FINAL
DRAFT

INTERNATIONAL
STANDARD

ISO/FDIS 5167-3

ISO/TC **30**/SC **2**

Secretariat: **BSI**

Voting begins on:
2022-06-29

Voting terminates on:
2022-09-21

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

Part 3:
Nozzles and Venturi nozzles

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

Partie 3: Tuyères et Venturi-tuyères

ISO/CEN PARALLEL PROCESSING

Reference number
ISO/FDIS 5167-3:2022(E)

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Published in Switzerland

Contents

Page

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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee 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 third edition cancels and replaces the second edition (ISO 5167-3:2020), of which it constitutes a minor revision. The main changes are as follows:.

— harmonization with ISO/IEC Guide 98-3;

— minor changes to give harmonization with the other parts of ISO 5167.

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

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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 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. ISO 5167 also provides methdology for bespoke calibration of differential pressure meters.

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 (ISO 2186) and tertiary devices will be mentioned only occasionally.

Aspects of safety are not dealt within ISO 5167-1 to ISO 5167-6. It is the responsibility of the user to ensure that the system meets applicable safety regulations.

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

This document 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 document deals with

a) three types of standard nozzles:
   1) ISA 1932[1] nozzle;
   2) the long radius nozzle[2];
   3) the throat-tapped nozzle
b) the Venturi nozzle.

The three types of standard nozzle are fundamentally different and are described separately in this document. 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 all 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.

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.

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

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

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 and ISO 5167-1 apply.

ISO and IEC maintain terminological 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/

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 document.

The mass flowrate can be determined by Formula (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 ISO 5167-1:2022, Clause 8.

Similarly, the value of the volume flowrate can be calculated by Formula (2) 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;

q_V is the volume flowrate.

Computation of the flowrate, 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. Tables A.1 to A.5 are given for convenience. Tables A.1, A.2 and A.4 give the values of C as a function of β. Table A.3 gives the values of C as a function of Re_d. Table A.5 gives expansibility (expansion) factors, ε. They are not intended for precise interpolation. Extrapolation is not permitted.

The discharge coefficient C may be dependent on Re_D or 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 Formula (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 with a 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;
- 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 = (2/3)D, the radial width of this flat part is zero.

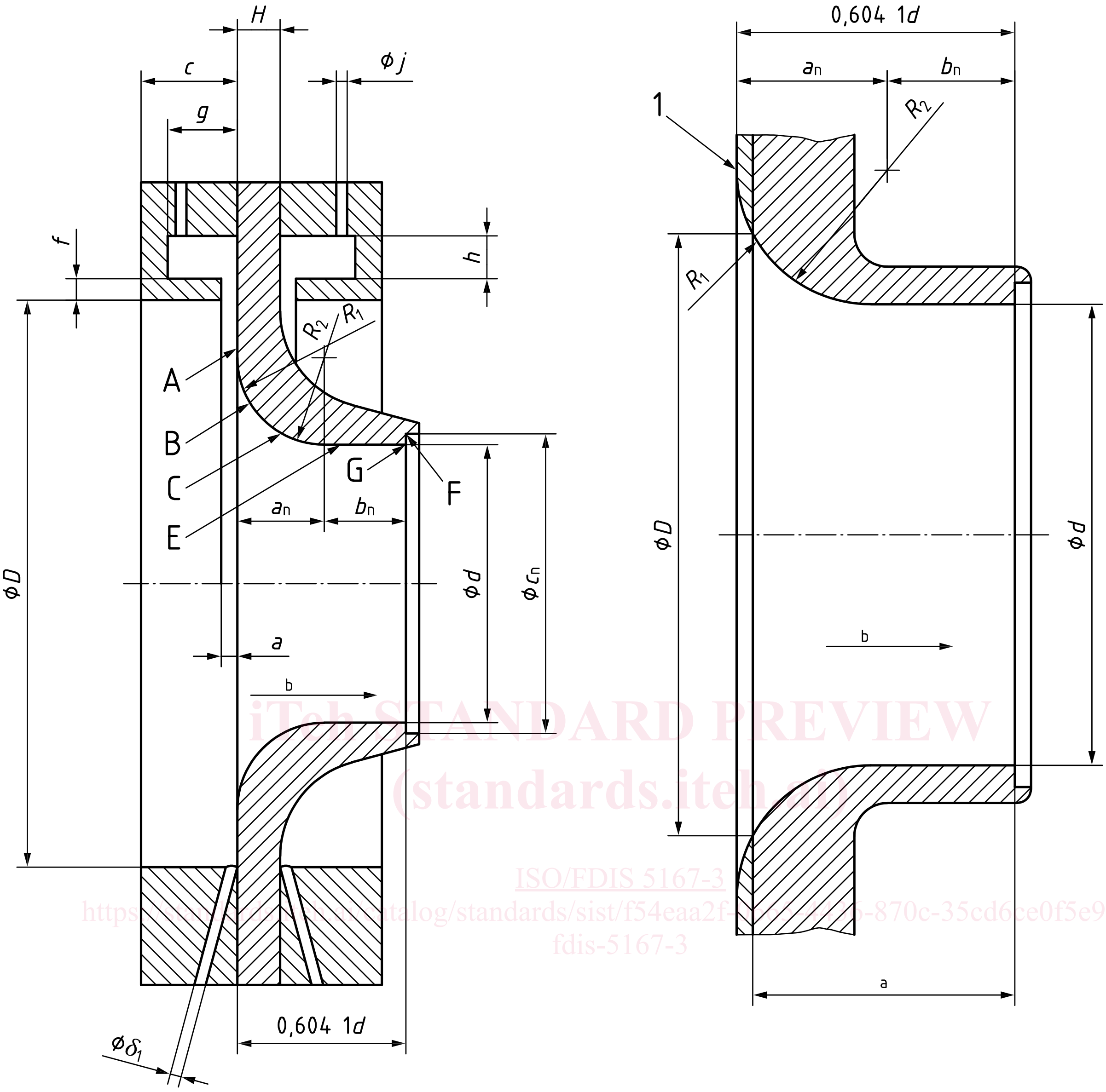
When d is greater than (2/3)D, the upstream face of the nozzle does not include a flat inlet part within the pipe. In this case, the nozzle is manufactured as if D were greater than 1,5d, and the inlet flat part is then faced off so that the largest diameter of the convergent profile is just equal to 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 $d < (2/3)D$ while its radius R_1 is equal to 0,2d ± 0,02d for $\beta < 0{,}5$ and to 0,2d ± 0,006d for $\beta \geq 0{,}5$. 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 $d/3$ ± 0,033d for $\beta < 0{,}5$ and to $d/3$ ± 0,01d for $\beta \geq 0{,}5$. Its centre is at $d/2 + d/3 = (5/6)$ d from the axial centreline and as given by Formula (3), at

$$a_n = \left(\frac{12 + \sqrt{39}}{60} \right) d = 0{,}304\,1\,d \tag{3}$$

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 depth $(c_n - d)/2$ 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

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

and

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

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 such that they have a roughness criterion $Ra \le 10^{-4}d$.

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 $\beta \le 0{,}65$: $0{,}005D \le a$ or $\delta_1 \le 0{,}03D$

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

For any value of β:

- for clean fluids: 1 mm ≤ a or $\delta_1 \leq$ 10 mm
- for vapours, in the case of annular chambers: 1 mm ≤ a ≤ 10 mm
- for vapours and for liquefied gases, in the case of single tappings: 4 mm ≤ δ_1 ≤ 10 mm.

NOTE The requirements on size as a fraction of pipe diameter are based on geometrical similarity to the original nozzle runs on which the discharge coefficient is based. For vapours and for liquefied gases, there are pipe diameters for which it is not possible to manufacture a system using single tappings that is in accordance with this document.

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:

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

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 subclause.

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

- ≤0,15D for $\beta \leq 0{,}67$;
- ≤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 document when

— $50 \text{ mm} \le D \le 500 \text{ mm}$;

— $0{,}3 \le \beta \le 0{,}8$;

and when Re_D is within the following limits:

— for $0{,}30 \le \beta < 0{,}44$ $\quad 7 \times 10^4 \le Re_D \le 10^7$;

— for $0{,}44 \le \beta \le 0{,}80$ $\quad 2 \times 10^4 \le Re_D \le 10^7$.

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	≤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 $Re_D \le 10^6$; 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 document are based were carried out in pipes with a relative roughness $Ra/D \le 1{,}2 \times 10^{-4}$. 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 Formula (5):

$$C = 0{,}990\ 0 - 0{,}226\ 2\beta^{4{,}1} - \left(0{,}001\ 75\beta^2 - 0{,}003\ 3\beta^{4{,}15}\right)\left(\frac{10^6}{Re_D}\right)^{1{,}15} \qquad (5)$$

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 Formula (6):

$$\varepsilon = \sqrt{\left(\frac{\kappa\tau^{2/\kappa}}{\kappa-1}\right)\left(\frac{1-\beta^4}{1-\beta^4\tau^{2/\kappa}}\right)\left(\frac{1-\tau^{(\kappa-1)/\kappa}}{1-\tau}\right)} \qquad (6)$$

Formula (6) 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, Formula (6) is applicable only if $p_2/p_1 \geq 0{,}75$.

Values of the expansibility [expansion] factor for a range of isentropic exponents, pressure ratios and diameter ratios are given for convenience in Table A.5. 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, U_C', the relative expanded uncertainty of the value of C at $k = 2$ (approximately 95 % confidence level), is equal to

— 0,8 % for $\beta \leq 0{,}6$;

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

5.1.7.2 Uncertainty of expansibility [expansion] factor ε

U_ε', the relative expanded uncertainty of the value of ε at $k = 2$ (approximately 95 % confidence level), is equal to

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

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 Formula (7)

$$\Delta\varpi = \frac{\sqrt{1-\beta^4\left(1-C^2\right)}-C\beta^2}{\sqrt{1-\beta^4\left(1-C^2\right)}+C\beta^2}\Delta p \qquad (7)$$

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

$$K = \left[\frac{\sqrt{1-\beta^4\left(1-C^2\right)}}{C\beta^2} - 1 \right]^2 \tag{8}$$

where *K* is defined by Formula (9):

$$K = \frac{\Delta\varpi}{\frac{1}{2}\rho_1 U^2} \tag{9}$$

5.2 Long radius nozzles

5.2.1 General

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

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

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

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;

— 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 0,6*d*.

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.