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

**Part 2:
Orifice plates**

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

ISO 5167-2:2003
Partie 2: Diaphragmes

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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 5167-2, together with the second edition of ISO 5167-1 and the first editions of ISO 5167-3 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 tapplings. All other instruments or devices required for the measurement are known as “secondary devices”. ISO 5167 (all parts) covers primary devices; secondary devices¹⁾ 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 tapplings, D and $D/2$ pressure tapplings²⁾, and flange pressure tapplings.
- c) ISO 5167-3 specifies ISA 1932 nozzles³⁾, long radius nozzles and Venturi nozzles, which differ in shape and in the position of the pressure tapplings.
- d) ISO 5167-4 specifies classical Venturi tubes⁴⁾.

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.

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 tapplings 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.

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

Part 2: Orifice plates

1 Scope

This part of ISO 5167 specifies the geometry and method of use (installation and operating conditions) of orifice plates 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 primary devices having an orifice plate used with flange pressure tapings, or with corner pressure tapings, or with D and $D/2$ pressure tapings. Other pressure tapings such as “vena contracta” and pipe tapings have been used with orifice plates but are not covered by this part of ISO 5167. This part of ISO 5167 is applicable only to a flow which remains subsonic throughout the measuring section and where the fluid can be considered as single phase. It is not applicable to the measurement of pulsating flow. It does not cover the use of orifice plates in pipe sizes less than 50 mm or more than 1 000 mm, or for pipe Reynolds numbers below 5 000.

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, definitions and symbols

For the purposes of this document, the terms, definitions and symbols 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 an orifice plate into a pipeline in which a fluid is running full. The presence of the orifice plate causes a static pressure difference between the upstream and downstream sides of the plate. The mass flowrate, q_m , can be determined using Equation (1):

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

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

Computation of the mass flowrate, which is a purely arithmetic process, can be performed by replacing the different terms on the right hand side of the basic Equation (1) by their numerical values.

Similarly, the value of volume flowrate, q_V , is calculated from:

$$q_V = \frac{q_m}{\rho} \quad (2)$$

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

As will be seen later in this part of ISO 5167, the coefficient of discharge, C , is dependent on the Reynolds number, Re , which is itself dependent on q_m , and has to be obtained by iteration (see Annex A of ISO 5167-1:2003 for guidance regarding the choice of the iteration procedure and initial estimates).

The diameters d and D mentioned in the formula 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 orifice plate 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 the 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 Orifice plates

NOTE 1 The various types of standard orifice meters are similar and therefore only a single description is needed. Each type of standard orifice meter is characterized by the arrangement of the pressure tapings.

NOTE 2 Limits of use are given in 5.3.1.

5.1 Description

5.1.1 General

The axial plane cross-section of a standard orifice plate is shown in Figure 1.

The letters given in the following text refer to the corresponding references in Figure 1.

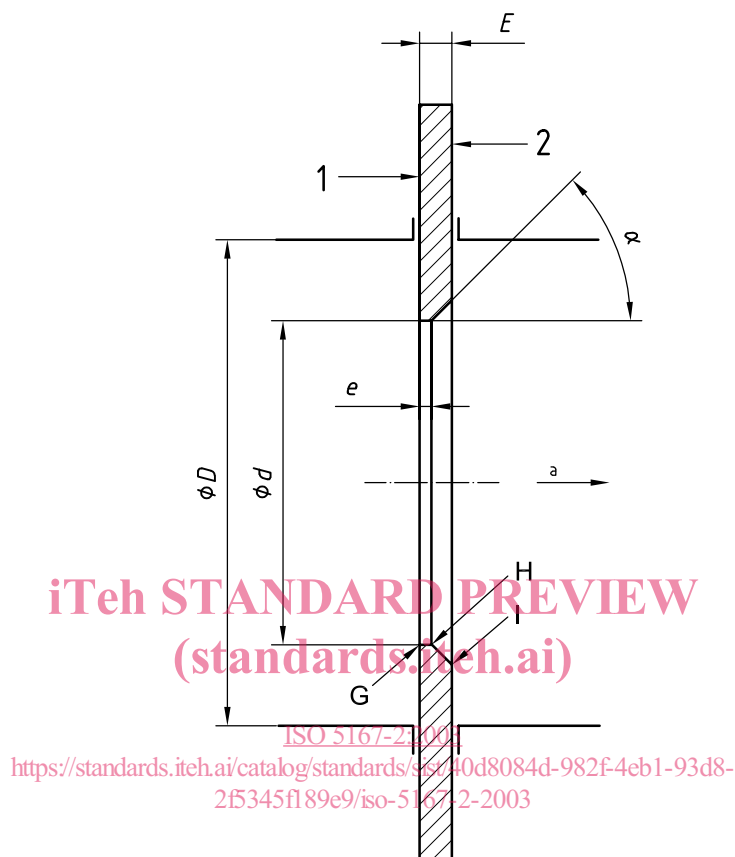
5.1.2 General shape

5.1.2.1 The part of the plate inside the pipe shall be circular and concentric with the pipe centreline. The faces of the plate shall always be flat and parallel.

5.1.2.2 Unless otherwise stated, the following requirements apply only to that part of the plate located within the pipe.

5.1.2.3 Care shall be taken in the design of the orifice plate and its installation to ensure that plastic buckling and elastic deformation of the plate, due to the magnitude of the differential pressure or of any other stress, do not cause the slope of the straight line defined in 5.1.3.1 to exceed 1 % under working conditions.

NOTE Further information is given in 8.1.1.3 of ISO/TR 9464:1998.



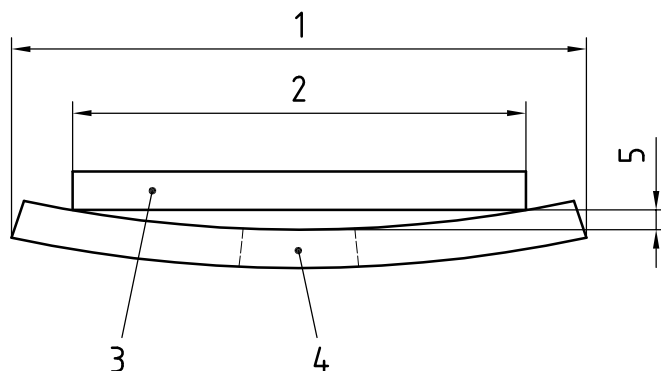
Key

- 1 upstream face A
- 2 downstream face B
- ^a Direction of flow.

Figure 1 — Standard orifice plate

5.1.3 Upstream face A

5.1.3.1 The upstream face A of the plate shall be flat when the plate is installed in the pipe with zero differential pressure across it. Provided that it can be shown that the method of mounting does not distort the plate, this flatness may be measured with the plate removed from the pipe. Under these circumstances, the plate may be considered to be flat when the maximum gap between the plate and a straight edge of length D laid across any diameter of the plate (see Figure 2) is less than $0,005(D - d)/2$, i.e. the slope is less than 0,5 % when the orifice plate is examined prior to insertion into the meter line. As can be seen from Figure 2, the critical area is in the vicinity of the orifice bore. The uncertainty requirements for this dimension can be met using feeler gauges.

**Key**

- 1 orifice plate outside diameter
- 2 pipe inside diameter (D)
- 3 straight edge
- 4 orifice
- 5 departure from flatness (measured at edge of orifice)

Figure 2 — Orifice plate-flatness measurement

5.1.3.2 The upstream face of the orifice plate shall have a roughness criterion $Ra < 10^{-4}d$ within a circle of diameter not less than D and which is concentric with the orifice. In all cases, the roughness of the upstream face of the orifice plate shall not be such that it affects the edge sharpness measurement. If, under working conditions, the plate does not fulfil the specified conditions, it shall be repolished or cleaned to a diameter of at least D .

5.1.3.3 Where possible, it is useful to provide a distinctive mark which is visible even when the orifice plate is installed to show that the upstream face of the orifice plate is correctly installed relative to the direction of flow.

5.1.4 Downstream face B

5.1.4.1 The downstream face B shall be flat and parallel with the upstream face (see also 5.1.5.4).

5.1.4.2 Although it may be convenient to manufacture the orifice plate with the same surface finish on each face, it is unnecessary to provide the same high quality finish for the downstream face as for the upstream face (see Reference [1]; but also see 5.1.9).

5.1.4.3 The flatness and surface condition of the downstream face may be judged by visual inspection.

5.1.5 Thicknesses E and e

5.1.5.1 The thickness e of the orifice shall be between $0,005D$ and $0,02D$.

5.1.5.2 The difference between the values of e measured at any point on the orifice shall not be greater than $0,001D$.

5.1.5.3 The thickness E of the plate shall be between e and $0,05D$.

However, when $50 \text{ mm} \leq D \leq 64 \text{ mm}$, a thickness E up to 3,2 mm is acceptable.

It shall also meet the requirements of 5.1.2.3.

5.1.5.4 If $D \geq 200 \text{ mm}$, the difference between the values of E measured at any point of the plate shall not be greater than $0,001D$. If $D < 200 \text{ mm}$, the difference between the values of E measured at any point of the plate shall not be greater than 0,2 mm.

5.1.6 Angle of bevel α

5.1.6.1 If the thickness E of the plate exceeds the thickness e of the orifice, the plate shall be bevelled on the downstream side. The bevelled surface shall be well finished.

5.1.6.2 The angle of bevel α shall be $45^\circ \pm 15^\circ$.

5.1.7 Edges G, H and I

5.1.7.1 The upstream edge G shall not have wire-edges or burrs.

5.1.7.2 The upstream edge G shall be sharp. It is considered so if the edge radius is not greater than $0,000\ 4d$.

If $d \geq 25$ mm, this requirement can generally be considered as satisfied by visual inspection, by checking that the edge does not reflect a beam of light when viewed with the naked eye.

If $d < 25$ mm, visual inspection is not sufficient.

If there is any doubt as to whether this requirement is met, the edge radius shall be measured.

5.1.7.3 The upstream edge shall be square; it is considered to be so when the angle between the orifice bore and the upstream face of the orifice plate is $90^\circ \pm 0,3^\circ$. The orifice bore is the region of the orifice plate between edges G and H.

5.1.7.4 The downstream edges H and I are within the separated flow region and hence the requirements for their quality are less stringent than those for edge G. This being the case, small defects (for example, a single nick) are acceptable.

5.1.8 Diameter of orifice d

5.1.8.1 The diameter d shall in all cases be greater than or equal to 12,5 mm. The diameter ratio, $\beta = d/D$, shall be always greater than or equal to 0,10 and less than or equal to 0,75.

Within these limits, the value of β may be chosen by the user.

5.1.8.2 The value d of the diameter of the orifice shall be taken as the mean of the measurements of at least four diameters at approximately equal angles to each other. Care shall be taken that the edge and bore are not damaged when making these measurements.

5.1.8.3 The orifice shall be cylindrical.

No diameter shall differ by more than 0,05 % from the value of the mean diameter. This requirement is deemed to be satisfied when the difference in the length of any of the measured diameters complies with the said requirement in respect of the mean of the measured diameters. In all cases, the roughness of the orifice bore cylindrical section shall not be such that it affects the edge sharpness measurement.

5.1.9 Bidirectional plates

5.1.9.1 If the orifice plate is intended to be used for measuring reverse flows, the following requirements shall be fulfilled:

- a) the plate shall not be bevelled;
- b) the two faces shall comply with the specifications for the upstream face given in 5.1.3;

- c) the thickness E of the plate shall be equal to the thickness e of the orifice specified in 5.1.5; consequently, it may be necessary to limit the differential pressure to prevent plate distortion (see 5.1.2.3);
- d) the two edges of the orifice shall comply with the specifications for the upstream edge specified in 5.1.7.

5.1.9.2 Furthermore, for orifice plates with D and $D/2$ tapplings (see 5.2), two sets of upstream and downstream pressure taps shall be provided and used according to the direction of the flow.

5.1.10 Material and manufacture

The plate may be manufactured from any material and in any way, provided that it is and remains in accordance with the foregoing description during the flow measurements.

5.2 Pressure tapplings

5.2.1 General

For each orifice plate, at least one upstream pressure tapping and one downstream pressure tapping shall be installed in one or other of the standard locations, i.e. as D and $D/2$, flange or corner tapplings.

A single orifice plate may be used with several sets of pressure tapplings suitable for different types of standard orifice meters, but to avoid mutual interference, several tapplings on the same side of the orifice plate shall be offset by at least 30° .

The location of the pressure tapplings characterizes the type of standard orifice meter.

5.2.2 Orifice plate with D and $D/2$ tapplings or flange tapplings

5.2.2.1 The spacing l of a pressure tapping is the distance between the centreline of the pressure tapping and the plane of a specified face of the orifice plate. When installing the pressure tapplings, due account shall be taken of the thickness of the gaskets and/or sealing material.

5.2.2.2 For orifice plates with D and $D/2$ tapplings (see Figure 3), the spacing l_1 of the upstream pressure tapping is nominally equal to D , but may be between $0,9D$ and $1,1D$ without altering the discharge coefficient.

The spacing l_2 of the downstream pressure tapping is nominally equal to $0,5D$ but may be between the following values without altering the discharge coefficient:

- between $0,48D$ and $0,52D$ when $\beta \leq 0,6$;
- between $0,49D$ and $0,51D$ when $\beta > 0,6$.

Both l_1 and l_2 spacings are measured from the *upstream* face of the orifice plate.

5.2.2.3 For orifice plates with flange tapplings (see Figure 3), the spacing l_1 of the upstream pressure tapping is nominally 25,4 mm and is measured from the *upstream* face of the orifice plate.

The spacing l'_2 of the downstream pressure tapping is nominally 25,4 mm and is measured from the *downstream* face of the orifice plate.

These upstream and downstream spacings l_1 and l'_2 may be within the following ranges without altering the discharge coefficient:

- 25,4 mm \pm 0,5 mm when $\beta > 0,6$ and $D < 150$ mm;
- 25,4 mm \pm 1 mm in all other cases, i.e. $\beta \leq 0,6$, or $\beta > 0,6$, but $150 \text{ mm} \leq D \leq 1\,000 \text{ mm}$.

5.2.2.4 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.

5.2.2.5 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.

5.2.2.6 Conformity of the pressure tapplings with the requirements specified in 5.2.2.4 and 5.2.2.5 may be judged by visual inspection.

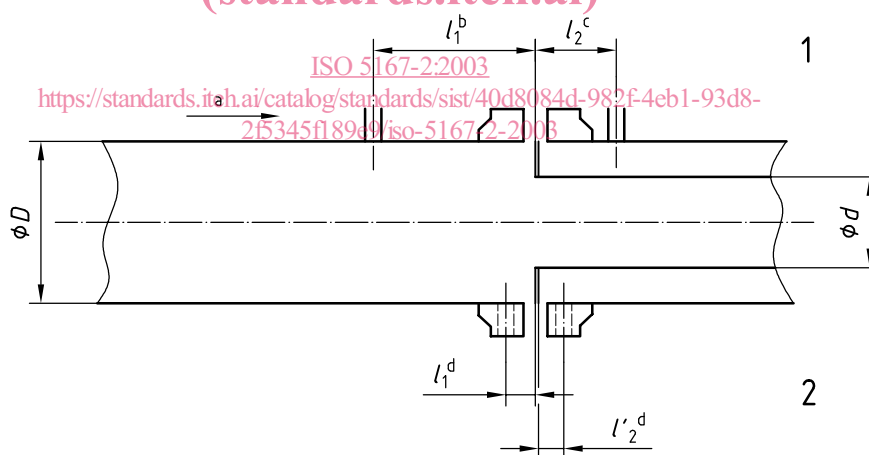
5.2.2.7 The diameter of pressure tapplings shall be less than $0,13D$ and less than 13 mm.

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 tapplings shall have the same diameter.

5.2.2.8 The pressure tapplings 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.

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

5.2.2.10 The axis of the upstream tapping and that of the downstream tapping may be located in different axial planes, but are normally located in the same axial plane.



Key

- 1 D and $D/2$ pressure tapplings
- 2 flange tapplings

a Direction of flow.

b $l_1 = D \pm 0,1D$

c $l_2 = 0,5D \pm 0,02D$ for $\beta \leq 0,6$
 $0,5D \pm 0,01D$ for $\beta > 0,6$

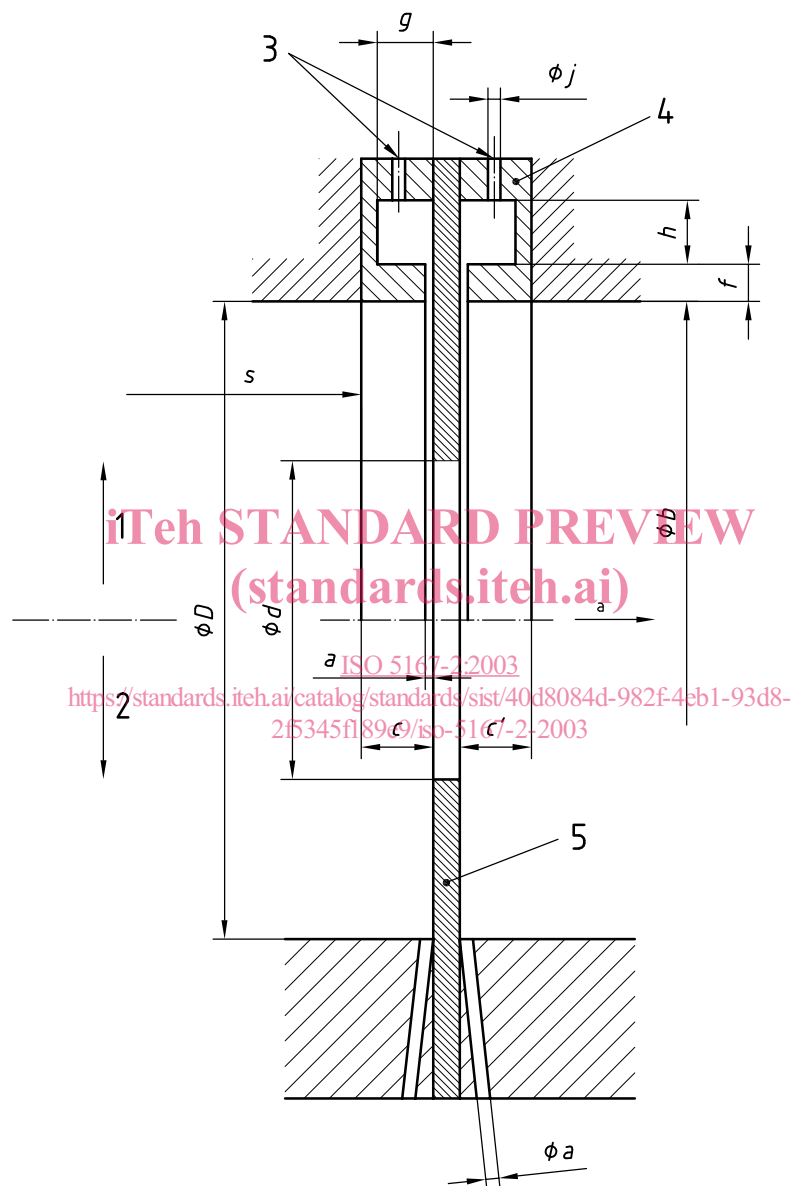
d $l_1 = l_2 = (25,4 \pm 0,5)$ mm for $\beta > 0,6$ and $D < 150$ mm
 $(25,4 \pm 1)$ mm for $\beta \leq 0,6$
 $(25,4 \pm 1)$ mm for $\beta > 0,6$ and $150 \text{ mm} \leq D \leq 1\,000$ mm

Figure 3 — Spacing of pressure tapplings for orifice plates with D and $D/2$ tapplings or flange tapplings

5.2.3 Orifice plate with corner tapings (see Figure 4)

5.2.3.1 The spacing between the centrelines of the tapings and the respective faces of the plate is equal to half the diameter or to half the width of the tapings themselves, so that the tapping holes break through the wall flush with the faces of the plate (see also 5.2.3.5).

5.2.3.2 The pressure tapings may be either single tapings or annular slots. Both types of tapings may be located either in the pipe or its flanges or in carrier rings as shown in Figure 4.



Key

- 1 carrier ring with annular slot
- 2 individual tapings
- 3 pressure tapings
- 4 carrier ring
- 5 orifice plate

^a Direction of flow.

- f = thickness of the slot
- c = length of upstream ring
- c' = length of the downstream ring
- b = diameter of the carrier ring
- a = width of annular slot or diameter of single tapping
- s = distance from upstream step to carrier ring
- g, h = dimensions of the annular chamber
- ϕ_j = chamber tapping diameter

Figure 4 — Corner tapings

5.2.3.3 The diameter a of a single 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 $\beta \leq 0,65$: $0,005D \leq a \leq 0,03D$;
- for $\beta > 0,65$: $0,01D \leq a \leq 0,02D$.

If $D < 100$ mm, a value of a up to 2 mm is acceptable for any β .

For any values of β

- for clean fluids: $1 \text{ mm} \leq a \leq 10 \text{ mm}$;
- for vapours, in the case of annular chambers: $1 \text{ mm} \leq a \leq 10 \text{ mm}$;
- for vapours and for liquefied gases, in the case of single tapplings: $4 \text{ mm} \leq a \leq 10 \text{ mm}$.

5.2.3.4 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 .

5.2.3.5 If individual pressure tapplings, as shown in Figure 4, are used, the centreline of the tapplings shall meet the centreline of the pipe at an angle as near to 90° as possible.

If there are several individual pressure tapplings in the same upstream or downstream plane, their centrelines shall form equal angles with each other. The diameters of individual pressure tapplings are specified in 5.2.3.3.

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

The upstream and downstream pressure tapplings shall have the same diameter.

5.2.3.6 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:

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

The lengths c and c' of the upstream and downstream rings (see Figure 4) 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.

5.2.3.7 All surfaces of the ring that are in contact with the measured fluid shall be clean and shall have a well-machined finish. The surface finish shall meet the pipe roughness requirements (see 5.3.1).

5.2.3.8 The pressure tapplings connecting the annular chambers to the secondary devices are pipe-wall tapplings, circular at the point of break-through and with a diameter j between 4 mm and 10 mm (see 5.2.2.5).

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