FINAL DRAFT

TECHNICAL REPORT

ISO/DTR 12767

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

Secretariat: **BSI**

Voting begins on:
2023-06-26

Voting terminates on:
2023-08-21

Measurement of fluid flow by means of pressure differential devices — Guidelines on the effect of departure from the specifications and operating conditions given in ISO 5167

Mesurage du débit des fluides au moyen d'appareils déprimogènes — Lignes directrices relatives aux effets des écarts par rapport aux spécifications et aux conditions d'utilisation données dans l'ISO 5167

Reference number
ISO/DTR 12767:2023(E)

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

This third edition cancels and replaces the second edition (ISO/TR 12767:2007), which has been technically revised.

The main changes are as follows:

— editorial changes throughout the document.

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 series specifies methods for flowrate measurement using pressure differential devices. Adherence to ISO 5167 series results in flowrate measurements whose uncertainty lies within specified limits. If, however, a flow-metering installation departs, for whatever reason, from the conditions specified in ISO 5167 series, the specified limits of uncertainty might not be achieved. Many metering installations exist where these conditions either have not been or cannot be met. In these circumstances, it is usually not possible to evaluate the precise effect of any such deviations. However, a considerable amount of data exists which can be used to give a general indication of the effect of non-conformity to ISO 5167 series and it is presented in this document as a guideline to users of flow-metering equipment.

Measurement of fluid flow by means of pressure differential devices — Guidelines on the effect of departure from the specifications and operating conditions given in ISO 5167

1 Scope

This document provides guidance on estimating the flowrate when using pressure differential devices constructed or operated outside the scope of ISO 5167 series.

Additional tolerances or corrections cannot necessarily compensate for the effects of deviating from ISO 5167 series. The information is given, in the first place, to indicate the degree of care necessary in the manufacture, installation and maintenance of pressure differential devices by describing some of the effects of non-conformity to the requirements; and in the second place, to permit those users who cannot comply fully with the requirements to assess, however roughly, the magnitude and direction of the resulting error in flowrate.

Each variation dealt with is treated as though it were the only one present. Where more than one is known to exist, there might be unpredictable interactions and care has to be taken when combining the assessment of these errors. If there is a significant number of errors, means of eliminating some of them have to be considered. The variations included in this document are by no means complete and relate largely to examples with orifice plates. An example with Venturi tubes has been placed at the end of its section. This document does not apply to cone meters or wedge meters. There are, no doubt, many similar examples of installations not conforming to ISO 5167 series for which no comparable data have been published. Such additional information from users, manufacturers and any others can be taken into account in future revisions of this document.

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 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 5167-1 and the following apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
square edge
angular relationship between the orifice bore of the flow-measurement device and the upstream face, when the angle between them is 90° ± 0,3°

3.2
sharpness
radius of the edge between the orifice bore of the flow-measurement device and the upstream face

Note 1 to entry: The upstream edge of the orifice bore is considered to be sharp when its radius is not greater than 0,000 4*d*, where *d* is the diameter of the orifice bore.

4 Symbols

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

Table 1 — Symbols an units

Symbol	Quantity represented	Dimension M: mass L: length T: time	SI unit
c	Percentage change in discharge coefficient $[\equiv 100(\Delta C\,/\,C)]$	dimensionless	
C	Discharge coefficient	dimensionless	
C_c	Contraction coefficient	dimensionless	
d	Diameter of orifice or throat of primary device under working conditions	L	m
D	Upstream internal pipe diameter at operating conditions	L	m
D_1	Carrier ring diameter	L	m
D_2	Orifice-plate support diameter	L	m
e	Orifice thickness	L	m
E	Orifice-plate thickness	L	m
k	Uniform equivalent roughness	L	m
L_1	Distance of upstream pressure tapping from upstream face of plate divided by pipe bore, *D*	dimensionless	
L'_2	Distance of downstream pressure tapping from downstream face of plate divided by pipe bore, *D*	dimensionless	
q_m	Mass flow rate	MT^{-1}	kg/s
r	Orifice-plate edge radius	L	m
Re_d	Throat Reynolds number	dimensionless	
Re_D	Pipe Reynolds number	dimensionless	
u	Local axial velocity	LT^{-1}	m/s
u_{CL}	Centreline axial velocity	LT^{-1}	m/s
U	Mean axial velocity	LT^{-1}	m/s
U'	Relative expanded uncertainty	dimensionless	
Y	Modulus of elasticity of orifice-plate material	$ML^{-1}T^{-2}$	Pa
β	Diameter ratio, (= d/D)	dimensionless	
Δp	Differential pressure	$ML^{-1}T^{-2}$	Pa
Δp_y	Differential pressure required to reach orifice-plate yield stress	$ML^{-1}T^{-2}$	Pa
ε	Expansibility (expansion) factor	dimensionless	
λ	Friction factor	dimensionless	
ρ	Fluid density	ML^{-3}	kg/m^3
ρ_1	Fluid density at the upstream pressure tapping	ML^{-3}	kg/m^3
σ_y	Yield stress of orifice-plate material	$ML^{-1}T^{-2}$	Pa

5 Effect of errors on flowrate calculations

5.1 General

In this document, the effects of deviations from the conditions specified in ISO 5167 series are described in terms of changes in the discharge coefficient, ΔC, of the meter. The discharge coefficient, C, of a pressure differential device is given by Formula (1):

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

The sharp edge of an orifice plate ensures separation of the flow and consequently contraction of the fluid stream to the vena contracta. Defining the contraction coefficient, C_c, as the ratio of the flow area to the geometric area the orifice produces $C_c \approx 0{,}6$, which mainly accounts for the discharge coefficient, $C \approx 0{,}6$.

The effect of change in the discharge coefficient is illustrated by the following example.

Consider an orifice plate with an unduly rounded edge. The result of this is to reduce the separation and increase C_c, leading in turn to reduced velocities at the vena contracta. The observed differential pressure therefore decreases. From Formula (1), it can be seen that the discharge coefficient therefore increases. Alternatively, as C_c increases, so does C. If no correction is made for this change in C, the meter reading is less than the actual value.

It can therefore be concluded that

a) an effect which causes an increase in discharge coefficient results in a flowrate reading lower than the actual value if the coefficient is not corrected,

and conversely,

b) an effect which causes a decrease in discharge coefficient results in a flowrate reading higher than the actual value if the coefficient is not corrected.

5.2 Quantifiable effects

When the user is aware of such effects and they can be quantified, the appropriate discharge coefficient can be used and the correct flowrate calculated. However, the precise quantification of these effects is difficult and so any flowrate calculated in such a manner is considered to have an increased uncertainty.

Except where otherwise stated, an additional uncertainty factor, equivalent to 100 % of the discharge coefficient correction, is added arithmetically to the relative expanded uncertainty of the discharge coefficient when estimating the overall uncertainty in the flowrate measurement.

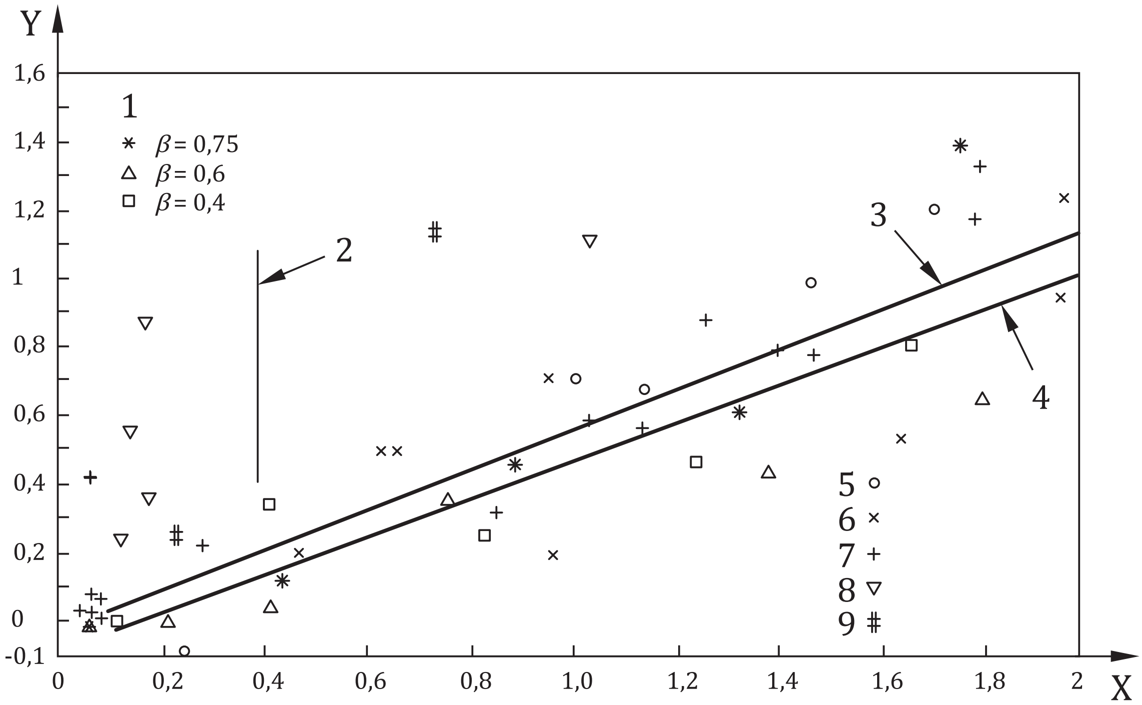
6 Effects of deviations in construction

6.1 Orifice-plate edge sharpness

Orifice plates that do not have the specified sharpness of the inlet edge (edge radius $r \leq 0{,}000\,4d$ in accordance with ISO 5167-2:2022, 5.1.7.2), have progressively increasing discharge coefficients as the edge radius increases. Tests have shown that the effect on the discharge coefficient, C, is to increase it by 0,5 % for r/d of 0,001, and by about 5 % for r/d of 0,01. This is an approximately linear relationship (see Figure 1 and Reference [6]). These values apply particularly to Re_d values above 300 000 and for β values below 0,7, but they can be used as a general guide for other values.

Measurement techniques for edge radius are available, but in general it is better to improve the edge sharpness to the required value rather than to attempt to measure it and make appropriate corrections.

The effect of nicks in orifice plates has also been measured in Reference [6].



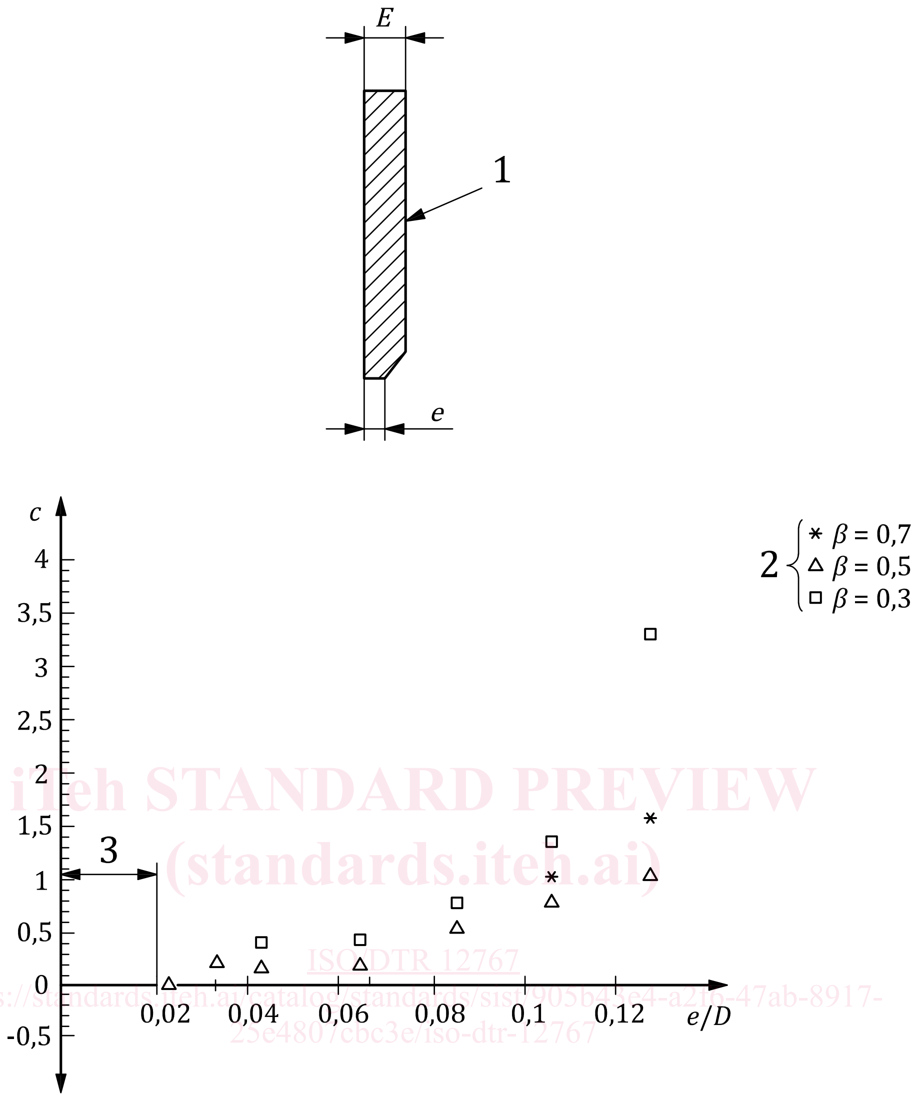
Key

X	radius ratio (×10^3)
Y	change in discharge coefficient (%)
1	national engineering laboratory (NEL, UK) tests — *D* = 300 mm
2	ISO limit — *r* = 0,000 4*d*
3	others
4	NEL
5	*D* = 50 mm (Reference [59])
6	*D* = 100 mm (Reference [59])
7	*D* = 150 mm (Reference [37])
8	*D* = 75 mm (Reference [60])
9	*D* = 100 mm (Reference [61])

Figure 1 — Effect of edge radius on discharge coefficient

6.2 Thickness of orifice edge

For orifice plates, the increase in discharge coefficient due to excessive thickness of the orifice edge (see ISO 5167-2:2022, 5.1.5) can be appreciable. With a straight-bore orifice plate in a 150 mm pipe, the changes in discharge coefficient shown in Figure 2 were obtained (see Reference [2]). Additional data are shown in Reference [62].



Key

1 section of an orifice plate

2 symbol

3 limit of standard

c change in discharge coefficient (%)

e/*D* orifice thickness to upstream internal pipe diameter ratio

Figure 2 — Change in discharge coefficient as a function of orifice thickness

6.3 Condition of upstream and downstream faces of orifice plate

The upstream face of an orifice plate is flat and smooth. Excessive roughness leads to an increase in the discharge coefficient. Tests have indicated that a surface roughness of 0,000 3d causes an increase in discharge coefficient of the order of 0,1 % (see Reference [34]). Since the requirement for edge sharpness is $r \leq 0{,}000\,4d$, an increase in plate roughness makes it difficult to define the edge sharpness or to confirm that the sharp edge requirement has been met.

Local damage to the upstream face or edge of an orifice plate does not adversely affect the discharge coefficient, provided that the damage is kept as far away from the pressure tapping as possible (see Reference [1]). The discharge coefficient is much less sensitive to the surface condition of the downstream face of the plate (Reference [1]).

Large-scale lack of flatness, e.g. "dishing", leads to flow-measurement errors. A "dishing" of 1 % in the direction of flow causes the reading to be below the actual value, i.e. an increase in C of about 0,2 % for β = 0,2 and of about 0,1 % for β = 0,7. Distortion against the direction of flow also causes errors which could be either positive or negative depending on the amount of distortion.

6.4 Position of pressure tappings for an orifice

6.4.1 General

Values of the orifice-plate discharge coefficient for the three standard tapping positions (corner, flange, D and $D/2$) can be calculated using ISO 5167-2:2022, Formula (4) (see Reference [58]). Where the tapping positions fall outside the tolerances permitted in ISO 5167-2 for the three positions, the discharge coefficient is estimated as described in 6.4.2. An additional uncertainty factor is associated with the use of non-standard tapping positions.

6.4.2 Calculation of discharge coefficient

Calculate the actual values of L_1 and L'_2. The discharge coefficient can be estimated only if $L_1 \leq 1$ and $L'_2 \leq 0{,}47$.

Using the actual values of L_1 and L'_2 estimate the discharge coefficient using ISO 5167-2:2022, Formula (4).

6.4.3 Estimation of additional uncertainty

If tappings lie between the flange and the corner tappings, the additional uncertainty, $\delta U'$, expressed as a percentage, can be estimated from Formula (2):

$$\delta U' = 25\left|\frac{C_{\mathrm{F}}}{C_{\mathrm{CT}}} - 1\right| \quad (2)$$

where

C_{F} is the discharge coefficient for flange tappings;

C_{CT} is the discharge coefficient for corner tappings.

If tappings lie between the D and $D/2$ tappings and the flange tappings, the additional uncertainty, $\delta U'$, expressed as a percentage, can be estimated from Formula (3):

$$\delta U' = 25\left|\frac{C_{D\ \mathrm{and}\ D/2}}{C_{\mathrm{F}}} - 1\right| \quad (3)$$

where $C_{D\ \mathrm{and}\ D/2}$ is the discharge coefficient for D and $D/2$ tappings.

6.4.4 Example

Consider an orifice meter with β = 0,6, $Re_D = 10^6$, D = 250 mm and tappings at 0,15D upstream and downstream of the plate.

To estimate the discharge coefficient, use ISO 5167-2:2022, Formula (4), with $L_1 = L'_2 = 0{,}15$.

The tappings in this example lie between the flange tapping and D and $D/2$ tapping positions. From, respectively, ISO 5167-2:2022, Tables A.8 and A.2: C_F = 0,605 1; $C_{D \text{ and } D/2}$ = 0,607 0. Therefore

$$\delta U' = 25\left|\frac{0{,}605\ 1}{0{,}607\ 0} - 1\right| = 0{,}078$$

The relative expanded uncertainty in the discharge coefficient at k = 2 (approximately 95 % confidence level) is 0,5 % (see ISO 5167-2:2022, 5.3.3.1.

Therefore, the overall relative expanded uncertainty at k = 2 (approximately 95 % confidence level) is 0,5 + 0,078 ≈ 0,6 % (i.e. the uncertainties have simply been added together).

6.5 Condition of pressure tappings

Experience has shown that large errors can be created by pressure tappings which have burrs or deposits on, or close to, the edge where the tapping penetrates the pipe wall. This is particularly the case where the tappings are in the main flow stream, such as throat tappings in nozzles or Venturi tubes, where small burrs can give rise to significant percentage errors. Upstream corner tappings and downstream tappings in relatively dead zones are much less liable to cause this problem.

The installation is inspected before use and at regular intervals to ensure that these anomalies are not present.

7 Effects of pipeline near the meter

7.1 Pipe diameter

The internal diameter of the pipe upstream and downstream of the primary device is always measured to ensure that it is in accordance with ISO 5167-2:2022, 6.4, ISO 5167-3:2022, 6.4 or ISO 5167-4:2022, 6.4.1. Errors in the upstream internal diameter measurement cause errors in the calculated flowrate, which are given by Formula (4):

$$\frac{\delta q_m}{q_m} = \frac{-2\beta^4}{(1-\beta^4)}\frac{\delta D}{D} \tag{4}$$

These errors become significant for large β, e.g. with β = 0,75, a positive 1 % error in D causes a negative 1 % error in q_m.

The downstream pipe is far less critical, as for an orifice plate, an ISA 1932 nozzle or a long radius nozzle its diameter need only be within 3 % of that of the upstream pipe (see ISO 5167-2:2022, 6.4.6 or ISO 5167-3:2022, 6.4.6) and for a Venturi nozzle or a Venturi tube its diameter need only be ≥90 % of the diameter at the end of the divergent section (see ISO 5167-3:2022 6.4.6 or ISO 5167-4:2022, 6.4.1.3).

7.2 Steps and taper sections

Sudden enlargements of the pipe in the vicinity of the primary device are always to be avoided as large errors in flow measurement result from their use. Similarly, tapering sections of pipe can lead to significant errors, as can be seen from Table 2 which gives the order of errors to be expected when an orifice plate with corner tappings is immediately preceded or followed by a taper piece.

The information in Table 2 indicates that a taper piece divergent in the direction of flow, and placed immediately upstream, is not recommended, since discharge-coefficient increases of up to 50 % result. On the other hand, a convergent taper piece, whether installed before or after the orifice plate, and provided it is not of a steeper angle than those shown, results in coefficient changes of generally less than 2 %.