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Measurement of fluid flow by means of pressure-differential devices — Guidelines to the effect of departure from the specifications and operating conditions given in ISO 5167-1

Mesurage du débit des fluides au moyen d'appareils déprimogènes — Lignes directrices relatives aux effets de divergence par rapport aux spécifications et conditions de fonctionnement données dans l'ISO 5167-1

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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.

The main task of technical committees is to prepare International Standards. In exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard (“state of the art”, for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 12767, which is a Technical Report of type 3, was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 2, *Pressure-differential devices.*

Annex A of this Technical Report is for information only.

Introduction

ISO 5167-1 is an International Standard for flowrate measurement using a differential-pressure device. Adherence to that standard will result in flowrate measurements the uncertainty of which will lie within specified limits. If, however, a flowmetering installation departs, for whatever reason, from the conditions specified in ISO 5167-1, the specified limits of uncertainty may 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 5167-1, and it is presented in this Technical Report as a guideline to users of flow-metering equipment.

Measurement of fluid flow by means of pressure-differential devices — Guidelines to the effect of departure from the specifications and operating conditions given in ISO 5167-1

1 Scope

This Technical Report provides guidance to assist in estimating the flowrate when using pressure-differential devices constructed or operated outside the scope of ISO 5167-1.

It should not be inferred that additional tolerances or corrections can necessarily compensate for the effects of deviating from ISO 5167-1. 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 may not be able to 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 may 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 must be considered. The variations included in this Technical Report are by no means complete and relate largely to examples with orifice plates. There are, no doubt, many similar examples of installations not conforming to ISO 5167-1 for which no comparable data have been published. Such additional information from users, manufacturers and any others may be taken into account in future revisions of this Technical Report.

2 Reference

ISO 5167-1:1991, *Measurement of fluid flow by means of pressure-differential devices — Part 1: Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full*.

3 Symbols and definitions

3.1 Symbols

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

3.2 Definitions

For the purposes of this Technical Report, the definitions given in ISO 5167-1 and the following definitions apply.

3.2.1
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°

3.2.2
sharpness
radius of the edge between the orifice bore of the flow measurement device and the upstream face

NOTE The upstream edge of the orifice bore is considered to be sharp when its radius is not greater than 0,0004 d, where d is the diameter of the orifice bore.

Table 1 — Symbols

Symbol	**Represented quantity**	**Dimensions** M: mass L: length T: time	**SI units**
c	Percentage change in discharge coefficient $\left(\equiv 100\ \dfrac{\Delta C}{C}\right)$	dimensionless	
C	Discharge coefficient	dimensionless	
C_c	Contraction coefficient	dimensionless	
d	Diameter of orifice or throat of primary device at operating 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	Relative uncertainty	dimensionless	
E	Orifice plate thickness	L	m
E_e	Thickness of orifice	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 rate of flow	MT^{-1}	kg/s
r	Orifice plate edge radius	L	m
Re_D	Reynolds number based on upstream pipe diameter	dimensionless	
Re_d	Reynolds number based on throat bore of device	dimensionless	
$S_{L,1}$	Distance from upstream fitting to straightener	L	m
$S_{L,2}$	Distance from straightener to primary device	L	m
$S_{L,3}$	Distance from primary device to downstream fitting	L	m
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
Y	Modulus of elasticity of orifice plate material	$\mathrm{ML}^{-1}\mathrm{T}^{-2}$	Pa
β	Diameter ratio, $\beta = d/D$	dimensionless	
Δp	Differential pressure	$\mathrm{ML}^{-1}\mathrm{T}^{-2}$	Pa
Δp_y	Differential pressure required to reach orifice plate yield stress	$\mathrm{ML}^{-1}\mathrm{T}^{-2}$	Pa
ε_1	Expansibility (expansion) factor at the upstream pressure tapping	dimensionless	
λ	Friction factor	dimensionless	
ρ	Fluid density	ML^{-3}	$\mathrm{kg/m^3}$
ρ_1	Fluid density at the upstream pressure tapping	ML^{-3}	$\mathrm{kg/m^3}$
σ_y	Yield stress of orifice plate material	$\mathrm{ML}^{-1}\mathrm{T}^{-2}$	Pa

4 Effect of errors on flowrate calculations

4.1 General

In this Technical Report the effects of deviations from the conditions specified in ISO 5167-1 are described in terms of changes in the discharge coefficient of the meter. The discharge coefficient of a pressure-differential device (C) is given by the following equation:

$$C = \frac{4\ q_m \sqrt{(1-\beta^4)}}{\varepsilon_1\ \pi\ d^2 \sqrt{(2\Delta p\ \rho_1)}} \tag{1}$$

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

$$\frac{flow\ \ area}{geometric\ area},$$

the orifice produces $C_c \cong 0{,}6$, which mainly accounts for the discharge coefficient, $C \cong 0{,}6$.

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 will be to reduce the separation and increase C_c, leading in turn to reduced velocities at the vena contracta. The observed differential pressure will therefore decrease. From the equation above, it can be seen that the discharge coefficient would therefore increase. Alternatively, as C_c increases so does C. If no correction is made for this change in C, the meter will under-read (register).

It can therefore be concluded that:

a) an effect which causes an increase in discharge coefficient will result in an under-reading of flow if the coefficient is not corrected;

and conversely,

b) an effect which causes a decrease in discharge coefficient will result in an over-reading of flow if the coefficient is not corrected.

4.2 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 should be considered to have an increased uncertainty.

Except where otherwise stated, an additional uncertainty factor, equivalent to 100 % of the discharge coefficient correction, should be added arithmetically to that of the discharge coefficient when estimating the overall uncertainty of the flowrate measurement.

5 Effects of deviations in construction

5.1 Orifice plate edge sharpness

Orifice plates that do not have the specified sharpness of the inlet edge (edge radius $r \leq 0{,}0004\ d$ in accordance with 8.1.6.2 of ISO 5167-1 : 1991), will 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 Hobbs and

Humphreys[1]). 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 attempt to measure it and make appropriate corrections.

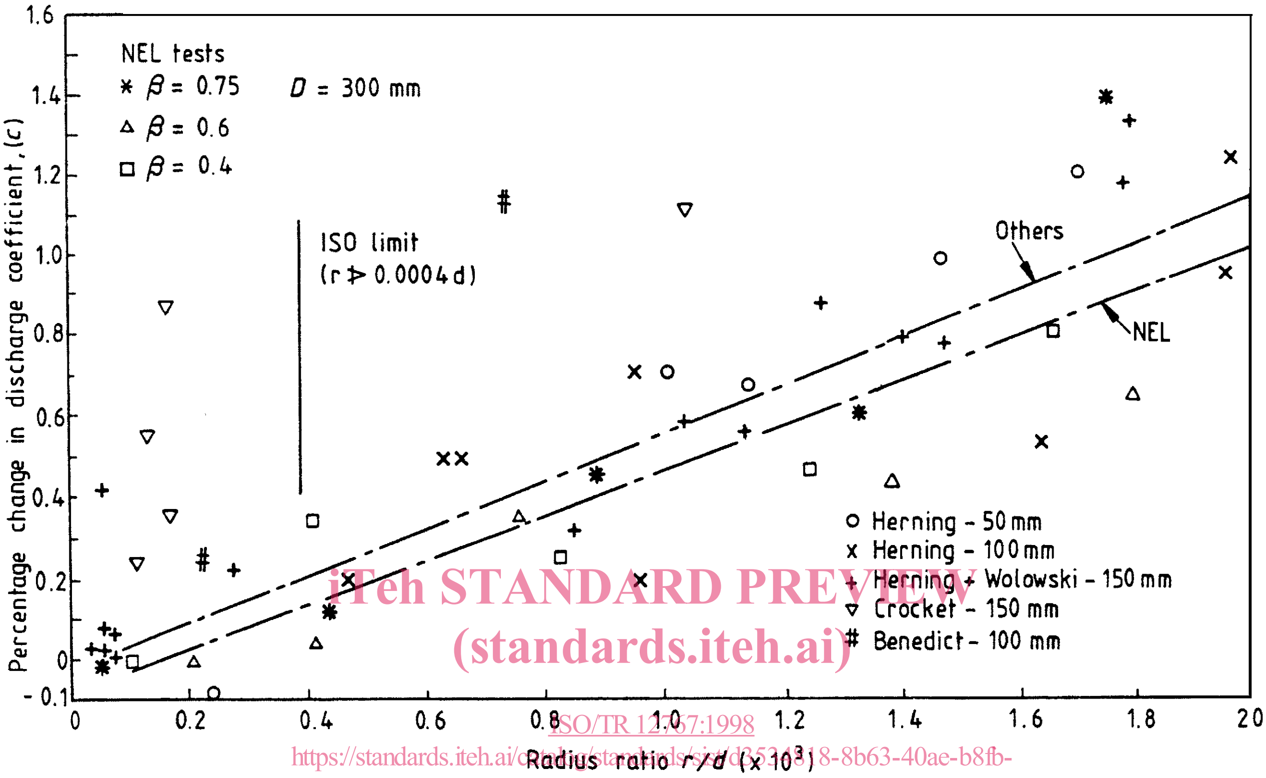


Figure 1 — Effect of edge radius on discharge coefficient

5.2 Thickness of orifice edge

For orifice plates, the increase in discharge coefficient due to the excessive thickness of the orifice edge (see 8.1.4 of ISO 5167-1 : 1991) 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 Husain and Teyssandier [2]).

5.3 Condition of upstream and downstream faces of orifice plate

The upstream face should be flat and smooth. Excessive roughness leads to an increase in the discharge coefficient. Tests have indicated that a surface roughness of 0,0003 d will cause an increase in discharge coefficient of the order of 0,1 %. Since the requirement for edge sharpness is $r \leq 0,0004\ d$, an increase in plate roughness will make it difficult to define or 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 Hobbs and Humphreys [1]). The discharge coefficient is much less sensitive to the surface condition of the downstream face of the plate (Hobbs and Humphreys [1]).

Large scale lack of flatness, e.g. ‘dishing’, leads to flow measurement errors. A ‘dishing’ of 1 % in the direction of flow will cause an under-reading, i.e. an increase in C, of about 0,2 % for β = 0,2 and 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.

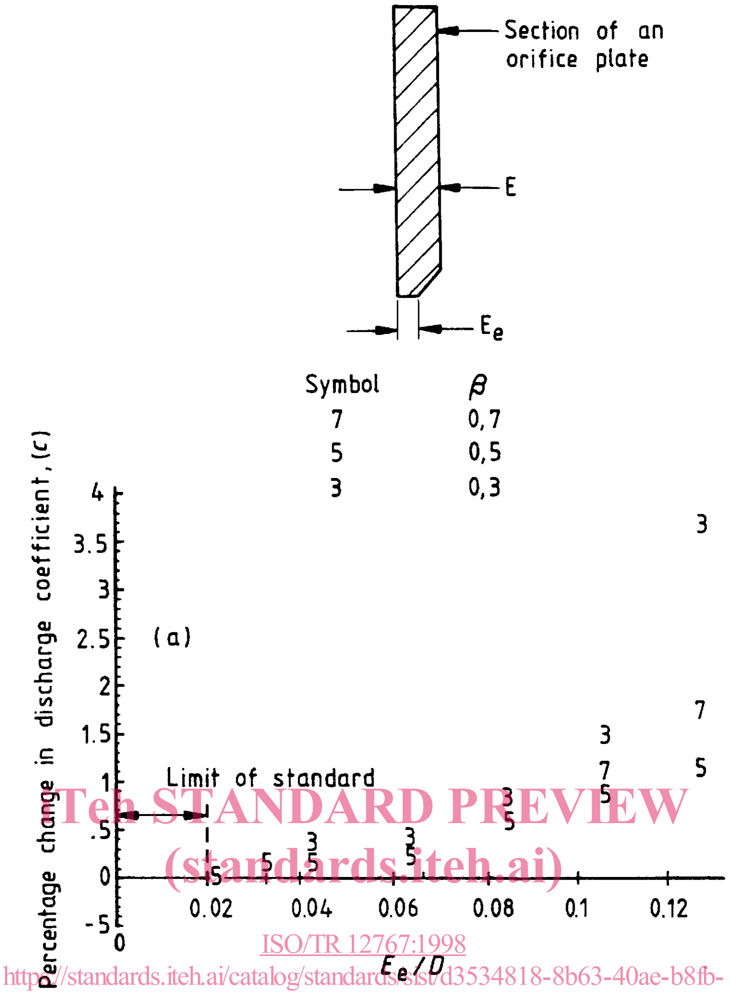


Figure 2 — Change in discharge coefficient as a function of orifice thickness

5.4 Position of pressure meter tappings for an orifice

5.4.1 General

Values of the orifice plate discharge coefficient for the three standard tapping positions (corner, flange, D and $D/2$) can be calculated using the Stolz equation (see 8.3.2.1 of ISO 5167-1 : 1991). Where the tapping positions fall outside the tolerances permitted in ISO 5167-1 for the three positions, the discharge coefficient may be estimated as described in 5.4.2. It should be emphasized that an additional uncertainty factor needs to be associated with the use of non-standard tapping positions.

5.4.2 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 the Stolz equation.

5.4.3 Estimation of additional uncertainty

If tappings lie between the flange and corner taps, the additional uncertainty (e), expressed as a percentage, can be estimated from:

$$e = 25\left|\frac{C_{FL}}{C_{CT}} - 1\right| \qquad (2)$$

where

C_{FL} is the discharge coefficient for flange taps;

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

If tappings lie between D and $D/2$ and flange taps, the additional uncertainty (e), expressed as a percentage, can be estimated from:

$$e = 25 \left| \frac{C_{D\&D/2}}{C_{\mathrm{FL}}} - 1 \right| \tag{3}$$

where

$C_{D\&D/2}$ is the discharge coefficient for D and $D/2$ taps.

5.4.4 Example

Consider an orifice meter with $\beta = 0,6$, $Re_D = 10^6$, $D = 254$ mm and tappings at 0,15 D upstream and downstream of the plate.

To estimate the discharge coefficient, use the Stolz equation with $L_1 = L'_2 = 0,15$.

The tappings in this example lie between the flange and D and $D/2$ tapping positions. From tables A.8 and A.2 respectively of ISO 5167-1 : 1991:

$C_{\mathrm{FL}} = 0,6049$

$C_{D\&D/2} = 0,6067$

Therefore, additional uncertainty = $25 \left| \frac{0,6067}{0,6049} - 1 \right| \%$ (4)

$= 0,074\ \%$

The uncertainty of the discharge coefficient is 0,6 % (see 8.3.3.1 of ISO 5167-1 : 1991);

Therefore, overall uncertainty = 0,6 + 0,074 ≈ 0,7 % (i.e. the uncertainty has been simply added arithmetically).

5.5 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 tapping is in the main flow stream such as throat taps in nozzles or Venturi tubes, where quite small burrs can give rise to significant percentage errors. Upstream corner tappings and downstream tappings in relatively dead zones are much less susceptible to this problem.

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

6 Effects of pipeline near the meter

6.1 Pipe diameter

The internal diameter of the pipe upstream and downstream of the primary device should always be measured to ensure that it is in accordance with 7.5 and 7.6 of ISO 5167-1 : 1991. Errors in the upstream internal diameter measurement will cause errors in the calculated rate of flow, which are given by:

$$\frac{\delta q_{\mathrm{m}}}{q_{\mathrm{m}}} = \frac{-2\ \beta^4}{(1-\ \beta^4)} \cdot \frac{\delta D}{D} \qquad (5)$$

These errors become significant for large β, e.g. with $\beta = 0{,}75$, a positive 1 % error in D will cause a negative 1 % error in q_{m}.

The downstream pipe is far less critical, as its diameter need only be within 3 % of that of the upstream pipe (see 7.5.1.6 of ISO 5167-1 : 1991).

6.2 Steps and taper sections

Sudden enlargements of the pipe in the vicinity of the primary device should always 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.

From Table 2 it will be seen 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 % are caused. 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 %.

6.3 Diameter of carrier ring

The requirements concerning the sizing and concentric mounting of carrier rings for orifice plates and nozzles are specified in 7.5.1.3, 7.5.1.4, 7.5.2.3, 7.5.2.4 and figure 6 of ISO 5167-1 : 1991. If the requirement of 7.5.2.4 (i.e. that the centred carrier ring should not protrude into the pipe) is not met, relatively large flow measurement errors will be introduced. Figure 3 shows such an installation and figure 4, using the same notation, shows the approximate errors introduced for the given conditions. It is emphasized that in arriving at these errors, the internal diameter of the carrier ring, D_1, and not the diameter of the main line, has been used in determining the calculated flowrate and is to be used for D in determining the correction factor when making use of the values shown.

Where the carrier is oversize, experimental results indicate that for $\beta = 0{,}74$, a carrier 11 % oversize and extending 0,05 D upstream from the plate increased the discharge coefficient by approximately 0,5 %. However, for a similar geometry but with $\beta = 0{,}63$, no effect was found.

6.4 Undersize joint rings

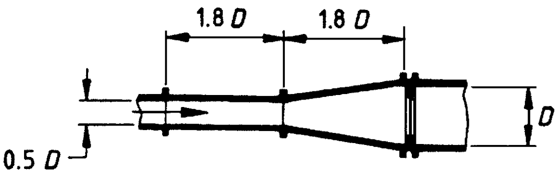
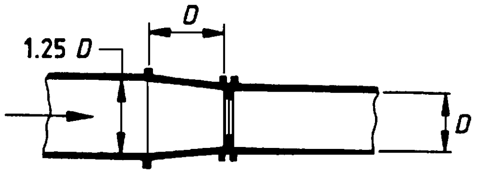
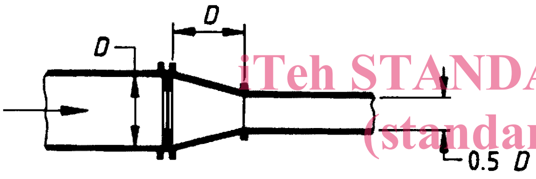
When the inside diameter of a joint ring or gasket is smaller than the pipe diameter, especially on the upstream side of an orifice plate or nozzle, very large flow measurement errors may occur. The magnitude and sign of the effect in relation to the measurement of flowrate is dependent on the combination of a number of variables, e.g. the thickness of the joint ring upstream of the orifice plate, the extent of its protrusion into the flow, its position relative to the orifice plate and pressure tappings, as well as on the degree of roughness of the upstream pipe.

6.5 Protruding welds

The effect of an undressed circumferential weld protruding into the pipe bore adjacent to the primary device will be similar to that of an undersize joint ring. Such an effect may arise from the fitting of a weld-neck flange, and the magnitude of the effect will depend on the height uniformity, or otherwise, of the protruding weld, and its position in relation to the single or multiple pressure tapping arrangement employed to measure the differential pressure across the primary device. To quantify the resulting error in a specific situation is difficult without a direct calibration.

From 7.1.5 in ISO 5167-1 : 1991 it should be noted that "seamed pipe may be used provided that the internal weld bead is parallel to the pipe axis throughout the length of the pipe and satisfies the special requirements for the type of primary element. The seam shall not be situated in any sector of ± 30° centred on any pressure tapping".

Table 2 — Effect of taper pieces

Position of orifice plate	β	**Order of the discharge coefficient change to be expected** %
a) Immediately downstream from a divergent taper piece 	0,4	+ 10
	0,7	+ 50
b) Immediately downstream from a convergent taper piece 	0,4	– 0,5
	0,7	– 2
c) Immediately upstream from a convergent taper piece 	0,4	0 to – 1
	0,7	+ 1

6.6 Eccentricity

The requirements for concentric mounting of the device are given in 7.5.2.3, 7.5.2.4 and 7.6.3 of ISO 5167-1 : 1991. The geometric measure of eccentricity is the distance between the pipe and orifice plate centrelines and is often expressed as a percentage of the pipe diameter D. Deviations from the permitted eccentricity values for the mounting of an orifice plate relative to the upstream and downstream pipe sections will result in errors in the measurement of flowrate. Figure 5 shows the eccentric mounting of an orifice plate in a sideways direction relative to the upstream pipeline. The displacement is to the right and the eccentricity is a combination of the dimensional tolerances arising from the bolt hole pitch circle diameter, the bolt diameter, the bolt hole diameter and the outer diameter of the orifice plate.

Experimental evidence on the effects of eccentricity is limited, but it has been shown that for orifice plates, the effect on discharge coefficient is a function of β, pipe size and roughness, pressure tapping type, location and magnitude, as well as the position of the orifice centre relative to the pressure tapping.

Experimental work indicates that the errors due to eccentricity increase in general with β. For β = 0,2 and eccentricity up to 5 % of D, discharge coefficient increases are unlikely to exceed 0,1 %. For larger β, the changes are best shown graphically as in figure 6.

Below 3 % eccentricity, the error varies with type of taps and direction of eccentricity. The meter is least sensitive to eccentricity perpendicular to the taps. Above 3 % eccentricity, errors for all taps and directions increase rapidly.