the same upstream face as the ISA 1932 nozzle, but has a divergent section and, therefore, a different location for the downstream pressure tappings, and is described separately. This design has a lower pressure loss than a similar nozzle. For both of these nozzles and for the Venturi nozzle 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.

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[5]   ISA is the abbreviation for the International Federation of the National Standardizing Associations, which was superseded by ISO in 1946.

[6]   The long radius nozzle differs from the ISA 1932 nozzle in shape and in the position of the pressure tappings.

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2 Normative references

The following referenced documents are indispensable for the application 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 4006:1991, *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 and ISO 5167-1 apply.

4 Principles of the method of measurement and computation

The principle of the method of measurement is based on the installation of a nozzle or a Venturi nozzle into a pipeline in which a fluid is running full. The installation of the primary device causes a static pressure difference between the upstream side and the throat. The flowrate can be determined from the measured value of this pressure difference and from the knowledge of the characteristics of the flowing fluid as well as the circumstances under which the device is being used. It is assumed that the device is geometrically similar to one on which calibration has been carried out and that the conditions of use are the same, i.e. that it is in accordance with this part of ISO 5167.

The mass flowrate can be determined by Equation (1):

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

The uncertainty limits can be calculated using the procedure given in Clause 8 of ISO 5167-1:2003.

Similarly, the value of the volume flowrate can be calculated since

$$q_V = \frac{q_m}{\rho} \tag{2}$$

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

Computation of the flowrate, which is a purely arithmetic process, is performed by replacing the different items on the right-hand side of Equation (1) by their numerical values. Tables A.1 to A.4 are given for convenience. Tables A.1 to A.3 give the values of C as a function of β. Table A.4 gives expansibility (expansion) factors ε. They are not intended for precise interpolation. Extrapolation is not permitted.

The coefficient of discharge C may be dependent on Re_D, which is itself dependent on q_m and has to be obtained by iteration. (See ISO 5167-1 for guidance regarding the choice of the iteration procedure and initial estimates.)

The diameters d and D mentioned in Equation (1) 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.

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 Nozzles and Venturi nozzles

5.1 ISA 1932 nozzle

5.1.1 General shape

The part of the nozzle inside the pipe is circular. The nozzle consists of a convergent section, of rounded profile, and a cylindrical throat.

Figure 1 shows the cross-section of an ISA 1932 nozzle at a plane passing through the centreline of the throat.

The letters in the following text refer to those shown on Figure 1.

5.1.2 Nozzle profile

5.1.2.1   The profile of the nozzle may be characterized by distinguishing:

— a flat inlet part A, perpendicular to the centreline;

— a convergent section defined by two arcs of circumference B and C;

— a cylindrical throat E; and

— a recess F which is optional (it is required only if damage to the edge G is feared).

5.1.2.2   The flat inlet part A is limited by a circumference centred on the axis of revolution, with a diameter of $1,5d$, and by the inside circumference of the pipe, of diameter D.

When $d = 2D/3$, the radial width of this flat part is zero.

When d is greater than $2D/3$, the upstream face of the nozzle does not include a flat inlet part within the pipe. In this case, the nozzle is manufactured as if D is greater than $1,5d$, and the inlet flat part is then faced off so that the largest diameter of the convergent profile is just equal to D [see 5.1.2.7 and Figure 1 b)].

5.1.2.3   The arc of circumference B is tangential to the flat inlet part A when $d < 2D/3$ while its radius R_1 is equal to $0,2d \pm 0,02d$ for $\beta < 0,5$ and to $0,2d \pm 0,006d$ for $\beta \geqslant 0,5$. Its centre is at $0,2d$ from the inlet plane and at $0,75d$ from the axial centreline.

5.1.2.4   The arc of circumference C is tangential to the arc of circumference B and to the throat E. Its radius R_2 is equal to $d/3 \pm 0,033d$ for $\beta < 0,5$ and to $d/3 \pm 0,01d$ for $\beta \geqslant 0,5$. Its centre is at $d/2 + d/3 = 5d/6$ from the axial centreline and at

$$a_n = \left(\frac{12 + \sqrt{39}}{60} \right) d = 0,304\ 1\ \ d$$

from the flat inlet part A.

a) $d \leq (2/3)D$

b) $d > (2/3)D$
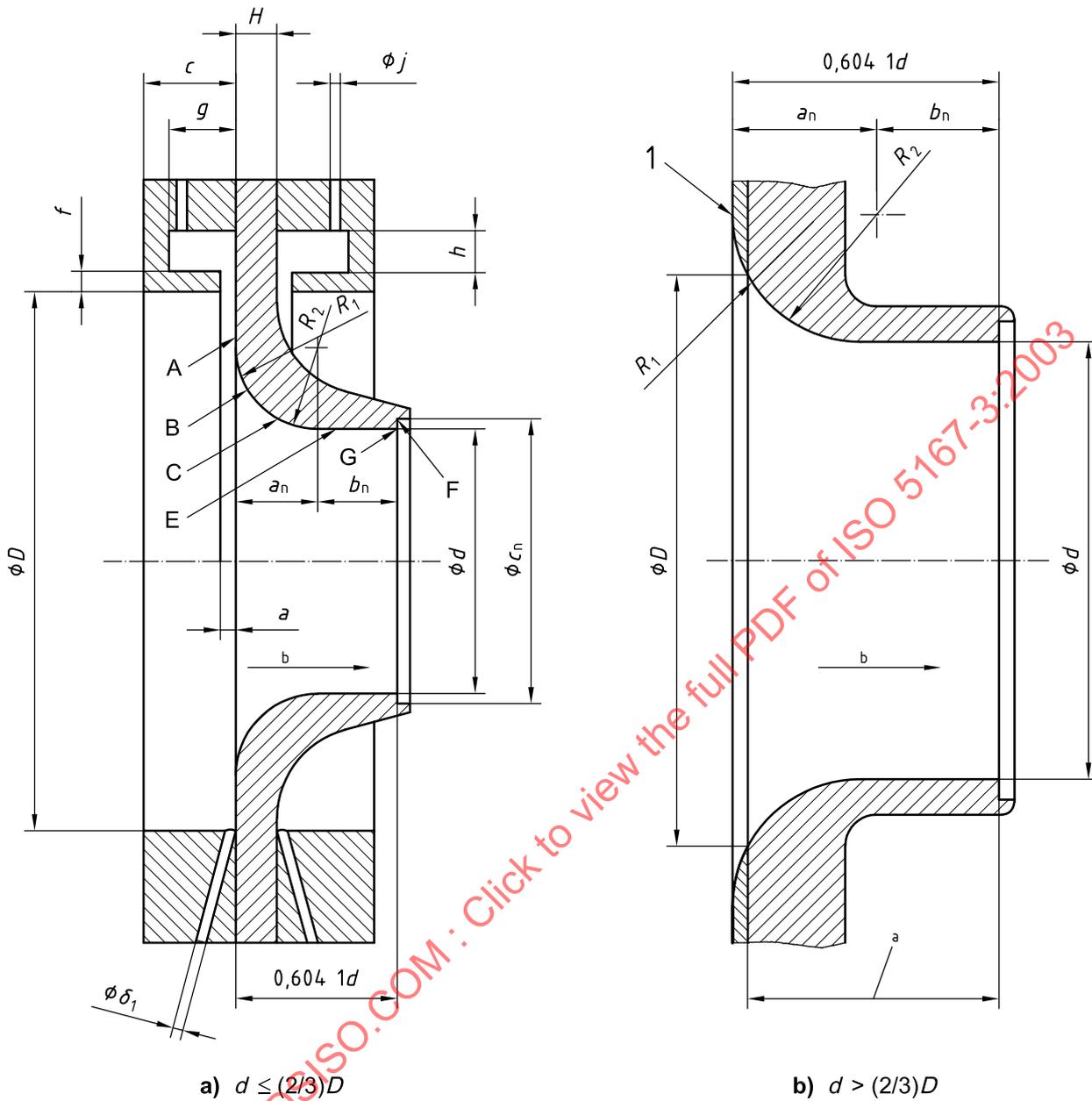
Key

1   portion to be cut off

a   See 5.1.2.7.

b   Direction of flow.

Figure 1 — ISA 1932 nozzle

5.1.2.5   The throat E has a diameter d and a length $b_n = 0,3d$.

The value d of the diameter of the throat shall be taken as the mean of the measurements of at least four diameters distributed in axial planes and at approximately equal angles to each other.

The throat shall be cylindrical. No diameter of any cross-section shall differ by more than 0,05 % from the value of the mean diameter. This requirement is considered to be satisfied when the deviations in the length of any of the measured diameters comply with the said requirement in respect of deviation from the mean.

5.1.2.6 The recess F has a diameter c_n equal to at least $1,06d$ and a length less than or equal to $0,03d$. The ratio of the height $(c_n - d)/2$ of the recess to its axial length shall not be greater than 1,2.

The outlet edge G shall be sharp.

5.1.2.7 The total length of the nozzle, excluding the recess F, as a function of β is equal to

$$0,604\ 1d \text{ for } 0,3 \leqslant \beta \leqslant \frac{2}{3}$$

and

$$\left(0,404\ 1 + \sqrt{\frac{0,75}{\beta} - \frac{0,25}{\beta^2} - 0,522\ 5}\right)d \text{ for } \frac{2}{3} < \beta \leqslant 0,8 .$$

5.1.2.8 The profile of the convergent inlet shall be checked by means of a template.

Two diameters of the convergent inlet in the same plane perpendicular to the axial centreline shall not differ from each other by more than 0,1 % of their mean value.

5.1.2.9 The surface of the upstream face and the throat shall be polished such that they have a roughness criterion $Ra \leqslant 10^{-4}d$.

5.1.3 Downstream face

5.1.3.1 The thickness H shall not exceed $0,1D$.

5.1.3.2 Apart from the condition given in 5.1.3.1, the profile and the surface finish of the downstream face are not specified (see 5.1.1).

5.1.4 Material and manufacture

The ISA 1932 nozzle may be manufactured from any material and in any way, provided that it remains in accordance with the foregoing description during flow measurement.

5.1.5 Pressure tappings

5.1.5.1 Corner pressure tappings shall be used upstream of the nozzle.

The upstream pressure tappings may be either single tappings or annular slots. Both types of tappings may be located either in the pipe or its flanges or in carrier rings as shown in Figure 1.

The spacing between the centrelines of individual upstream tappings and face A is equal to half the diameter or to half the width of the tappings themselves, so that the tapping holes break through the wall flush with face A. The centreline of individual upstream tappings shall meet the centreline of the primary device at an angle of as near 90° as possible.

The diameter δ_1 of a single upstream tapping and the width a of annular slots are specified below. The minimum diameter is determined in practice by the need to prevent accidental blockage and to give satisfactory dynamic performance.

For clean fluids and vapours:

— for $\beta \leqslant 0,65$: $0,005D \leqslant a$ or $\delta_1 \leqslant 0,03D$;

— for $\beta > 0,65$: $0,01D \leqslant a$ or $\delta_1 \leqslant 0,02D$.

For any value of β:

— for clean fluids: 1 mm $\leqslant a$ or $\delta_1 \leqslant$ 10 mm;

— for vapours, in the case of annular chambers: 1 mm $\leqslant a \leqslant$ 10 mm;

— for vapours and for liquefied gases, in the case of single tappings: 4 mm $\leqslant \delta_1 \leqslant$ 10 mm.

The annular slots usually break through the pipe over the entire perimeter, with no break in continuity. If not, each annular chamber shall connect with the inside of the pipe by at least four openings, the axes of which are at equal angles to one another and the individual opening area of which is at least 12 mm^2.

The internal diameter b of the carrier rings shall be greater than or equal to the diameter D of the pipe, to ensure that they do not protrude into the pipe, but shall be less than or equal to 1,04D. Moreover, the following condition shall be met:

$$\frac{b-D}{D} \times \frac{c}{D} \times 100 \leqslant \frac{0,1}{0,1+2,3\beta^4}$$

The length c of the upstream ring (see Figure 1) shall not be greater than 0,5D.

The thickness f of the slot shall be greater than or equal to twice the width a of the annular slot. The area of the cross-section of the annular chamber, gh, shall be greater than or equal to half the total area of the opening connecting this chamber to the inside of the pipe.

All surfaces of the ring which are in contact with the measured fluid shall be clean and shall have a well-machined finish.

The pressure tappings connecting the annular chambers to the secondary devices are pipe-wall tappings, circular at the point of break-through and with a diameter j between 4 mm and 10 mm.

The upstream and downstream carrier rings need not necessarily be symmetrical in relation to each other, but they shall both conform to the preceding requirements.

The diameter of the pipe shall be measured as specified in 6.4.2, the carrier ring being regarded as part of the primary device. This also applies to the distance requirement given in 6.4.4 so that s shall be measured from the upstream edge of the recess formed by the carrier ring.

5.1.5.2   The downstream pressure tappings may either be corner tappings as described in 5.1.5.1 or be as described in the remainder of this section.

The distance between the centre of the tapping and the upstream face of the nozzle shall be

— $\leqslant$ 0,15D for $\beta \leqslant$ 0,67

— $\leqslant$ 0,20D for $\beta >$ 0,67

When installing the pressure tappings, due account shall be taken of the thickness of the gaskets and/or sealing material.

The centreline of the tapping shall meet the pipe centreline at an angle as near to 90° as possible but in every case within 3° of the perpendicular. At the point of break-through, the hole shall be circular. The edges shall be flush with the internal surface of the pipe wall and as sharp as possible. To ensure the elimination of all burrs or wire edges at the inner edge, rounding is permitted but shall be kept as small as possible and, where it can be measured, its radius shall be less than one-tenth of the pressure-tapping diameter. No irregularity shall appear inside the connecting hole, on the edges of the hole drilled in the pipe wall or on the pipe wall close to the pressure tapping. Conformity of the pressure tappings with the requirements of this paragraph may be judged by visual inspection.

The diameter of pressure tappings shall be less than 0,13D and less than 13 mm.

No restriction is placed on the minimum diameter, which is determined in practice by the need to prevent accidental blockage and to give satisfactory dynamic performance. The upstream and downstream tappings shall have the same diameter.

The pressure tappings shall be circular and cylindrical over a length of at least 2,5 times the internal diameter of the tapping, measured from the inner wall of the pipeline.

The centrelines of the pressure tappings may be located in any axial plane of the pipeline.

The axis of the upstream tapping and that of the downstream tapping may be located in different axial planes.

5.1.6   Coefficients of ISA 1932 nozzles

5.1.6.1   Limits of use

This type of nozzle shall only be used in accordance with this part of ISO 5167 when

— 50 mm $\leqslant D \leqslant$ 500 mm

— 0,3 $\leqslant \beta \leqslant$ 0,8

and when Re_D is within the following limits:

— for 0,30 $\leqslant \beta <$ 0,44 $7 \times 10^4 \leqslant Re_D \leqslant 10^7$

— for 0,44 $\leqslant \beta \leqslant$ 0,80 $2 \times 10^4 \leqslant Re_D \leqslant 10^7$

In addition, the relative roughness of the pipe shall conform to the values given in Table 1.

Table 1 — Upper limits of relative roughness of the upstream pipe for ISA 1932 nozzles

β	$\leqslant$ 0,35	0,36	0,38	0,40	0,42	0,44	0,46	0,48	0,50	0,60	0,70	0,77	0,80
$10^4 \, Ra/D$	8,0	5,9	4,3	3,4	2,8	2,4	2,1	1,9	1,8	1,4	1,3	1,2	1,2
NOTE Most of the data on which this table is based were probably collected in the range $Re_D \leqslant 10^6$; at higher Reynolds numbers more stringent limits on pipe roughness are probably required.													

Most of the experiments on which the values of the discharge coefficient C given in this part of ISO 5167 are based were carried out in pipes with a relative roughness $Ra/D \leqslant 1,2 \times 10^{-4}$. Pipes with higher relative roughness may be used if the roughness for a distance of at least 10D upstream of the nozzle is within the limits given in Table 1. Information as to how to determine Ra is given in ISO 5167-1.

5.1.6.2   Discharge coefficient, C

The discharge coefficient, C, is given by Equation (3):

$$C = 0,990\,0 - 0,226\,2\beta^{4,1} - \left(0,001\,75\beta^2 - 0,003\,3\beta^{4,15}\right)\left(\frac{10^6}{Re_D}\right)^{1,15} \tag{3}$$

Values of C as a function of β and Re_D are given for convenience in Table A.1. These values are not intended for precise interpolation. Extrapolation is not permitted.

5.1.6.3 Expansibility [expansion] factor, ε

The expansibility [expansion] factor, ε, is calculated by means of Equation (4):

$$\varepsilon = \sqrt{\left(\frac{\kappa \tau^{2/\kappa}}{\kappa - 1}\right)\left(\frac{1 - \beta^4}{1 - \beta^4 \tau^{2/\kappa}}\right)\left(\frac{1 - \tau^{(\kappa-1)/\kappa}}{1 - \tau}\right)} \tag{4}$$

Equation (4) is applicable only for values of β, D and Re_D as specified in 5.1.6.1. Test results for determination of ε are only known for air, steam and natural gas. However, there is no known objection to using the same formula for other gases and vapours for which the isentropic exponent is known.

However, Equation (4) is applicable only if $p_2/p_1 \geqslant 0{,}75$.

Values of the expansibility [expansion] factor for a range of isentropic exponents, pressure ratios and diameter ratios are given for convenience in Table A.4. These values are not intended for precise interpolation. Extrapolation is not permitted.

5.1.7 Uncertainties

5.1.7.1 Uncertainty of discharge coefficient C

When β, D, Re_D and Ra/D are assumed to be known without error, the relative uncertainty of the value of C is equal to

— 0,8 % for $\beta \leqslant 0{,}6$;

— $(2\beta - 0{,}4)$ % for $\beta > 0{,}6$.

5.1.7.2 Uncertainty of expansibility [expansion] factor ε

The relative uncertainty of ε is equal to

$$2\frac{\Delta p}{p_1} \text{ \%}$$

5.1.8 Pressure loss, $\Delta\varpi$

The pressure loss, $\Delta\varpi$, for the ISA 1932 nozzle is approximately related to the differential pressure Δp by Equation (5)

$$\Delta\varpi = \frac{\sqrt{1 - \beta^4(1 - C^2)} - C\beta^2}{\sqrt{1 - \beta^4(1 - C^2)} + C\beta^2}\Delta p \tag{5}$$

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

The pressure loss coefficient, K, for the ISA 1932 nozzle is

$$K = \left[\frac{\sqrt{1 - \beta^4(1 - C^2)}}{C\beta^2} - 1\right]^2 \tag{6}$$

where K is defined by Equation (7):

$$K = \frac{\Delta \varpi}{\frac{1}{2}\rho_1 U^2} \tag{7}$$

5.2 Long radius nozzles

5.2.1 General

There are two types of long radius nozzle, which are called

— high-ratio nozzles ($0{,}25 \leqslant \beta \leqslant 0{,}8$), and

— low-ratio nozzles ($0{,}20 \leqslant \beta \leqslant 0{,}5$).

For β values between 0,25 and 0,5 either design may be used.

Figure 2 illustrates the geometric shapes of long radius nozzles, showing cross-sections passing through the throat centrelines.

The reference letters used in the text refer to those shown on Figure 2.

Both types of nozzles consist of a convergent inlet, whose shape is a quarter ellipse, and a cylindrical throat.

That part of the nozzle which is inside the pipe shall be circular, with the possible exception of the holes of the pressure tappings.

5.2.2 Profile of high-ratio nozzle

5.2.2.1 The inner face can be characterized by

— a convergent section A,

— a cylindrical throat B, and

— a plain end C.

5.2.2.2 The convergent section A has the shape of a quarter ellipse.

The centre of the ellipse is at a distance $D/2$ from the axial centreline. The major centreline of the ellipse is parallel to the axial centreline. The value of half the major axis is $D/2$. The value of half the minor axis is $(D-d)/2$.

The profile of the convergent section shall be checked by means of a template. Two diameters of the convergent section in the same plane perpendicular to the centreline shall not differ from each other by more than 0,1 % of their mean value.

5.2.2.3 The throat B has a diameter d and a length $0{,}6d$.

The value d of the diameter of the throat shall be taken as the mean of the measurements of at least four diameters distributed in axial planes and at approximately equal angles to each other.

The throat shall be cylindrical. Any diameter of any cross-section shall not differ by more than 0,05 % from the value of the mean diameter. Measurement at a sufficient number of cross-sections shall be made to determine that under no circumstances is the throat divergent in the direction of flow; within the stated uncertainty limits it may be slightly convergent. The section nearest the outlet is particularly important in this respect. This requirement is considered to be satisfied when the deviations in the length of any of the measured diameters comply with the said requirement in respect of its deviation from the mean.

a) **High ratio** $0,25 \leqslant \beta \leqslant 0,8$

b) **Low ratio** $0,2 \leqslant \beta \leqslant 0,5$

a   Direction of flow.

Figure 2 — Long radius nozzles

5.2.2.4   The distance between the pipe wall and the outside face of the throat shall be greater than or equal to 3 mm.

5.2.2.5   The thickness H shall be greater than or equal to 3 mm and less than or equal to $0,15D$. The thickness F of the throat shall be greater than or equal to 3 mm, unless $D \leqslant 65$ mm, in which case F shall be greater than or equal to 2 mm. The thickness shall be sufficient to prevent distortion due to machining stresses.

5.2.2.6   The surface of the inner face shall have a roughness criterion $Ra \leqslant 10^{-4}d$.

5.2.2.7   The shape of the downstream (outside) face is not specified but shall comply with 5.2.2.4 and 5.2.2.5 and the last sentence of 5.2.1.

5.2.3   Profile of low-ratio nozzle

5.2.3.1   The requirements given in 5.2.2 for the high-ratio nozzle shall apply also to the low-ratio nozzle with the exception of the shape of the ellipse itself which is given in 5.2.3.2.

5.2.3.2   The convergent inlet A has the shape of a quarter ellipse. The centre of the ellipse is at a distance $d/2 + 2d/3 = 7d/6$ from the axial centreline. The major axis of the ellipse is parallel to the axial centreline. The value of half the major axis is d. The value of half the minor axis is $2d/3$.

5.2.4   Material and manufacture

The long radius nozzle may be manufactured from any material and in any way, provided that it remains in accordance with the foregoing description during flow measurement.

5.2.5   Pressure tappings

5.2.5.1   The centreline of the upstream tapping shall be at $1D^{+0,2D}_{-0,1D}$ from the inlet face of the nozzle.

The centreline of the downstream tapping shall be at $0,50D \pm 0,01D$ from the inlet face of the nozzle except in the case of a low ratio nozzle with $\beta < 0,318\ 8$ for which the centreline of the downstream tapping shall be at $1,6d^{+0}_{-0,02D}$ from the inlet face of the nozzle.

When installing the pressure tappings, due account shall be taken of the thickness of the gaskets and/or sealing material.

5.2.5.2   The centreline of the tapping shall meet the pipe centreline at an angle as near to 90° as possible but in every case within 3° of the perpendicular. At the point of break-through the hole shall be circular. The edges shall be flush with the internal surface of the pipe wall and as sharp as possible. To ensure the elimination of all burrs or wire edges at the inner edge, rounding is permitted but shall be kept to a minimum and, where it can be measured, its radius shall be less than one-tenth of the pressure-tapping diameter. No irregularity shall appear inside the connecting hole, on the edges of the hole drilled in the pipe wall or on the pipe wall close to the pressure tapping. Conformity of the pressure tappings with the requirements of this paragraph may be judged by visual inspection.

The diameter of pressure tappings shall be less than $0,13D$ and less than 13 mm.

No restriction is placed on the minimum diameter, which is determined in practice by the need to prevent accidental blockage and to give satisfactory dynamic performance. The upstream and downstream tappings shall have the same diameter.

The pressure tappings shall be circular and cylindrical over a length of at least 2,5 times the internal diameter of the tapping, measured from the inner wall of the pipeline.

The centrelines of the pressure tappings may be located in any axial plane of the pipeline.

The axis of the upstream tapping and that of the downstream tapping may be located in different axial planes.

5.2.6 Coefficients of long radius nozzles

5.2.6.1 Limits of use

The long radius nozzles shall only be used in accordance with this part of ISO 5167 when

— 50 mm $\leqslant D \leqslant$ 630 mm

— $0,2 \leqslant \beta \leqslant 0,8$

— $10^4 \leqslant Re_D \leqslant 10^7$

— $Ra/D \leqslant 3,2 \times 10^{-4}$ in the upstream pipe work.

Pipes with higher relative roughness may be used if the roughness for a distance of at least $10D$ upstream of the nozzle is within the limit given above. Information as to how to determine Ra is given in ISO 5167-1.

NOTE Most of the data on which this pipe roughness limit is based, were probably collected in the range $Re_d \leqslant 10^6$; at higher Reynolds numbers more stringent limits on pipe roughness are probably required.

5.2.6.2 Discharge coefficient, C

The discharge coefficients, C, are the same for both types of long radius nozzle when the tappings are in accordance with 5.2.5.

The discharge coefficient, C, is given by Equation (8), when referring to the upstream pipe Reynolds number Re_D:

$$C = 0,996\,5 - 0,006\,53\sqrt{\frac{10^6\,\beta}{Re_D}} \tag{8}$$

When referring to the Reynolds number at the throat Re_d, Equation (8) becomes

$$C = 0,996\,5 - 0,006\,53\sqrt{\frac{10^6}{Re_d}} \tag{9}$$

and, in this case, C is independent of the diameter ratio β.

Values of C as a function of β and Re_D are given for convenience in Table A.2. These values are not intended for precise interpolation. Extrapolation is not permitted.

5.2.6.3 Expansibility [expansion] factor, ε

The indications given in 5.1.6.3 apply also to the expansibility [expansion] factor for long radius nozzles, but within the limits of use specified in 5.2.6.1.

5.2.7 Uncertainties

5.2.7.1 Uncertainty of discharge coefficient C

When β and Re_d are assumed to be known without error, the relative uncertainty of the value of C is 2,0 % for all values of β between 0,2 and 0,8.

5.2.7.2 Uncertainty of expansibility [expansion] factor ε

The relative uncertainty of ε is equal to

$$2\frac{\Delta p}{p_1} \;\% \tag{10}$$

5.2.8 Pressure loss, $\Delta\varpi$

Subclause 5.1.8 applies equally to the pressure loss of long radius nozzles.

5.3 Venturi nozzles

5.3.1 General shape

5.3.1.1 The profile of the Venturi nozzle (see Figure 3) is axisymmetric. It consists of a convergent section, with a rounded profile, a cylindrical throat and a divergent section.

5.3.1.2 The upstream face is identical with that of an ISA 1932 nozzle (see Figure 1).

5.3.1.3 The flat inlet part A is limited by a circumference centred on the axis of revolution, with a diameter of 1,5d, and by the inside circumference of the pipe, of diameter D.

When $d = 2D/3$, the radial width of this flat part is zero.

When d is greater than 2D/3, the upstream face of the nozzle does not include a flat inlet part within the pipe. In this case, the nozzle is manufactured as if D is greater than 1,5d and the inlet flat part is then faced off so that the largest diameter of the convergent profile is just equal to D.

5.3.1.4 The arc of circumference B is tangential to the flat inlet part A when $d < 2D/3$ while its radius R_1 is equal to 0,2$d \pm$ 0,02d for $\beta < 0,5$ and to 0,2$d \pm$ 0,006d for $\beta \geqslant 0,5$. Its centre is at 0,2d from the inlet plane and at 0,75d from the axial centreline.

5.3.1.5 The arc of circumference C is tangential to the arc of circumference B and to the throat E. Its radius R_2 is equal to d/3 $\pm$ 0,033d for $\beta < 0,5$ and to d/3 $\pm$ 0,01d for $\beta \geqslant 0,5$. Its centre is at $d/2 + d/3 = 5d/6$ from the axial centreline and at

$$a_n = \left(\frac{12+\sqrt{39}}{60}\right)d = 0{,}304\ 1d$$

from the flat inlet part A.

5.3.1.6 The throat (see Figure 3) consists of a part E of length 0,3d and a part F of a length 0,4d to 0,45d.

The value d of the diameter of the throat shall be taken as the mean of measurements of at least four diameters distributed in axial planes and at approximately equal angles to each other.

The throat shall be cylindrical. No diameter of any cross-section shall differ by more than 0,05 % from the value of the mean diameter. This requirement is considered as satisfied when the deviations in the length of any of the measured diameters comply with the said requirement in respect of deviation from the mean.

5.3.1.7 The divergent section (see Figure 3) shall be connected with the part F of the throat without a rounded part, but any burrs shall be removed.

The included angle of the divergent section, φ, shall be less than or equal to 30°.

The length L of the divergent section has practically no influence on the discharge coefficient C. However, the included angle of the divergent section, and hence the length, does influence the pressure loss.

Key

1   truncated divergent section
2   non-truncated divergent section

a   Direction of flow.

Figure 3 — Venturi nozzle

5.3.1.8   A Venturi nozzle is called "truncated" when the outlet diameter of the divergent section is less than the diameter D and "not truncated" when the outlet diameter is equal to diameter D. The divergent portion may be truncated by about 35 % of its length without notably modifying the pressure loss of the device.

5.3.1.9   The internal surfaces of the Venturi nozzle shall have a roughness criterion $Ra \leqslant 10^{-4}d$.

5.3.2   Material and manufacture

5.3.2.1   The Venturi nozzle may be manufactured from any material provided that it is in accordance with the description given in 5.3.1 and will remain so during use. In particular, the Venturi nozzle shall be clean when the flow measurements are made.

5.3.2.2   The Venturi nozzle is usually made of metal and shall be erosion and corrosion proof against the fluid with which it is to be used.
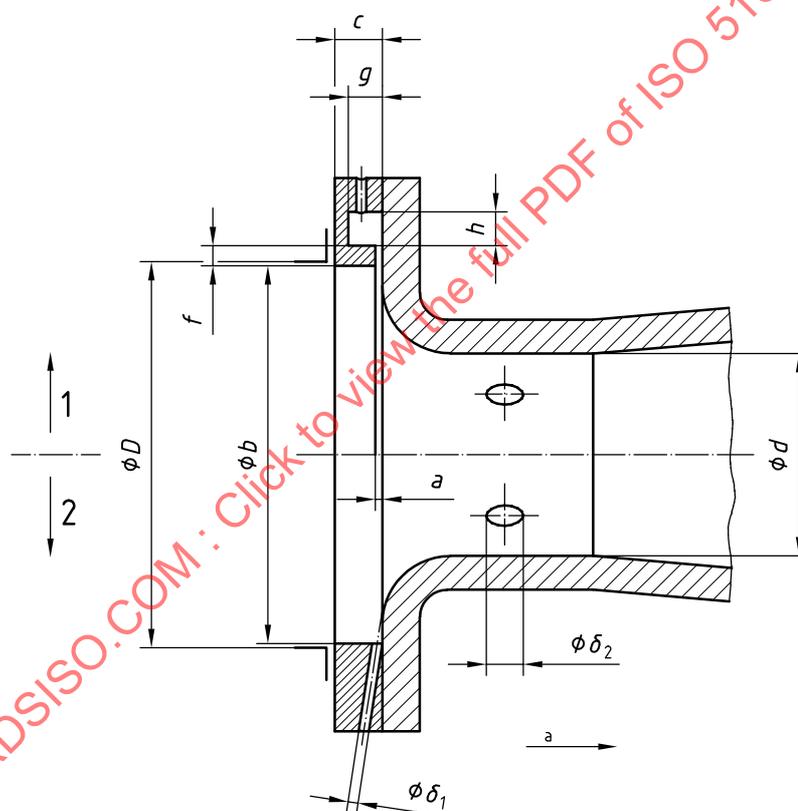
5.3.3 Pressure tappings

5.3.3.1   Angular position of the pressure tappings

The centrelines of the pressure tappings may be located in any axial sector of the pipe. However, consideration should be given to tapping position if contaminants, liquid droplets or gas bubbles are likely to be present. In these cases the base and top of the pipe should be avoided.

5.3.3.2   Upstream pressure tappings

The upstream pressure tappings shall be corner tappings (see 5.1.5.1). The tappings may be located either in the pipe or its flanges or in carrier rings as shown in Figure 4.

Key

1   with annular slot
2   with individual corner tappings

a   Direction of flow.

Figure 4 — Venturi nozzle — Pressure tappings

5.3.3.3   Throat pressure tappings

The throat pressure tappings shall comprise at least four single pressure tappings leading into an annular chamber, piezometer ring or, if there are four tappings, a "triple-T" arrangement (see 5.4.3 of ISO 5167-1:2003). Annular slots or interrupted slots shall not be used.

The centrelines of the pressure tappings shall meet the centreline of the Venturi nozzle and shall be at equal angles to each other. The centrelines of the throat pressure tappings shall lie in the plane perpendicular to the centreline of the Venturi nozzle, which is the imaginary border between the parts E and F of the cylindrical throat.

The diameter δ_2 of the individual tappings in the throat of Venturi nozzles shall be less than or equal to $0{,}04d$ and moreover shall be between 2 mm and 10 mm.

The pressure tappings shall be circular and cylindrical over a length of at least 2,5 times the internal diameter of the tappings, measured from the inner wall of the Venturi nozzle.

At the point of break-through the hole shall be circular. The edges shall be flush with the internal surface of the Venturi nozzle wall and as sharp as possible. To ensure the elimination of all burrs or wire edges at the inner edge, rounding is permitted but shall be kept to a minimum and where it can be measured, its radius shall be less than one-tenth of the pressure-tapping diameter. No irregularity shall appear inside the connecting hole, on the edges of the hole drilled in the Venturi nozzle, or on the pipe wall close to the pressure tapping.

Conformity of the pressure tappings with the requirements specified may be judged by visual inspection.

5.3.4 Coefficients

5.3.4.1 Limits of use

Venturi nozzles shall only be used in accordance with this part of ISO 5167 when

— $65 \text{ mm} \leqslant D \leqslant 500 \text{ mm}$

— $d \geqslant 50 \text{ mm}$

— $0{,}316 \leqslant \beta \leqslant 0{,}775$

— $1{,}5 \times 10^5 \leqslant Re_D \leqslant 2 \times 10^6$

In addition, the roughness of the pipe shall conform to the values given in Table 2.

Most of the experiments on which the values of the discharge coefficient C are based were carried out on pipes with a relative roughness $Ra/D \leqslant 1{,}2 \times 10^{-4}$. Pipes with higher relative roughness may be used if the roughness over a distance of at least $10D$ upstream of the Venturi nozzle is within the limits of Table 2. Information as to how to determine Ra is given in ISO 5167-1.

Table 2 — Upper limits of relative roughness of the upstream pipe for Venturi nozzles

β	$\leqslant 0{,}35$	0,36	0,38	0,40	0,42	0,44	0,46	0,48	0,50	0,60	0,70	0,775
$10^4\, Ra/D$	8,0	5,9	4,3	3,4	2,8	2,4	2,1	1,9	1,8	1,4	1,3	1,2

5.3.4.2 Discharge coefficient, C

The discharge coefficient, C, is given by the formula

$$C = 0{,}985\,8 - 0{,}196\,\beta^{4,5}$$

Values of C as a function of β are given for convenience in Table A.3. They are not intended for precise interpolation. Extrapolation is not permitted.

NOTE   Within the limits specified in 5.3.4.1, C is independent of the Reynolds number and of the pipe diameter D.

5.3.4.3 Expansibility [expansion] factor, ε

The indications given in 5.1.6.3 apply also to the expansibility [expansion] factor for Venturi nozzles, but within the limits of use specified in 5.3.4.1.

5.3.5 Uncertainties

5.3.5.1 Uncertainty of discharge coefficient C

Within the limits of use specified in 5.3.4.1 and when β is assumed to be known without error, the relative uncertainty of the values of the discharge coefficient C is equal to

$$(1,2 + 1,5\beta^4)\ \%$$

5.3.5.2 Uncertainty of expansibility [expansion] factor ε

The relative uncertainty of ε is equal to

$$(4 + 100\beta^8)\frac{\Delta p}{p_1}\ \%$$

5.3.6 Pressure loss

The indications given in 5.3.6 apply to Venturi nozzles when the divergent angle is not greater than 15°.

The relative pressure loss, ξ, is the value of the pressure loss $\Delta p'' - \Delta p'$ related to the differential pressure Δp:

$$\xi = \frac{\Delta p'' - \Delta p'}{\Delta p}$$

It is shown in Figure 5 and depends, in particular, on:

— the diameter ratio (ξ decreases when β increases);

— the Reynolds number (ξ decreases when Re_D increases);

— the manufacturing characteristics of the Venturi nozzle, i.e. angle of the divergent, manufacturing of the convergent, surface finish of the different parts, etc (ξ increases when φ and Ra/D increase);

— the installation conditions (good alignment, roughness of the upstream conduit, etc.).

For guidance, when the divergent angle is not greater than 15° the value of the relative pressure loss can be accepted as being generally between 5 % and 20 %.
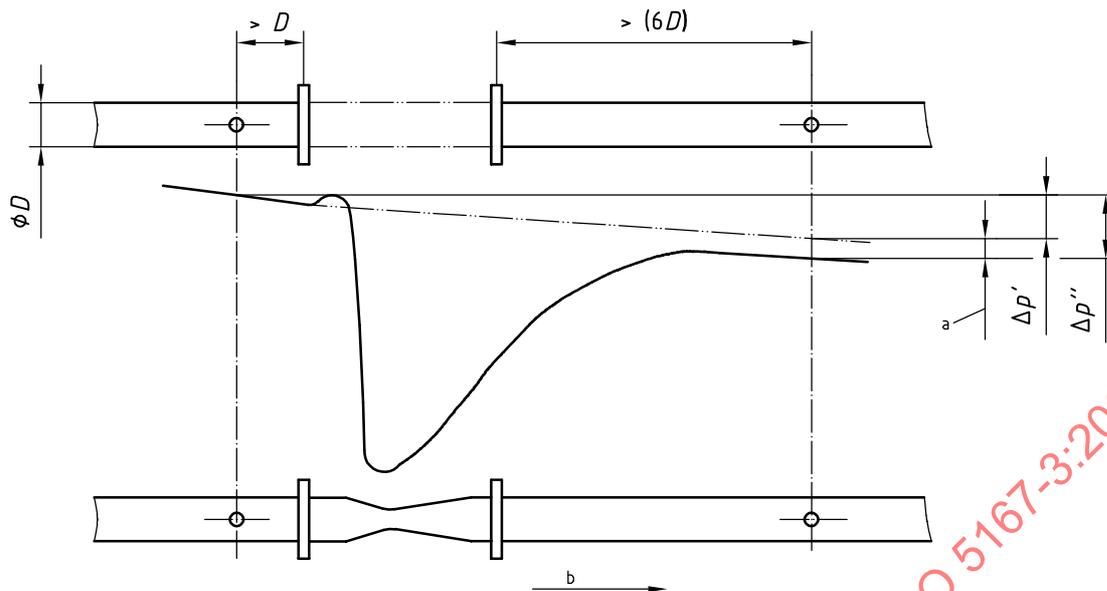
^a Pressure loss.

^b Direction of flow.

Figure 5 — Pressure loss across a Venturi nozzle

6 Installation requirements

6.1 General

General installation requirements for pressure differential devices are contained in Clause 7 of ISO 5167-1:2003 and should be followed in conjunction with the additional specific installation requirements for nozzles and Venturi nozzles given in this clause. The general requirements for flow conditions at the primary device are given in 7.3 of ISO 5167-1:2003. The requirements for use of a flow conditioner are given in 7.4 of ISO 5167-1:2003. For some commonly used fittings, as specified in Table 3, the minimum straight lengths of pipe indicated may be used (detailed requirements are given in 6.2).

6.2 Minimum upstream and downstream straight lengths for installation between various fittings and the primary device

6.2.1 The minimum straight lengths of pipe required upstream and downstream of the primary device for the specified fittings in the installation without flow conditioners are given in Table 3.

6.2.2 When a flow conditioner is not used the lengths specified in Table 3 shall be regarded as the minimum values. For research and calibration work in particular, it is recommended that the upstream values specified in Table 3 be increased by at least a factor of 2 to minimize the measurement uncertainty.

6.2.3 When the straight lengths used are equal to or longer than the values specified in Columns A of Table 3 for "zero additional uncertainty", it is not necessary to increase the uncertainty in discharge coefficient to take account of the effect of the particular installation.

6.2.4 When the upstream or downstream straight length is shorter than the value corresponding to "zero additional uncertainty" shown in Columns A and either equal to or greater than the "0,5 % additional uncertainty" value shown in Columns B of Table 3 for a given fitting, an additional uncertainty of 0,5 % shall be added arithmetically to the uncertainty in the discharge coefficient.

Table 3 — Required straight lengths for nozzles and Venturi nozzles

Values expressed as multiples of internal diameter, D

Diameter ratio β [a]	Upstream (inlet) side of the primary device																						Downstream (outlet) side of the primary device	
	Single 90° bend or tee (flow from one branch only)		Two or more 90° bends in the same plane		Two or more 90° bends in different planes		Reducer 2D to D over a length of 1,5D to 3D		Expander 0,5D to D over a length of D to 2D		Globe valve fully open		Full bore ball or gate valve fully open		Abrupt symmetrical reduction		Thermometer pocket or well [b] of diameter ≤ 0,03D		Thermometer pocket or well [b] of diameter between 0,03D and 0,13D		Fittings (Columns 2 to 8)	
1	2		3		4		5		6		7		8		9		10		11		12	
	A[c]	B[d]	A[c]	B[d]	A[c]	B[d]	A[c]	B[d]	A[c]	B[d]	A[c]	B[d]	A[c]	B[d]	A[c]	B[d]	A[c]	B[d]	A[c]	B[d]	A[c]	B[d]
0,20	10	6	14	7	34	17	5	e	16	8	18	9	12	6	30	15	5	3	20	10	4	2
0,25	10	6	14	7	34	17	5	e	16	8	18	9	12	6	30	15	5	3	20	10	4	2
0,30	10	6	16	8	34	17	5	e	16	8	18	9	12	6	30	15	5	3	20	10	5	2,5
0,35	12	6	16	8	36	18	5	e	16	8	18	9	12	6	30	15	5	3	20	10	5	2,5
0,40	14	7	18	9	36	18	5	e	16	8	20	10	12	6	30	15	5	3	20	10	6	3
0,45	14	7	18	9	38	19	5	e	17	9	20	10	12	6	30	15	5	3	20	10	6	3
0,50	14	7	20	10	40	20	6	5	18	9	22	11	12	6	30	15	5	3	20	10	6	3
0,55	16	8	22	11	44	22	8	5	20	10	24	12	14	7	30	15	5	3	20	10	6	3
0,60	18	9	26	13	48	24	9	5	22	11	26	13	14	7	30	15	5	3	20	10	7	3,5
0,65	22	11	32	16	54	27	11	6	25	13	28	14	16	8	30	15	5	3	20	10	7	3,5
0,70	28	14	36	18	62	31	14	7	30	15	32	16	20	10	30	15	5	3	20	10	7	3,5
0,75	36	18	42	21	70	35	22	11	38	19	36	18	24	12	30	15	5	3	20	10	8	4
0,80	46	23	50	25	80	40	30	15	54	27	44	22	30	15	30	15	5	3	20	10	8	4

NOTE 1   The minimum straight lengths required are the lengths between various fittings located upstream or downstream of the primary device and the primary device itself. All straight lengths shall be measured from the upstream face of the primary device.

NOTE 2   These lengths are not based on modern data.

a   For some types of primary device not all values of β are permissible.

b   The installation of thermometer pockets or wells will not alter the required minimum upstream straight lengths for the other fittings.

c   Column A for each fitting gives lengths corresponding to "zero additional uncertainty" values (see 6.2.3).

d   Column B for each fitting gives lengths corresponding to "0,5 % additional uncertainty" values (see 6.2.4).

e   The straight length in Column A gives zero additional uncertainty; data are not available for shorter straight lengths which could be used to give the required straight lengths for Column B.

6.2.5 This part of ISO 5167 cannot be used to predict the value of any additional uncertainty when either

a) straight lengths shorter than the "0,5 % additional uncertainty" values specified in Columns B of Table 3 are used, or

b) both the upstream and downstream straight lengths are shorter than the "zero additional uncertainty" values specified in Columns A of Table 3.

6.2.6 The valves included in Table 3 shall be set fully open during the flow measurement process. It is recommended that control of the flowrate be achieved by valves located downstream of the primary device. Isolating valves located upstream of the primary device shall be set fully open, and these valves shall be full bore. The valve should be fitted with stops for alignment of the ball or gate, in the open position. The valve shown in Table 3 is one which is of the same nominal diameter as the upstream pipe, but whose bore diameter is such that a diameter step is larger than that permitted in 6.4.3.

6.2.7 In the metering system, upstream valves which are match-bored to the adjacent pipework and are designed in such a manner that in the fully opened condition there are no steps greater than those permitted in 6.4.3, can be regarded as part of the metering pipework length and do not need to have added lengths as in Table 3 provided that when flow is being measured they are fully open.

6.2.8 The values given in Table 3 were determined experimentally with a very long straight length mounted upstream of the fitting in question so that the flow immediately upstream of the fitting was considered as fully developed and swirl-free. Since in practice such conditions are difficult to achieve, the following information may be used as a guide for normal installation practice.

a) If the primary device is installed in a pipe leading from an upstream open space or large vessel, either directly or through any other fittings covered by Table 3, the total length of pipe between the open space and the primary device shall never be less than $30D$. If a fitting covered by Table 3 is installed then the straight lengths specified in the Tables shall also apply between this fitting and the primary device.

A metering system header is not an open space or large vessel in this instance. A large vessel shall have a cross-sectional area of at least 10 times that of the metering tube. In the case of a normal header whose cross-sectional area is typically equal to 1,5 times the cross-sectional area of the operating flowmeter tubes, it is strongly recommended that a flow conditioner be installed downstream of the header (see 7.4 of ISO 5167-1:2003) since there will always be distortion of the flow profile and a high probability of swirl.

b) If several fittings of the type covered by Table 3, other than the combinations of 90° bends already covered by these Tables, are placed in series upstream of the primary device the following shall be applied:

   1) Between the fitting immediately upstream of the primary device, fitting 1, and the primary device itself the minimum length criterion given in Table 3 shall be adopted appropriate for the specific primary device.

   2) Furthermore, between fitting 1 and the next fitting further from the primary device (fitting 2), a straight length at least equal to half the product of the diameter of the pipe between fitting 1 and fitting 2 and the number of diameters given in Table 3 for a nozzle of diameter ratio 0,7 used in conjunction with fitting 2 shall be included between fittings 1 and 2 irrespective of the actual β for the nozzle. If either of the minimum straight lengths is selected from Columns B (i.e. prior to taking the half value from fitting 1 to 2) of Table 3, a 0,5 % additional uncertainty shall be added arithmetically to the discharge coefficient uncertainty.

   3) If the upstream metering section has a full bore valve (as in Column 8 of Table 3) preceded by another fitting, e.g. an expander, then the valve can be installed at the outlet of the 2nd fitting from the primary device. The required length between the valve and the 2nd fitting according to 2) should be added to the length between the primary device and the 1st fitting specified in Table 3; see the example in Figure 6. Note that 6.2.8 c) shall also be satisfied (as it is in Figure 6).

c) In addition to the requirement in b) any fitting, treating any two consecutive 90° bends as a single fitting, shall be located at a distance from the primary device at least as great as the distance given by the

product of the pipe diameter at the primary device and the number of diameters required between that fitting and a primary device of the same diameter ratio in Table 3, regardless of the number of fittings between that fitting and the primary device. The distance between the primary device and the fitting shall be measured along the pipe axis. If for any upstream fitting the distance meets this requirement using the number of diameters in Column B, but not that in Column A, then a 0,5 % additional uncertainty shall be added arithmetically to the discharge coefficient uncertainty, but this additional uncertainty shall not be added more than once under the provisions of b) and c).

d) For the case of two or more 90° bends, these shall be treated as a single fitting in accordance with Table 3 Columns 3 and 4, if the length between the consecutive bends is less than 15D.
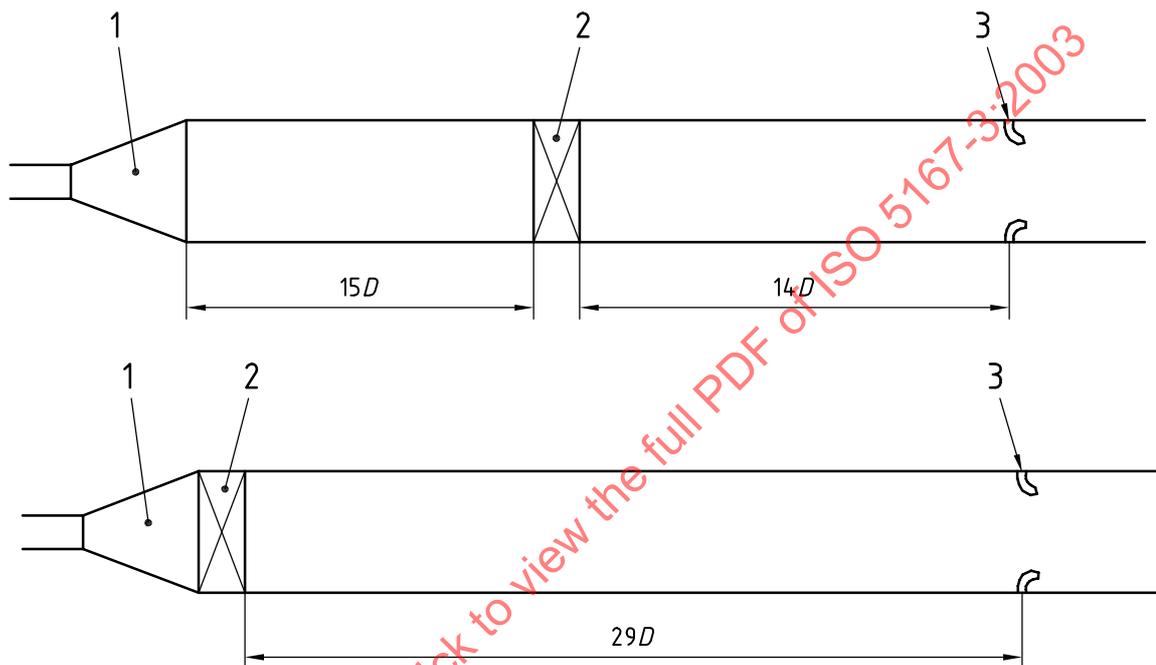
Key

1   expander
2   full bore ball valve or gate valve fully open
3   nozzle

Figure 6 — Layout including a full bore valve for β = 0,6

6.2.9   By way of example three cases of the application of 6.2.8 b) and c) are considered. In each case the second fitting from the nozzle is two bends in perpendicular planes and the nozzle has diameter ratio 0,65.

a) If the first fitting is a full bore ball valve fully open [see Figure 7a)] the distance between the valve and the nozzle shall be at least 16D (from Table 3) and that between the two bends in perpendicular planes and the valve shall be at least 31D [from 6.2.8 b)]; the distance between the two bends in perpendicular planes and the nozzle shall be at least 54D [from 6.2.8 c)]. If the valve has length 1D an additional total length of 6D is required which may be either upstream or downstream of the valve or partly upstream and partly downstream of it. The recommendations given in 6.2.8 b) 3) could be applied and the valve moved to a position adjacent to the two bends in perpendicular planes provided that there is at least 54D from the two bends in perpendicular planes to the nozzle [see Figure 7 b)].

b) If the first fitting is a reducer from 2D to D over a length of 2D [see Figure 7 c)] the distance between the reducer and the nozzle shall be at least 11D (from Table 3) and that between the two bends in perpendicular planes and the reducer shall be at least 31 × 2D [from 6.2.8 b)]; the distance between the two bends in perpendicular planes and the nozzle shall be at least 54D [from 6.2.8 c)]. So no additional length is required because of 6.2.8 c).
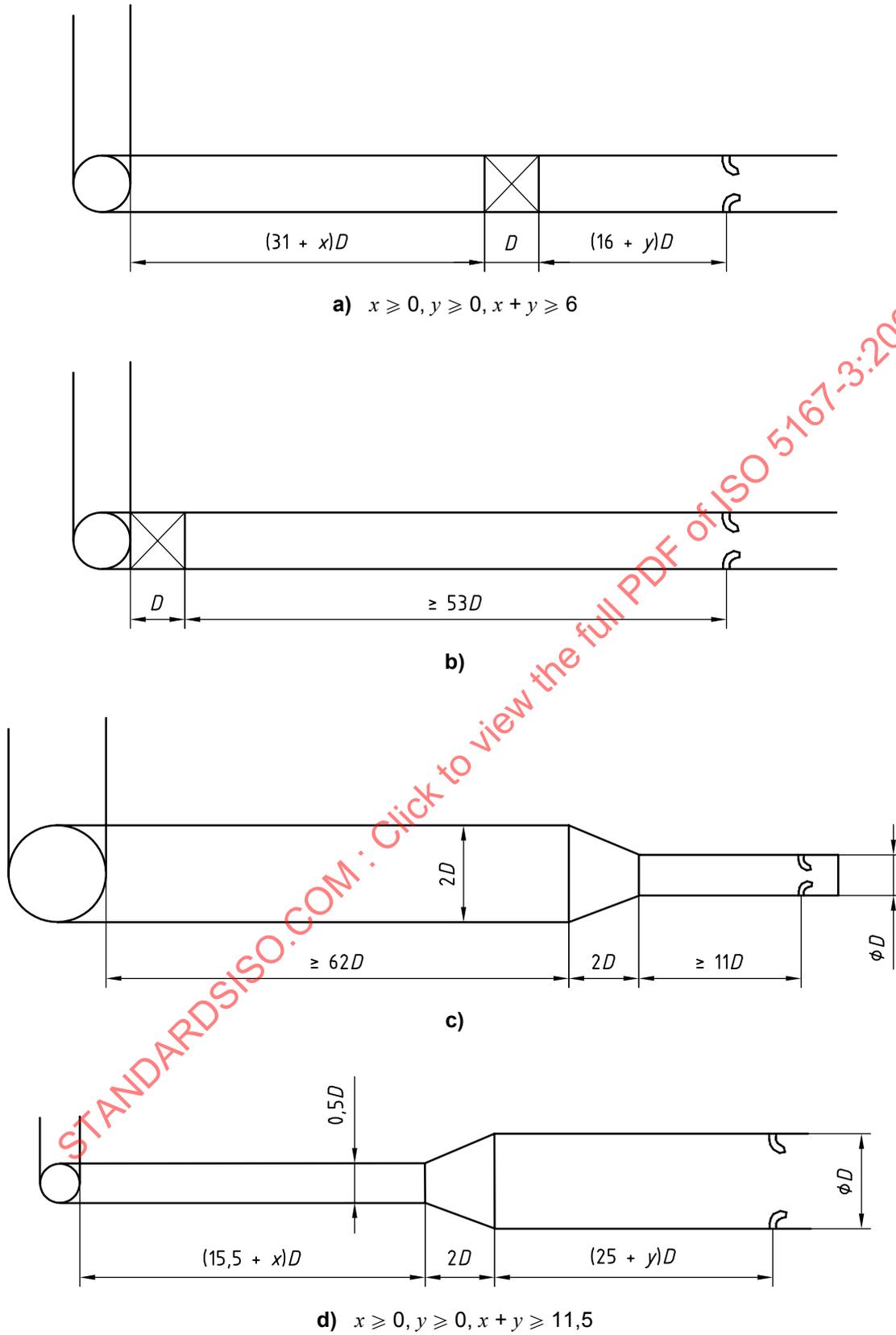
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a) $x \geqslant 0, y \geqslant 0, x + y \geqslant 6$

b)

c)

d) $x \geqslant 0, y \geqslant 0, x + y \geqslant 11,5$

Figure 7 — Examples of acceptable installations (see 6.2.9)

c)   If the first fitting is an expander from 0,5D to D over a length of 2D [see Figure 7d)], the distance between the expander and the nozzle shall be at least 25D (from Table 3) and that between the two bends in perpendicular planes and the expander shall be at least 31 × 0,5D [from 6.2.8 b)]; the distance between the two bends in perpendicular planes and the nozzle shall be at least 54D [from 6.2.8 c)]. So an additional total length of 11,5D is required which may be either upstream or downstream of the expander or partly upstream and partly downstream of it.

6.3   Flow conditioners

A flow conditioner can be used to reduce upstream straight lengths either through meeting the compliance test given in 7.4.1 of ISO 5167-1:2003, in which case it can be used downstream of any upstream fitting, or through meeting the requirements of 7.4.2 of ISO 5167-1:2003, which gives additional possibilities outside the compliance test. In either case, the test shall be carried out using the same type of nozzle as that used for the measurement of flow.

6.4   Circularity and cylindricality of the pipe

6.4.1   The 2D length of the upstream pipe section adjacent to the nozzle (or to the carrier ring if there is one) shall be manufactured with special care and shall meet the requirement that no diameter in any plane in this length shall differ by more than 0,3 % from the mean value of D obtained from the measurements specified in 6.4.2.

6.4.2   The value for the pipe diameter D shall be the mean of the internal diameters over a length of 0,5D upstream of the upstream pressure tapping. The internal mean diameter shall be the arithmetic mean of measurements of at least twelve diameters, namely four diameters positioned at approximately equal angles to each other, distributed in each of at least three cross-sections evenly distributed over a length of 0,5D, two of these sections being at distance 0D and 0,5D from the upstream tapping and one being in the plane of the weld in the case of a weld-neck construction. If there is a carrier ring (see Figure 4) this value of 0,5D shall be measured from the upstream edge of the carrier ring.

6.4.3   Beyond 2D from the primary device, the upstream pipe run between the primary device and the first upstream fitting or disturbance may be made up of one or more sections of pipe.

Between 2D and 10D from the nozzle no additional uncertainty in the discharge coefficient is involved provided that the diameter step (the difference between the diameters) between any two sections does not exceed 0,3 % of the mean value of D obtained from the measurements specified in 6.4.2. Moreover, the actual step caused by misalignment and/or change in diameter shall not exceed 0,3 % of D at any point of the internal circumference of the pipe. Therefore mating flanges would require the bores to be matched and the flanges aligned on installation. Dowels or self-centring gaskets could be used.

Beyond 10D from the nozzle no additional uncertainty in the discharge coefficient is involved provided that the diameter step (the difference between the diameters) between any two sections does not exceed 2 % of the mean value of D obtained from the measurements specified in 6.4.2. Moreover, the actual step caused by misalignment and/or change in diameter shall not exceed 2 % of D at any point of the internal circumference of the pipe. If the pipe diameter upstream of the step is greater than that downstream of it the permitted diameter and actual steps are increased from 2 % of D to 6 % of D. On each side of the step the pipe shall have a diameter between 0,98D and 1,06D. Beyond 10D from the nozzle, the use of gaskets between sections will not violate this requirement provided that in use they are no thicker than 3,2 mm and they do not protrude into the flow.

Beyond the first location where an expander could be fitted in accordance with Column 6A of Table 3, no additional uncertainty in the discharge coefficient is involved, provided that the diameter step (the difference between the diameters) between any two sections does not exceed 6 % of the mean value of D obtained from the measurements specified in 5.4.2. Moreover, the actual step caused by misalignment and/or change in diameter shall not exceed 6 % of D at any point of the internal circumference of the pipe. On each side of the step, the pipe shall have a diameter between 0,94D and 1,06D. The first location where an expander could be fitted in accordance with Column 6A of Table 3 depends on the diameter ratio of the primary device, for example, it is 22D from the primary device if β = 0,6.

6.4.4 An additional uncertainty of 0,2 % shall be added arithmetically to the uncertainty for the discharge coefficient if the diameter step ΔD between any two sections exceeds the limits given in 6.4.3, but complies with the following relationships:

$$\frac{\Delta D}{D} \leqslant 0,002 \left(\frac{\dfrac{s}{D} + 0,4}{0,1 + 2,3\beta^4} \right) \tag{11}$$

and

$$\frac{\Delta D}{D} \leqslant 0,05 \tag{12}$$

where s is the distance of the step from the upstream pressure tapping or, if a carrier ring is used, from the upstream edge of the recess formed by the carrier ring.

6.4.5 If a step is greater than any one of the limits given in the inequalities above or if there is more than one step outside the limits in 6.4.3, the installation is not in accordance with this part of ISO 5167. For further guidance refer to 6.1.1 of ISO 5167-1:2003.

6.4.6 No diameter of the downstream straight length, considered along a length of at least $2D$ from the upstream face of an ISA 1932 nozzle or a long radius nozzle, shall differ from the mean diameter of the upstream straight length by more than 3 %. This can be judged by checking a single diameter of the downstream straight length.

The diameter of the pipe immediately downstream of a Venturi nozzle need not be measured accurately but it shall be checked that the downstream pipe diameter is not less than 90 % of the diameter at the end of the divergent section. This means that, in most cases, pipes having the same nominal bore as that of the Venturi nozzle tube can be used.

6.5 Location of primary device and carrier rings

6.5.1 The primary device shall be placed in the pipe in such a way that the fluid flows from the upstream face towards the throat.

6.5.2 The primary device shall be perpendicular to the centreline of the pipe to within 1°.

6.5.3 The primary device shall be centred in the pipe. The distance e_x between the centreline of the throat and the centrelines of the pipe on the upstream and downstream sides shall be less than or equal to

$$\frac{0,005D}{0,1 + 2,3\beta^4}$$

In the case where

$$e_x > \frac{0,005D}{0,1 + 2,3\beta^4}$$

this part of ISO 5167 gives no information by which to predict the value of any additional uncertainty to be taken into account.

6.5.4 When carrier rings are used, they shall be centred such that they do not protrude into the pipe at any point.