TECHNICAL REPORT

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# Measurement of fluid flow by means of pressure-differential devices — Guidelines for the specification of orifice plates, nozzles and Venturi tubes beyond the scope of ISO 5167 series

*Mesurage du débit des fluides au moyen d'appareils déprimogènes — Lignes directrices pour la spécification des diaphragmes, des tuyères et des tubes de Venturi non couverts par la série de l'ISO 5167*



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# Foreword

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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.



# Measurement of fluid flow by means of pressure-differential devices — Guidelines for the specification of orifice plates, nozzles and Venturi tubes beyond the scope of ISO 5167 series

## 1 Scope

This document describes the geometry and method of use for conical-entrance orifice plates, quarter-circle orifice plates, eccentric orifice plates and Venturi tubes with 10,5° convergent angles. Information is also given for square-edged orifice plates and nozzles under conditions outside the scope of ISO 5167 series.

NOTE The data on which this document is based are limited in some cases.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies

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

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

## 3 Terms and definitions

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

## 4 Symbols

For the purposes of this document, the symbols given in Table 1 apply.

**Table 1 — Symbols**

| Symbols | Represented quantity | Dimensions<br>M: mass<br>L: length<br>T: time | SI unit |
|---|---|---|---|
| $a$ | Orifice plate pressure-tapping hole diameter | L | m |
| $C$ | Discharge coefficient | dimensionless | |
| $d$ | Diameter of orifice (or throat) of primary device under working conditions[a] | L | m |
| $d_k$ | Measured drain hole diameter | L | m |

[a] In applications with drain holes, $d$ is calculated from the measured values $d_m$ and $d_k$ [see Formulae (1) and (11)].

NOTE 1 Other symbols used in this document are defined at their place of use.

NOTE 2 Subscript 1 refers to the cross-section at the plane of the upstream pressure tapping. Subscript 2 refers to the cross-section at the plane of the downstream pressure tapping.

**Table 1** *(continued)*

| Symbols | Represented quantity | Dimensions<br>M: mass<br>L: length<br>T: time | SI unit |
|---|---|---|---|
| $d_m$ | Measured orifice or throat diameter (where the orifice or nozzle has a drain hole) | L | m |
| $D$ | Upstream internal pipe diameter (or upstream diameter of a classical Venturi tube) under working conditions | L | m |
| $d_{tap}$ | Diameter of Venturi tube pressure tappings | L | m |
| $e$ | Thickness of bore | L | m |
| $E$, $E_1$ | Thickness of orifice plate | L | m |
| $F_E$ | Correction factor | dimensionless | |
| $k$ | Uniform equivalent roughness | L | m |
| $l$ | Pressure tapping spacing | L | m |
| $L$ | Relative pressure tapping spacing: $L = l/D$ | dimensionless | |
| $p$ | Static pressure of the fluid | $ML^{-1} T^{-2}$ | Pa |
| $q_m$ | Mass flowrate | $MT^{-1}$ | kg/s |
| $r$ | Radius of profile | L | m |
| $Ra$ | Arithmetical mean deviation of the (roughness) profile | L | m |
| $Re$ | Reynolds number | dimensionless | |
| $Re_D$ | Pipe Reynolds number | dimensionless | |
| $Re_d$ | Throat Reynolds number | dimensionless | |
| $Re^*$ | Throat-tapping Reynolds number (= $d_{tap}\, Re_d/d$) | dimensionless | |
| $\beta$ | Diameter ratio, $\beta = \frac{d}{D}$ | dimensionless | |
| $\Delta p$ | Differential pressure | $ML^{-1} T^{-2}$ | Pa |
| $\varepsilon$ | Expansibility (expansion) factor | dimensionless | |
| $\theta$ | Angle between the tappings used and the radius from the centre of the pipe to the centre of the drain hole | dimensionless | ° |
| $\kappa$ | Isentropic exponent | dimensionless | |
| $\lambda$ | Friction factor | dimensionless | |
| $\rho$ | Mass density of the fluid | $ML^{-3}$ | kg/m$^3$ |
| $\tau$ | Pressure ratio, $\tau = \frac{p_2}{p_1}$ | dimensionless | |

[a] In applications with drain holes, $d$ is calculated from the measured values $d_m$ and $d_k$ [see Formulae (1) and (11)].

NOTE 1 Other symbols used in this document are defined at their place of use.

NOTE 2 Subscript 1 refers to the cross-section at the plane of the upstream pressure tapping. Subscript 2 refers to the cross-section at the plane of the downstream pressure tapping.



# 5 Square-edged orifice plates and nozzles: with drain holes, in pipes below 50 mm diameter, and as inlet and outlet devices

## 5.1 Drain holes through the upstream face of the square-edged orifice plate or nozzle

### 5.1.1 General

Square-edged orifice plates and nozzles with drain holes are used, installed and manufactured in accordance with the following guidelines.

NOTE 1 The guidelines presented in this document are applicable to both drain holes for liquid in gas and vent holes for gas in liquid.

In a horizontal pipe, a drain hole is positioned at the bottom of the pipe. In a horizontal pipe, a vent hole is positioned at the top of the pipe.

NOTE 2 Use of drain or vent holes can help alleviate the problem of fluid hold-up, but will not resolve measurement errors arising from the presence of two-phase flow.

### 5.1.2 Square-edged orifice plates

If a drain hole is drilled through the orifice plate, the coefficient values specified in ISO 5167-2 are not used unless the following conditions are observed.

a) The diameter of the drain hole does not exceed 0,1$d$ and no part of the hole lies within a circle, concentric with the orifice, of diameter ($D$ – 0,2$d$). The outer edge of the drain hole is as close to the pipe wall as practicable. It is very important that neither the upstream nor the downstream pipe obscure the drain hole and that the hole is not so small that it blocks.

b) The drain hole is deburred and the upstream edge is sharp. Spark erosion is a good method of producing the drain hole.

c) Single pressure tappings are orientated so that they are between 90° and 180° to the position of the drain hole. Upstream and downstream pressure tappings are at the same orientation relative to the drain hole.

d) The measured orifice diameter, $d_m$, is corrected to allow for the additional orifice area represented by the drain hole of measured diameter $d_k$, as shown in Formula (1):

$$d = \frac{d_m}{\left\{ \left(1-\beta''^4\right) C_1{}^2 \frac{\left[ 1 + a\left(1-\frac{\theta}{180}\right)^n - a\left(1-\frac{\theta^*}{180}\right)^n \right]}{\left(1 + C_2 \frac{d_k{}^2}{d_m{}^2}\right)^2} + \beta_m{}^4 \right\}^{0,25}} \quad (1)$$

where

$$\beta_m = \frac{d_m}{D} \quad (2)$$

$a, n, \theta', C_2, \beta''$ and $C_1$ are given in Formulae (3) to (8):

$$a = 0,66\beta_m{}^{4,6} \exp\left(-0,15 \frac{L'_2 d_m}{\beta_m d_k}\right) \quad (3)$$

$$n = -0,45 + 7,3\beta_m{}^{4,6} + 0,117 \frac{d_m}{d_k} \quad (4)$$

$$\theta^* = 92 - 62\beta_m^{4,6} \tag{5}$$

$$C_2 = \begin{cases} 1,08 & \text{if} \quad E/d_k \leq 0,5 \\ 0,767\,5 + 0,625 E/d_k & \text{if} \quad 0,5 < E/d_k < 0,9 \\ 1,33 & \text{if} \quad 0,9 \leq E/d_k \end{cases} \tag{6}$$

$$\beta'' = \beta_m \sqrt{1 + C_2 \frac{d_k^{\,2}}{d_m^{\,2}}} \tag{7}$$

and

$$C_1 = \frac{C(Re_D', \beta)}{C(Re_D', \beta'')} \tag{8}$$

where $C(Re_D', \beta^*)$ is the discharge coefficient given by the Reader-Harris/Gallagher (1998) equation[5] [ISO 5167-2:2022, Formula (4)] for an orifice plate of diameter ratio $\beta^*$ and Reynolds number $Re_D'$ ($L_1$ and $L'_2$ are determined for the actual orifice plate; $\beta^*$ is either $\beta$ or $\beta''$);

$$\beta = \frac{d}{D} \tag{9}$$

[$d$ is given by Formula (1)]

| | |
|---|---|
| $Re_D'$ | is a fixed value of Reynolds number typical of the flow being measured. In high-pressure gas flows $Re_D'$ might be taken as, say, $4 \times 10^6$ (the actual Reynolds number cannot be used in the calculation of $d$, since in that case for an orifice plate with a drain hole $d$ would not have a fixed value); |
| $L_1 (= l_1 / D)$ | is the quotient of the distance of the upstream tapping from the upstream face of the plate and the pipe diameter; |
| $L'_2 (= l'_2 / D)$ | is the quotient of the distance of the downstream tapping from the downstream face of the plate and the pipe diameter; |
| $\theta$ | is the angle (in degrees) between the pressure tappings used and the radius from the centre of the pipe to the centre of the drain hole (90° ≤ $\theta$ ≤ 180°); |
| $E$ | is the thickness of the orifice plate. |

Because of the presence of $C_1$ this is an iterative computation, but convergence is rapid.

When estimating the relative expanded uncertainty of the flow measurement the following additional percentage uncertainty is added arithmetically to the discharge-coefficient percentage relative expanded uncertainty given by ISO 5167-2:2022, 5.3.3.1:

$$2\frac{d_k}{d_m} \tag{10}$$

If $\beta_m \leq 0,63$, or both $\beta_m \leq 0,7$ and $\theta = 90°$, $C_1$ can be set equal to 1, with no increase in uncertainty; in this case there will be no need to iterate.

NOTE 1 There are very limited data for $D$ smaller than 100 mm.

NOTE 2 The formulae given here are based on work described in Reference [10].

Because the formulae in this subclause are complex, there is an example in Annex A so that a computer program can be checked.

### 5.1.3 ISA 1932 nozzles

If a drain hole is drilled through the nozzle upstream face, the coefficient values specified in ISO 5167-3 are not used unless the following conditions are observed:

a) the value of $\beta$ is less than 0,625;

b) the diameter of the drain hole does not exceed 0,1$d$ and no part of the hole lies within a circle, concentric with the throat, of diameter ($D$ – 0,2$d$);

c) the length of the drain hole does not exceed 0,1$D$;

d) the drain hole is deburred and the upstream edge is sharp;

e) single pressure tappings are orientated so that they are between 90° and 180° to the position of the drain hole;

f) the measured diameter, $d_m$, is corrected to allow for the additional throat area represented by the drain hole of diameter $d_k$, as shown in Formula (11):

$$d = d_m \left[ 1 + 0{,}40 \left( \frac{d_k}{d_m} \right)^2 \right] \quad (11)$$

NOTE Formula (11) is based on the assumption that the value for $C\varepsilon(1 - \beta^4)^{-0,5}$ for flow through the drain hole is 20 % less than the value for flow through the throat of the nozzle.

When estimating the overall uncertainty of the flow measurement, the following additional percentage uncertainty is added arithmetically to the discharge-coefficient percentage relative expanded uncertainty:

$$40 \left( \frac{d_k}{d_m} \right)^2 \quad (12)$$

### 5.1.4 Long radius nozzles

Drain holes through these primary elements are not used.

## 5.2 Square-edged orifice plates installed in pipes of diameter 25 mm ≤ $D$ < 50 mm

### 5.2.1 General

Orifice plates are installed and manufactured according to ISO 5167-2.

### 5.2.2 Limits of use

When square-edged orifice plates are installed in pipes of bore 25 mm to 50 mm, it is essential to observe the following conditions:

a) The pipes have high-quality internal surfaces such as drawn copper or brass tubes, glass or plastic pipes or drawn or fine-machined steel tubes. The steel tubes are of stainless steel for use with corrosive fluids such as water. The roughness is according to ISO 5167-2:2022, 5.3.1.

b) Corner tappings are used, preferably of the carrier ring type detailed in ISO 5167-2:2022, Figure 4.

c) The diameter ratio, $\beta$, is within the range 0,5 ≤ $\beta$ ≤ 0,7.

NOTE It is possible to have 0,23 ≤ $\beta$ < 0,5, but the uncertainty increases significantly if $d$ < 12,5 mm.

### 5.2.3 Discharge coefficients and corresponding uncertainties

The Reader-Harris/Gallagher (1998) equation[5] for corner tappings given in ISO 5167-2:2022, 5.3.2.1 is used for deriving the discharge coefficients, provided the pipe Reynolds numbers are within the limits given in ISO 5167-2:2022, 5.3.1.

An additional uncertainty of 0,5 % is added arithmetically to the relative expanded uncertainty derived from ISO 5167-2:2022, 5.3.3.1.

## 5.3 No upstream or downstream pipeline

### 5.3.1 General

This subclause applies where there is no pipeline on either the upstream or the downstream side of the device or on both the upstream and the downstream sides of the device, that is for flow from a large space into a pipe or vice versa, or flow through a device installed in the partition wall between two large spaces.

### 5.3.2 Flow from a large space (no upstream pipeline) into a pipeline or another large space

#### 5.3.2.1 Upstream and downstream tappings

The space on the upstream side of the device is considered large if

a) there is no wall closer than 4*d* to the axis of the device or to the plane of the upstream face of the orifice or nozzle,

b) the velocity of the fluid at any point more than 4*d* from the device is less than 3 % of the velocity in the orifice or throat, and

c) the diameter of the downstream pipeline is not less than 2*d*.

NOTE 1 The first condition implies, for example, that an upstream pipeline of diameter greater than 8*d* (that is where $\beta$ < 0,125) can be regarded as a large space. The second condition, which excludes upstream disturbances due to draughts, swirl and jet effects, implies that the fluid is to enter the space uniformly over an area of not less than 33 times the area of the orifice or throat. For example, if the flow is provided by a fall in level of a liquid in a tank, the area of the liquid surface needs to be not less than 33 times the area of the orifice or throat through which the tank is discharged.

In an acceptable installation the distance of the upstream tapping (i.e. the tapping in the large space) from the orifice or nozzle centreline is greater than 4*d*.

The upstream tapping is preferably located in a wall perpendicular to the plane of the orifice and within a distance of 0,5*d* from that plane. The tapping does not necessarily need to be located in any wall; it can be in the open space. If the space is very large, for example a room, the tapping is shielded from draughts.

The downstream tapping is located as specified for corner tappings in ISO 5167-2. If the downstream side also consists of a large space, the tapping is located as for the upstream tapping, except for Venturi nozzles where the throat tapping is used.

NOTE 2 When the upstream and downstream tappings are at different horizontal levels, it might be necessary to make allowance for the difference in hydrostatic head. This is usually done by reading the differential-pressure transmitter with no fluid flow and making an appropriate correction.

#### 5.3.2.2 Square-edged orifice plates with corner tappings

**5.3.2.2.1** Square-edged orifice plates with corner tappings are manufactured according to ISO 5167-2:2022, Clause 5.



**5.3.2.2.2** The limits of use for square-edged orifice plates with corner tappings where there is a flow from a large space are as follows:

— $d \geq 12{,}5$ mm;

— downstream there is either a large space or a pipeline whose diameter is not less than $2d$;

— $Re_d \geq 3\,500$.

NOTE 1 It is possible to have $12{,}5 \text{ mm} > d > 6 \text{ mm}$, but the uncertainty increases significantly if $d < 12{,}5$ mm.

NOTE 2 Provided that $\beta \leq 0{,}2$ and $d \geq 12{,}5$ mm, the Reader-Harris/Gallagher (1998) equation[5] given in ISO 5167-2:2022, 5.3.2.1 can be used in a pipeline for $Re_d \geq 3\,500$ with a relative expanded uncertainty of the value of $C$ at $k = 2$ (approximately 95 % confidence level) of 1 % (if $Re_D < 5\,000$).

**5.3.2.2.3** The discharge coefficient, $C$, is given by Formula (13):

$$C = 0{,}596\,1 + 0{,}000\,521\left(\frac{10^6}{Re_d}\right)^{0{,}7} \tag{13}$$

The relative expanded uncertainty of the value of $C$ at $k = 2$ (approximately 95 % confidence level) is 1 %.

**5.3.2.2.4** The expansibility factor, $\varepsilon$, is given by Formula (14) and is only applicable if $p_2/p_1 > 0{,}75$:

$$\varepsilon = 1 - 0{,}351\left[1 - \left(\frac{p_2}{p_1}\right)^{1/\kappa}\right] \tag{14}$$

NOTE $p_1$ and $\Delta p$ are usually measured: $p_2 = p_1 - \Delta p$.

When $\Delta p/p_1$ and $\kappa$ are assumed to be known without error, the relative expanded uncertainty of the value of $\varepsilon$ at $k = 2$ (approximately 95 % confidence level) is equal to $3{,}5\frac{\Delta p}{\kappa p_1}$ %.

Test results for the determination of $\varepsilon$ are known for air, steam and natural gas only. However, there is no known objection to using the same formula for other gases and vapours whose isentropic exponent is known.

### 5.3.2.3 ISA 1932 nozzles

**5.3.2.3.1** ISA 1932 nozzles are manufactured according to ISO 5167-3:2022, 5.1.

**5.3.2.3.2** The limits of use for ISA 1932 nozzles where there is flow from a large space are as follows:

— $d \geq 11{,}5$ mm;

— downstream there is either a large space or a pipeline whose diameter is not less than $2d$;

— $Re_d \geq 100\,000$.

**5.3.2.3.3** The discharge coefficient, $C$, is equal to 0,99. The relative expanded uncertainty of the value of $C$ at $k = 2$ (approximately 95 % confidence level) is expected to be no better than 1 %.

**5.3.2.3.4** The expansibility factor, $\varepsilon$, is given by Formula (15) and is only applicable if $p_2/p_1 \geq 0{,}75$:

$$\varepsilon = \left[ \left( \frac{\kappa \tau^{2/\kappa}}{\kappa - 1} \right) \left( \frac{1 - \tau^{(\kappa-1)/\kappa}}{1 - \tau} \right) \right]^{0{,}5} \tag{15}$$

The relative expanded uncertainty of the value of $\varepsilon$ at $k$ = 2 (approximately 95 % confidence level) is equal to $2\Delta p/p_1$ %.

#### 5.3.2.4 Venturi nozzle

**5.3.2.4.1** Venturi nozzles are manufactured according to ISO 5167-3:2022, 5.4.

**5.3.2.4.2** The limits of use for Venturi nozzles where there is flow from a large space are as follows:

— $d \geq 50$ mm;

— downstream there is either a large space or a pipeline whose diameter is not less than 2$d$;

— $3 \times 10^5 \leq Re_d \leq 3 \times 10^6$.

**5.3.2.4.3** The discharge coefficient, $C$, is equal to 0,985 8. The relative expanded uncertainty of the value of $C$ at $k$ = 2 (approximately 95 % confidence level) is expected to be no better than 1,5 %.

**5.3.2.4.4** The expansibility factor, $\varepsilon$, is given by Formula (16) and is only applicable if $p_2/p_1 \geq 0{,}75$:

$$\varepsilon = \left[ \left( \frac{\kappa \tau^{2/\kappa}}{\kappa - 1} \right) \left( \frac{1 - \tau^{(\kappa-1)/\kappa}}{1 - \tau} \right) \right]^{0{,}5} \tag{16}$$

The relative expanded uncertainty of the value of $\varepsilon$ at $k$ = 2 (approximately 95 % confidence level) is equal to $4\ \Delta p/p_1$ %.

### 5.3.3 Flow into a large space (no downstream pipeline)

#### 5.3.3.1 General

The space on the downstream side of the device is considered large if there is no wall closer than 4$d$ to the axis of the device or to the downstream face of the orifice plate or nozzle.

The upstream tapping is located as specified for corner tappings in ISO 5167-2 and in ISO 5167-3 for orifice plates and nozzles respectively.

The distance of the downstream tapping (i.e. the tapping in the large space) from the orifice or nozzle centreline is greater than 4$d$.

For Venturi nozzles, the throat tapping is used.

The downstream tapping is preferably located in a wall perpendicular to the plane of the orifice and within a distance of 0,5$d$ from that plane. The tapping does not necessarily need to be located in any wall; it can be in the open space. If the space is very large, for example a room, the tapping is shielded from draughts.

NOTE Where the upstream and downstream tappings are at different horizontal levels, it might be necessary to make allowance for the difference in hydrostatic head.



#### 5.3.3.2 Square-edged orifice plates with corner tappings

**5.3.3.2.1** Square-edged orifice plates with corner tappings are manufactured according to ISO 5167-2:2022, Clause 5.

**5.3.3.2.2** Where 25 mm ≤ $D$ < 50 mm, the limits given in 5.2.2 and 5.2.3 apply.

Where 50 mm ≤ $D$ ≤ 1 000 mm, the limits given in ISO 5167-2:2022, 5.3.1 apply.

**5.3.3.2.3** Where 25 mm ≤ $D$ < 50 mm, the coefficients and uncertainties given in 5.2.3 apply.

Where 50 mm ≤ $D$ ≤ 1 000 mm, the coefficients and uncertainties given in ISO 5167-2:2022, 5.3.2 and 5.3.3 apply, except that an additional relative uncertainty of 0,4 % is to be added arithmetically to the relative expanded uncertainty derived from ISO 5167-2:2022, 5.3.3.1.

#### 5.3.3.3 ISA 1932 nozzles and Venturi nozzles

**5.3.3.3.1** ISA 1932 nozzles and Venturi nozzles are manufactured according to ISO 5167-3:2022, 5.1 or 5.4.

**5.3.3.3.2** The limits given in ISO 5167-3:2022, 5.1.6.1 or 5.4.4.1 apply.

**5.3.3.3.3** The coefficients and uncertainties given in ISO 5167-3:2022, 5.1.6.2, 5.1.6.3 and 5.1.7 or 5.4.4.2, 5.4.4.3 and 5.4.5 apply, except that in the case of an ISA 1932 nozzle an additional relative uncertainty of 0,4 % is added arithmetically to the relative expanded uncertainty derived from ISO 5167-3:2022, 5.1.7.1.

## 6 Orifice plates (except square-edged)

### 6.1 Conical entrance orifice plates

#### 6.1.1 General

NOTE A conical entrance orifice plate has the characteristic that its discharge coefficient remains constant down to a low Reynolds number, thus making it suitable for the measurement of the flowrate of viscous fluids such as oil. Conical entrance orifice plates are further distinguished from other types of orifice plates in that their discharge coefficient is the same for any diameter ratio within the limits in this document.

Conical entrance orifice plates are used and installed according to ISO 5167-1:2022, Clause 6 and ISO 5167-2:2022, Clause 6.

#### 6.1.2 Limits of use

The limits of use for conical entrance orifice plates are as follows:

— $d$ > 6 mm;

— $D$ ≤ 500 mm.

The lower limit of pipe diameter, $D$, depends on the internal roughness of the upstream pipeline and is in accordance with Table 2 and within the following limits:

— $0,1 \leq \beta \leq 0,316$;

— $80 \leq Re_D \leq 2 \times 10^5 \beta$.

NOTE Within these limits, the value of $\beta$ is chosen by the user taking into consideration parameters such as required differential pressure, uncertainty, acceptable pressure loss and available static pressure.

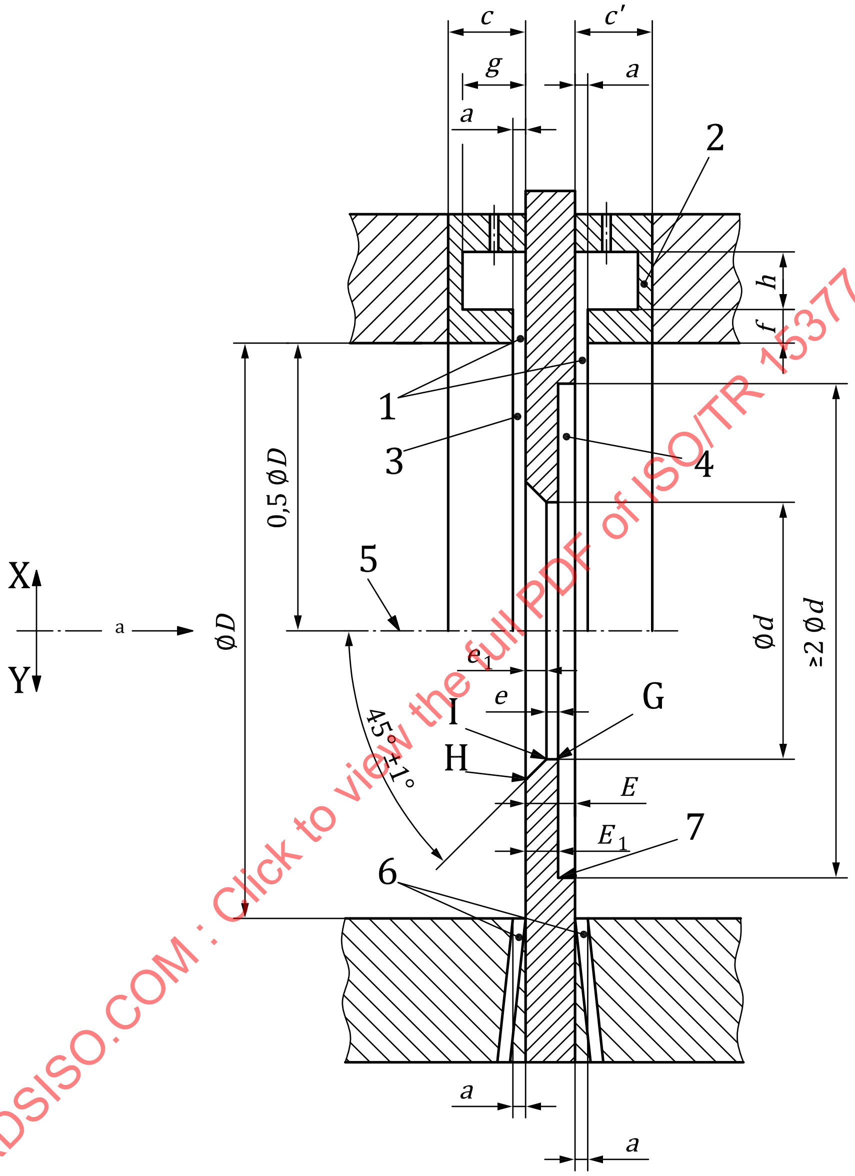
### 6.1.3 Description

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

NOTE The letters shown in Figure 1 are for reference purposes in 6.1.3.2 to 6.1.3.8 and 6.1.4 only; 6.1.4 refers to ISO 5167-2:2022, 5.2.3.

#### 6.1.3.1 General shape

**6.1.3.1.1** The part of the plate inside the pipe is circular and concentric with the pipe centreline. The faces of this plate are always flat and parallel.






**Key**

X carrier ring with annular slot
Y individual tappings
1 annular slots
2 carrier ring
3 upstream face A
4 downstream face B
5 axial centreline
6 pressure tappings
7 orifice plate
a Direction of flow.

G downstream edge
H, I upstream edges
*f* thickness of the slot
*c* length of upstream ring
*c*′ length of the downstream ring
*a* width of annular slot or diameter of single tapping
*g*, *h* dimensions of the annular chamber

**Figure 1 — Conical entrance orifice plate**

**Table 2 — Minimum internal diameter of upstream pipe for conical entrance orifice plates**

| Material | Condition | Minimum internal diameter<br>mm |
|---|---|---|
| Brass, copper, lead, glass, plastics | smooth, without sediments | 25 |
| Steel | new, cold drawn | 25 |
| | new, seamless | 25 |
| | new, welded | 25 |
| | slightly rusty | 25 |
| | rusty | 50 |
| | slightly encrusted | 200 |
| | bituminized, new or used | 25 |
| | galvanized | 25 |
| Cast iron | bituminized | 25 |
| | not rusty | 50 |
| | rusty | 200 |



**6.1.3.1.2** Unless otherwise stated, 6.1.3.1.3 and 6.1.3.2 to 6.1.3.8 apply only to that part of the plate located within the pipe.

**6.1.3.1.3** Correct design of the orifice plate and its installation ensures 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 6.1.3.2.1 to exceed 1 % under flowing conditions.

### 6.1.3.2 Upstream face A

**6.1.3.2.1** The upstream face of the plate A is flat when the plate is installed in the pipe with zero differential pressure across it.

Provided it can be shown that the method of mounting does not distort the plate, this flatness is measured with the plate removed from the pipe. Under these circumstances, the plate is considered flat when the maximum gap between the flat portion of the upstream face of the plate and a straight edge of length $D$, laid across any diameter of the plate, is less than $0{,}005(D - d - 2e_1)/2$; i.e. the slope is less than 0,5 % when the orifice plate is examined prior to insertion into the meter line (see also ISO 5167-2:2022, Figure 2). The critical area is in the vicinity of the orifice bore. The use of feeler gauges gives sufficiently low uncertainty to measure this dimension.

**6.1.3.2.2** The upstream face of the orifice plate has a roughness criterion $Ra \le 10^{-4}d$ within a circle whose diameter is not less than $1{,}5d$ and which is concentric with the orifice.

NOTE 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.

### 6.1.3.3 Downstream face B

The downstream face is flat and parallel to the upstream face.

NOTE It is unnecessary to provide the same quality of surface finish for the downstream face as for the upstream face. The flatness and surface condition of the downstream face can be judged by visual inspection.

### 6.1.3.4 Thicknesses $e_1$, $E_1$ and $E$

**6.1.3.4.1** The thickness, $e_1$, of the conical entrance is $0{,}084d \pm 0{,}003d$.

**6.1.3.4.2** The thickness, $E_1$, of the orifice plate for a distance of not less than 1,0*d* from the centreline axis does not exceed 0,105*d*.

**6.1.3.4.3** The thickness, *E*, of the orifice plate at a distance greater than 1,0*d* from the centreline axis is allowed to exceed 0,105*d* but does not exceed 0,1*D*, and the extra thickness, if any, is on the downstream face.

**6.1.3.4.4** If $D \geq 200$ mm, the difference between the values of $E_1$ measured at any point of the plate is not greater than 0,001*D*. If $D < 200$ mm, the difference between the values of $E_1$ measured at any point of the plate is not greater than 0,2 mm.

**6.1.3.4.5** The values of *E* measured at any point on the plate do not differ from each other by more than 0,005*D*.



### 6.1.3.5 Conical entrance

The upstream edge of the orifice is bevelled at an angle of 45° ± 1°.

### 6.1.3.6 Parallel bore

**6.1.3.6.1** The bore of the orifice is parallel within ±0,5° to the centreline.

**6.1.3.6.2** The axial length, *e*, of the parallel bore is 0,021*d* ± 0,003*d*.

### 6.1.3.7 Edges H, I and G

**6.1.3.7.1** The upstream edge H formed by the intersection of the conical entrance and the upstream face is not rounded.

**6.1.3.7.2** The upstream edge I formed by the intersection of the parallel bore and the conical entrance is not rounded.

**6.1.3.7.3** The upstream edges H and I and the downstream edge G do not have wire edges, burrs or any peculiarities visible to the naked eye.

### 6.1.3.8 Diameter of orifice

**6.1.3.8.1** The diameter of the orifice, *d*, is taken as the mean value of a number of measurements of the diameter distributed in axial planes and at approximately equal angles between adjacent measurements. At least four measurements of the diameter are made.

No diameter differs by more than 0,05 % from the value of the mean diameter.

**6.1.3.8.2** The parallel bore of the orifice is cylindrical and perpendicular to the upstream face.

### 6.1.4 Pressure tappings

Corner tappings as specified in ISO 5167-2:2022, 5.2.3 are used with conical entrance orifice plates. Both the upstream and downstream tappings are the same.

### 6.1.5 Coefficients and corresponding uncertainties

**6.1.5.1** The discharge coefficient, *C*, is equal to 0,734. The relative expanded uncertainty of the value of *C* at $k = 2$ (approximately 95 % confidence level) is 2 %.

**6.1.5.2** The value of the expansibility factor $\varepsilon$ for the conical entrance orifice plates is taken as the arithmetic mean of that for square-edged orifice plates and that for ISA 1932 nozzles specified in ISO 5167-2: 2022, 5.3.2.2 and ISO 5167-3:2022, 5.1.6.3, respectively.

The values used are calculated under the same conditions. The relative expanded uncertainty of the value of $\varepsilon$ at $k = 2$ (approximately 95 % confidence level) is given by $33(1 - \varepsilon)$ %.

**6.1.5.3** The uncertainties on other quantities are determined according to ISO 5167-1:2022, Clause 8.

## 6.2 Quarter-circle orifice plates

### 6.2.1 General

NOTE A quarter-circle orifice plate has the characteristic that its discharge coefficient remains constant down to a low Reynolds number, thus making it suitable for the measurement of the flowrate of viscous fluids such as oil.

Quarter-circle orifice plates are used and installed according to ISO 5167-1:2022, Clause 6 and ISO 5167-2:2022, Clause 6.

### 6.2.2 Limits of use

The limits of use for quarter-circle orifice plates are as follows:

— $d \geq 15$ mm;

— $D \leq 500$ mm.

The lower limit of pipe diameter, $D$, depends on the internal roughness of the upstream pipeline and is in accordance with Table 3 and such that:

— $0{,}245 \leq \beta \leq 0{,}6$;

— $Re_D \leq 10^5 \beta$.

The lower limit of the Reynolds number, $Re_\mathrm{D}$, is given by Formula (17):

$$Re_\mathrm{D}\,(\mathrm{min.}) = 1\,000\,\beta + 9{,}4 \times 10^6\,(\beta - 0{,}24)^8 \qquad (17)$$

For convenience, values of $Re_\mathrm{D}$ (min.) are given in Table 4 (see 6.2.5).

NOTE Within these limits, the value of $\beta$ is chosen by the user, taking into consideration parameters such as required differential pressure, uncertainty, acceptable pressure loss and available static pressure.

**Table 3 — Minimum internal diameter of upstream pipe for quarter-circle orifice plates**

| Material | Condition | Minimum internal diameter<br>mm |
|---|---|---|
| Brass, copper, lead, glass, plastics | smooth, without sediments | 25 |
| Steel | new, cold drawn | 25 |
| | new, seamless | 25 |
| | new, welded | 25 |
| | slightly rusty | 50 |
| | rusty | 100 |
| | slightly encrusted | 200 |
| | bituminized, new | 25 |
| | bituminized, used | 75 |
| | galvanized | 50 |
| Cast iron | bituminized | 25 |
| | not rusty | 50 |
| | rusty | 200 |

### 6.2.3 Description

The axial plane cross-section of the orifice plate is shown in Figure 2.

NOTE The letters shown in Figure 2 are for reference purposes in 6.2.3.2 to 6.2.3.7 only.

#### 6.2.3.1 General shape

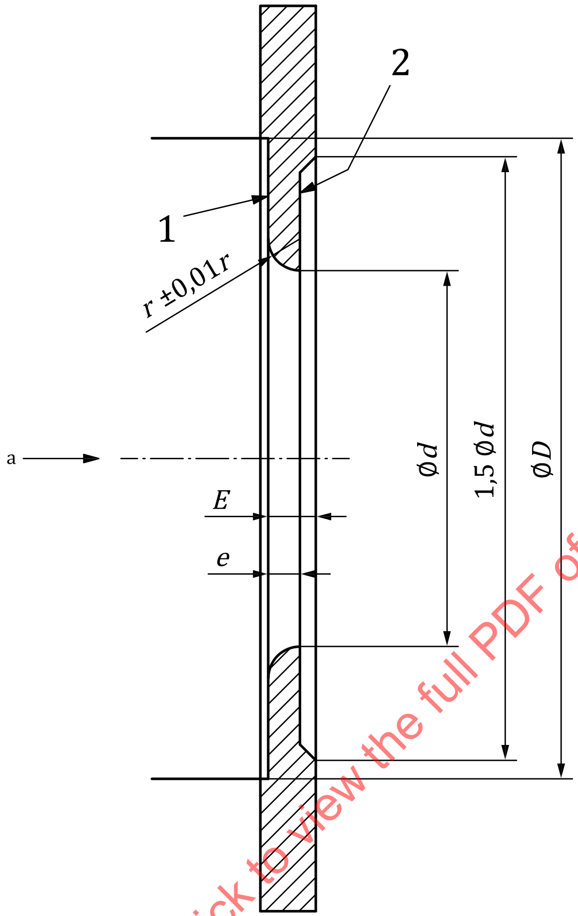
**6.2.3.1.1** The part of the plate inside the pipe is circular and concentric with the pipe centreline. The faces of this plate are always flat and parallel.

**6.2.3.1.2** Unless otherwise stated, 6.2.3.1.3 and 6.2.3.2 to 6.2.3.7 apply only to that part of the plate located within the pipe.



**6.2.3.1.3** Correct design of the orifice plate and its installation ensures 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 6.2.3.2.1 to exceed 1 % under flowing conditions.




**Key**

1 upstream face A

2 downstream face B

[a] Direction of flow.

**Figure 2 — Quarter-circle orifice plate**



### 6.2.3.2 Upstream face A

**6.2.3.2.1** The upstream face of the plate A is flat when the plate is installed in the pipe with zero differential pressure across it

Provided it can be shown that the method of mounting does not distort the plate, this flatness is measured with the plate removed from the pipe. Under these circumstances, the plate is considered flat when the maximum gap between the flat portion of the upstream face of the plate and a straight edge of length $D$, laid across any diameter of the plate, is less than the following values:

$$0{,}005\left(\frac{D-d-2r}{2}\right) \quad \text{if } \beta \leq 0{,}571$$

$$0{,}005\left[\left(\frac{D-d}{2}\right)-r+\sqrt{r^2-\frac{0{,}01d^2}{\beta^2}}\right] \quad \text{if } \beta > 0{,}571$$

That is, the slope is less than 0,5 % when the orifice plate is examined prior to insertion into the meter line (see also ISO 5167-2:2022, Figure 2). The critical area is in the vicinity of the orifice bore. The use of feeler gauges gives sufficiently low uncertainty to measure this dimension.

**6.2.3.2.2** The upstream face of the orifice plate has a roughness criterion $Ra \leq 10^{-4}d$ within a circle whose diameter is not less than 1,5$d$ and which is concentric with the orifice.

NOTE 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.

### 6.2.3.3 Downstream face B

The downstream face is flat and parallel to the upstream face.

NOTE It is unnecessary to provide the same quality of surface finish for the downstream face as for the upstream face. The flatness and surface condition of the downstream face can be judged by visual inspection.

### 6.2.3.4 Thicknesses *e* and *E*

**6.2.3.4.1** The thickness, $e$, of the bore section is not less than 2,5 mm and does not exceed 0,1$D$.

**6.2.3.4.2** Where the radius, $r$, of the profile exceeds 0,1$D$, which is the case when $\beta$ exceeds 0,571, the thickness of the plate is reduced from $r$ to 0,1$D$ by removing metal from the upstream face.

When the thickness, $E$, of the orifice plate exceeds the radius, $r$, then the thickness of the plate is reduced to equal this radius by removing metal from the downstream face to form a new downstream face in a recess of diameter 1,5$d$ with its edge bevelled to 45°.

**6.2.3.4.3** If $D \geq 200$ mm, the difference between the values of $e$ measured at any point of the plate is not greater than 0,001$D$. If $D < 200$ mm, the difference between the values of $e$ measured at any point of the plate is not greater than 0,2 mm.

### 6.2.3.5 Upstream orifice profile

**6.2.3.5.1** The profile of the upstream edge is circular and of radius $r$ with its centre on the downstream face of the plate.

NOTE The profile might not be a full quarter circle owing to the limit in 6.2.3.4.2.

**6.2.3.5.2** The radius, $r$, of the profile is determined from Formula (18):

$$r/d = 3{,}17 \times 10^{-6} e^{16{,}8\beta} + 0{,}055\,4\, e^{1{,}016\beta} + 0{,}029 \quad (18)$$

to within ±0,05$r$.

For convenience, values of $r/d$ are given in Table 4.

The radius of the profile is the same for all sections to within ±0,01$r$.

NOTE The variation in profile radius allows an orifice plate designed for a given $D$ to be used in pipes of 0,95$D$ to 1,05$D$.

**6.2.3.5.3** The tangent to the profile at the downstream edge is perpendicular to the upstream face of the plate to within ±1°.

**6.2.3.5.4** The profile surface does not have wire edges, burrs or any peculiarities visible to the naked eye.

#### 6.2.3.6 Downstream edge

The downstream edge of the orifice is square and does not have wire edges, burrs or any peculiarities visible to the naked eye.

#### 6.2.3.7 Diameter of orifice

The diameter of the orifice, $d$, is taken as the mean value of a number of measurements of the diameter distributed in axial planes and at approximately equal angles between adjacent measurements. At least four measurements of the diameter are made.

No diameter differs by more than 0,1 % from the value of the mean diameter.

### 6.2.4 Pressure tappings

For pipes of diameter up to 40 mm, corner tappings as specified in ISO 5167-2:2022, 5.2.3 are used with quarter-circle orifice plates. For pipes of diameter 40 mm or greater, either corner tappings as specified in ISO 5167-2:2022, 5.2.3 or flange tappings as specified in ISO 5167-2:2022, 5.2.2 are used with quarter-circle orifice plates.

### 6.2.5 Coefficients and corresponding uncertainties

#### 6.2.5.1 Discharge coefficient

The discharge coefficient, $C$, is given by the following Formula (19):

$$C = 0{,}738\,23 + 0{,}330\,9\,\beta - 1{,}161\,5\,\beta^2 + 1{,}508\,4\,\beta^3 \qquad (19)$$

The relative expanded uncertainty of the value of $C$ at $k = 2$ (approximately 95 % confidence level) is 2 % when $\beta > 0{,}316$ and 2,5 % when $\beta \leq 0{,}316$.

For convenience, Table 4 gives values of $C$ as a function of $\beta$.

#### 6.2.5.2 Expansibility (expansion) factor

For the two tapping arrangements, the empirical formula for computing the expansibility (expansion) factor, $\varepsilon$, is as follows in Formula (20) and is only applicable if $p_2/p_1 \geq 0{,}75$:

$$\varepsilon = 1 - (0{,}351 + 0{,}256\beta^4 + 0{,}93\beta^8)\left[1 - \left(\frac{p_2}{p_1}\right)^{1/\kappa}\right] \qquad (20)$$

NOTE $p_1$ and $\Delta p$ are usually measured: $p_2 = p_1 - \Delta p$.

Formula (20) is applicable only within the range of the limits of use given in 6.2.2.



Test results for the determination of $\varepsilon$ are known for air, steam and natural gas only. However, there is no known objection to using the same formula for other gases and vapours whose isentropic exponent is known.

When $\beta$, $\Delta p/p_1$ and $\kappa$ are assumed to be known without error, the relative expanded uncertainty of the value of $\varepsilon$ at $k = 2$ (approximately 95 % confidence level) is equal to $3{,}5\frac{\Delta p}{\kappa p_1}$ %.

#### 6.2.5.3 Uncertainties

The uncertainties of other quantities are determined according to ISO 5167-1:2022, Clause 8.

**Table 4 — Discharge coefficients for quarter-circle orifice plates**

| $\beta$ | $C$ | $r/d$ | $Re_D$ (min.) |
|---|---|---|---|
| 0,245 | 0,772 | 0,100 | 250 |
| 0,250 | 0,772 | 0,101 | 250 |
| 0,260 | 0,772 | 0,101 | 260 |
| 0,270 | 0,773 | 0,102 | 270 |
| 0,280 | 0,773 | 0,103 | 280 |
| 0,290 | 0,773 | 0,104 | 290 |
| 0,300 | 0,774 | 0,105 | 300 |
| 0,310 | 0,774 | 0,106 | 310 |
| 0,320 | 0,775 | 0,106 | 320 |
| 0,330 | 0,775 | 0,107 | 330 |
| 0,340 | 0,776 | 0,108 | 340 |
| 0,350 | 0,776 | 0,109 | 350 |
| 0,360 | 0,777 | 0,110 | 360 |
| 0,370 | 0,778 | 0,111 | 370 |
| 0,380 | 0,779 | 0,112 | 380 |
| 0,390 | 0,780 | 0,114 | 390 |
| 0,400 | 0,781 | 0,115 | 400 |
| 0,410 | 0,783 | 0,116 | 420 |
| 0,420 | 0,784 | 0,118 | 430 |
| 0,430 | 0,786 | 0,119 | 450 |
| 0,440 | 0,787 | 0,121 | 460 |
| 0,450 | 0,789 | 0,123 | 490 |
| 0,460 | 0,791 | 0,125 | 510 |
| 0,470 | 0,794 | 0,127 | 540 |
| 0,480 | 0,796 | 0,129 | 580 |
| 0,490 | 0,799 | 0,132 | 630 |
| 0,500 | 0,802 | 0,135 | 700 |
| 0,510 | 0,805 | 0,139 | 780 |
| 0,520 | 0,808 | 0,143 | 880 |
| 0,530 | 0,812 | 0,147 | 1 000 |
| 0,540 | 0,816 | 0,153 | 1 200 |
| 0,550 | 0,820 | 0,159 | 1 400 |
| 0,560 | 0,824 | 0,167 | 1 600 |
| 0,570 | 0,829 | 0,174 | 1 900 |

**Table 4** *(continued)*

| $\beta$ | $C$ | $r/d$ | $Re_D$ (min.) |
|---|---|---|---|
| 0,580 | 0,834 | 0,183 | 2 300 |
| 0,590 | 0,839 | 0,194 | 2 700 |
| 0,600 | 0,844 | 0,207 | 3 300 |

## 6.3 Eccentric orifice plates

### 6.3.1 General

The eccentric orifice plate is designed to be installed so that it does not obstruct the flow of entrained gas, liquid or sediments in a fluid, while remaining simple to manufacture and install. Eccentric orifice plates are used according to ISO 5167-1:2022, Clause 6 and installed according to ISO 5167-2:2022, Clause 6 (except 6.5.3).

### 6.3.2 Limits of use

The limits of use for eccentric orifice plates are as follows:

— $d \geq 50$ mm;

— 100 mm $\leq D \leq$ 1 000 mm;

— $0{,}46 \leq \beta \leq 0{,}84$;

— $2 \times 10^5 \beta^2 \leq Re_D \leq 10^6 \beta$.

### 6.3.3 Description

The eccentric orifice plate is shown in Figure 3.

NOTE The letters shown in Figure 3 are for reference purposes in 6.3.3.2 to 6.3.3.9 only.

#### 6.3.3.1 General shape

**6.3.3.1.1** The part of the plate inside the pipe is circular and the orifice is internally tangential to the pipe bore. The faces of the plate are flat and parallel.

**6.3.3.1.2** Unless otherwise stated, 6.3.3.1.3 and 6.3.3.2 to 6.3.3.9 apply only to that part of the plate located within the pipe.

**6.3.3.1.3** Correct design of the orifice plate and its installation ensures 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 6.3.3.2.1 to exceed 1 % under flowing conditions.

#### 6.3.3.2 Upstream face A

**6.3.3.2.1** The upstream face A of the plate is flat when the plate is installed in the pipe with zero differential pressure across it.

Provided it can be shown that the method of mounting does not distort the plate, this flatness is measured with the plate removed from the pipe. Under these circumstances, the plate is considered flat when the maximum gap between the flat portion of the upstream face of the plate and a straight edge of length $D$ laid across any diameter of the plate is less than $0{,}005(D - d)/2$; i.e. the slope is less than about 0,5 % when the orifice plate is examined prior to insertion into the meter line (see also



ISO 5167-2:2022, Figure 2). The critical area is in the vicinity of the orifice bore. The use of feeler gauges gives sufficiently low uncertainty to measure this dimension.

**6.3.3.2.2** The upstream face of the orifice plate has a roughness criterion $Ra \leq 10^{-4}d$ within a circle whose diameter is not less than 1,5*d* and which is concentric with the orifice, except for that part outside diameter *D* (see 6.3.3.1.2).

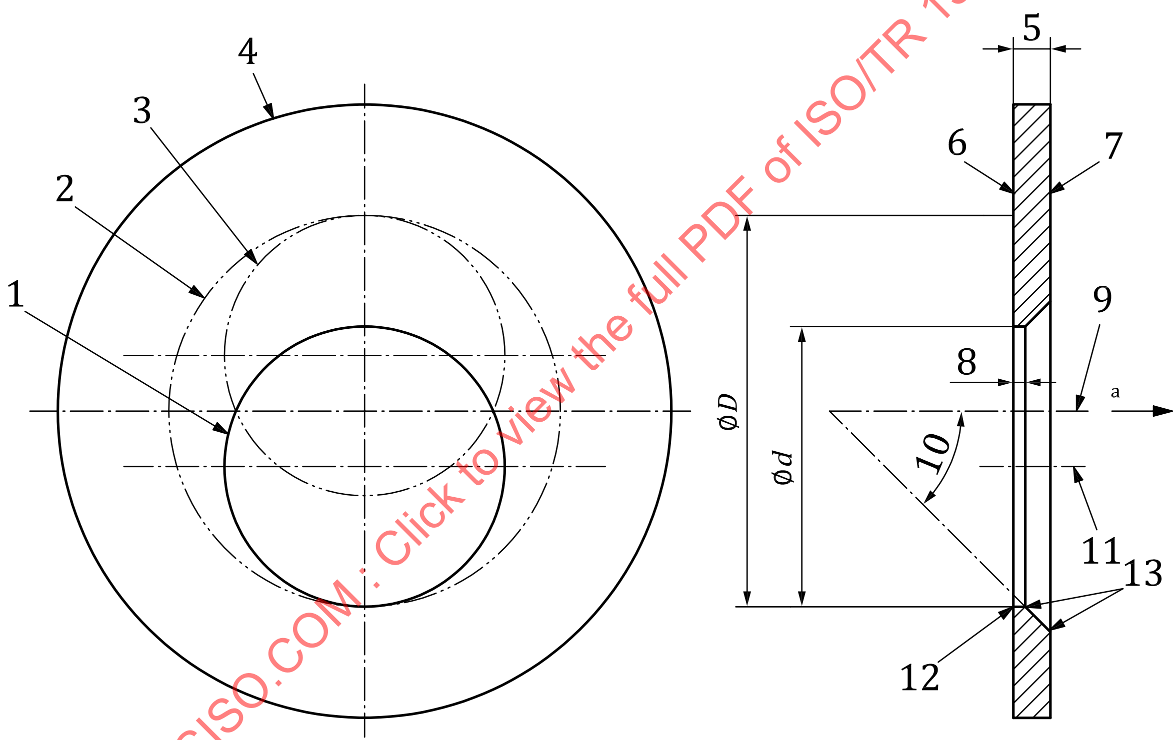
NOTE It is useful to provide a distinctive mark, which is visible even when the orifice plate is installed, to show that the upstream face of the orifice plate is correctly installed relative to the direction of flow.

#### 6.3.3.3 Downstream face B

The downstream face is flat and parallel to the upstream face.

NOTE It is unnecessary to provide the same quality of surface finish for the downstream face as for the upstream face. The flatness and surface condition of the downstream face can be judged by visual inspection.






**Key**

1 orifice
2 pipe bore
3 alternative position of orifice
4 outside diameter of the plate
5 thickness, *E*, of the plate
6 upstream face A
7 downstream face B
8 thickness, *e*, of the orifice
9 plate centreline
10 angle of bevel, *f*
11 orifice centreline
12 upstream edge G
13 downstream edges H and I
a Direction of flow.

**Figure 3 — Eccentric orifice plate**

#### 6.3.3.4 Thicknesses *e* and *E*

**6.3.3.4.1** The thickness, *e*, of the orifice is between 0,005*D* and 0,02*D*.

**6.3.3.4.2** The values of *e* measured at any point on the orifice do not differ from each other by more than 0,001*D*.

**6.3.3.4.3** The thickness, *E*, of the orifice plate is between *e* and 0,05*D*.

**6.3.3.4.4** If $D \geq 200$ mm, the difference between the values of *E* measured at any point of the plate is not greater than 0,001*D*. If $D < 200$ mm, the difference between the values of *E* measured at any point of the plate is not greater than 0,2 mm.

#### 6.3.3.5 Angle of bevel

**6.3.3.5.1** If the thickness, *E*, of the plate exceeds the thickness, *e*, of the orifice, the plate is bevelled on the downstream side and the bevelled surface is well finished.

**6.3.3.5.2** The angle of bevel, *f*, is 45° ± 15°.

**6.3.3.5.3** The plate is not bevelled if its thickness, *E*, is less than or equal to 0,02*D*.

NOTE Although detrimental effects from debris trapped in the invert of the downstream bevel are considered unlikely, entrapment will be eliminated by restricting the thickness, *E*, of the plate to the thickness, *e*, of the orifice, so that no bevel is necessary.

#### 6.3.3.6 Edges G, H and I

**6.3.3.6.1** The upstream edge G and the downstream edges H and I do not have wire edges, burrs or any peculiarities visible to the naked eye.

**6.3.3.6.2** The upstream edge G is considered sharp if the edge radius is not greater than 0,000 4*d*.

As $d \geq 50$ mm, 6.3.3.6.2 can be considered as satisfied by visual inspection, checking that the edge does not seem to reflect a beam of light when viewed by the naked eye.

If there is any doubt as to whether 6.3.3.6.2 is satisfied, the edge radius is measured.



#### 6.3.3.7 Diameter of orifice

**6.3.3.7.1** The diameter of the orifice, *d*, is taken as the mean value of a number of measurements of the diameter distributed in axial planes and at approximately equal angles between adjacent measurements. At least four measurements of the diameter are made.

No diameter differs by more than 0,05 % from the value of the mean diameter.

**6.3.3.7.2** The parallel bore of the orifice is cylindrical and perpendicular to the upstream face.

**6.3.3.7.3** The diameter, *d*, is between 0,46*D* and 0,84*D*.

NOTE Within these limits, the value of $\beta$ is chosen by the user taking into consideration parameters such as required differential pressure, uncertainty, acceptable pressure loss and available static pressure.

#### 6.3.3.8 Symmetrical plates

If the orifice plate is intended to be used for measuring reverse flows then

a) the plate is not bevelled;

b) the two faces are as described for the upstream face in 6.3.3.2;

c) the thickness, $E$, of the plate is equal to the thickness, $e$, of the orifice as described in 6.3.3.4.1; and

d) the two edges of the orifice are as described for the upstream edge in 6.3.3.6.2.

#### 6.3.3.9 Pressure tappings

Eccentric orifice plates are used with a single pair of corner tappings as specified in ISO 5167-2:2022, 5.2.3, except that the pressure-tapping hole diameter, $a$, is within the limits 3 mm ≤ $a$ ≤ 10 mm.

NOTE In an eccentric orifice plate, the orifice is not concentric with the pipe bore and, consequently, the pressure difference depends on the angular position of the pressure tappings.

Ideally, the pressure tappings are diametrically opposite the point at which the orifice is tangential to the wall of the pipe. All discharge coefficient values in this document are based on such a disposition. However, rotating the tappings by only 90° from the ideal position would result in an error of not more than +2 % in the discharge coefficient.

Since the orifice is usually either at the top or at the bottom of the pipe, placing the pressure tappings diametrically opposite can cause other problems, such as air entrainment if tappings are at the very top, or blockage by dirt when they are at the bottom of the pipe. In such cases, if the tappings are rotated by 30° from the vertical centreline of the pipe no significant additional flow metering uncertainty is incurred.

### 6.3.4 Coefficients and corresponding uncertainties

**6.3.4.1** The discharge coefficient, $C$, is given by Formula (21):

$$C = 0{,}935\,5 - 1{,}688\,9\beta + 3{,}042\,8\beta^2 - 1{,}798\,9\beta^3 \qquad (21)$$

For convenience, Table 5 gives values of $C$ as a function of $\beta$.

When $\beta$, $D$, $Re_D$ and $k/D$ are assumed to be known without error, the relative expanded uncertainty of the value of $C$ at $k = 2$ (approximately 95 % confidence level) is 1 % when $\beta \leq 0{,}75$.

The relative expanded uncertainty at $k = 2$ (approximately 95 % confidence level) is 2 % when $\beta > 0{,}75$.

**6.3.4.2** The discharge coefficient is multiplied by the appropriate correction factor for pipe roughness, $F_E$, given in Table 6 in terms of $\beta$ and relative pipe roughness $k/D$. The value of the uniform equivalent roughness, $k$, depends on several factors such as height, distribution, angularity and other geometric aspects of the roughness element at the pipe wall. A pressure loss test of a sample length of the particular pipe is carried out to determine the value satisfactorily. However, approximate values of $k$ for different materials can be obtained from ISO 5167-1:2022, Table B.1.

**6.3.4.3** The expansibility factor, $\varepsilon$, is given by Formula (22) and is only applicable if $p_2/p_1 \geq 0{,}75$:

$$\varepsilon = 1 - (0{,}351 + 0{,}256\beta^4 + 0{,}93\beta^8)\left[1 - \left(\frac{p_2}{p_1}\right)^{1/\kappa}\right] \qquad (22)$$

NOTE $p_1$ and $\Delta p$ are usually measured: $p_2 = p_1 - \Delta p$.

When $\beta$, $\Delta p/p_1$ and $\kappa$ are assumed to be known without error, the relative expanded uncertainty of the value of $\varepsilon$ at $k = 2$ (approximately 95 % confidence level) is equal to $3{,}5\,\Delta p/\kappa p_1$ %.

Test results for the determination of $\varepsilon$ are known for air, steam and natural gas only. However, there is no known objection to using the same formula for other gases and vapours whose isentropic exponent is known.



**Table 5 — Discharge coefficients for eccentric orifice plates**

| *β* | *C* |
|---|---|
| 0,46 | 0,627 |
| 0,47 | 0,627 |
| 0,48 | 0,627 |
| 0,49 | 0,627 |
| 0,50 | 0,627 |
| 0,51 | 0,627 |
| 0,52 | 0,627 |
| 0,53 | 0,627 |
| 0,54 | 0,627 |
| 0,55 | 0,628 |
| 0,56 | 0,628 |
| 0,57 | 0,628 |
| 0,58 | 0,628 |
| 0,59 | 0,629 |
| 0,60 | 0,629 |
| 0,61 | 0,629 |
| 0,62 | 0,629 |
| 0,63 | 0,629 |
| 0,64 | 0,629 |
| 0,65 | 0,629 |
| 0,66 | 0,629 |
| 0,67 | 0,629 |
| 0,68 | 0,628 |
| 0,69 | 0,628 |
| 0,70 | 0,627 |
| 0,71 | 0,626 |
| 0,72 | 0,625 |
| 0,73 | 0,624 |
| 0,74 | 0,623 |
| 0,75 | 0,621 |
| 0,76 | 0,620 |
| 0,77 | 0,618 |
| 0,78 | 0,616 |
| 0,79 | 0,613 |
| 0,80 | 0,611 |
| 0,81 | 0,608 |
| 0,82 | 0,605 |
| 0,83 | 0,601 |
| 0,84 | 0,597 |