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Guidelines for the use of ISO 5167:2003

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British Standards

National foreword

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TECHNICAL REPORT

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Guidelines for the use of ISO 5167:2003

Lignes directrices pour l'utilisation de l'ISO 5167:2003

Reference number
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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.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, 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), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 9464 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 2, *Pressure differential devices*.

This second edition cancels and replaces the first edition (ISO/TR 9464:1998), which has been technically revised.

Introduction

The objective of this Technical Report is to assist users of ISO 5167, which was published in 2003 in four parts. Guidance on particular clauses of ISO 5157:2003 is given.

Some clauses of ISO 5167:2003 (parts 1 to 4) are not commented upon and the corresponding clause numbers are therefore omitted from this Technical Report, except when it has been thought to be useful to keep a continuous numbering of paragraphs.

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Guidelines for the use of ISO 5167:2003

1 Scope

The objective of this Technical Report is to provide guidance on the use of ISO 5167:2003 (all parts). ISO 5167:2003 is an International Standard for flow measurement based on the differential pressure generated by a constriction introduced into a circular conduit (see ISO 5167-1:2003, 5.1). It presents a set of rules and requirements based on theory and experimental work undertaken in the field of flow measurement.

For a more detailed description of the scope, reference should be made to ISO 5167-1:2003, Clause 1. Definitions and symbols applicable to this Technical Report are given in ISO 5167-1:2003, Clauses 3 and 4.

Neither ISO 5167-1:2003 nor this Technical Report give detailed theoretical background, for which reference should be made to any general textbook on fluid flow.

With the application of the rules and requirements set out in ISO 5167-1:2003, it is practicable to achieve flow measurement within an uncertainty of approximately 1 % of the calculated flowrate. The constraints applicable to each of the primary devices described in ISO 5167:2003 (parts 2 to 4) need to be given consideration before determining the most suitable type for a particular application. Parts 2 to 4 can also be used to form the basis for preliminary design of a metering system.

The information necessary for detailed design, manufacture and final check is specified in the clauses and paragraphs of ISO 5167:2003 (parts 2 to 4).

Secondary instrumentation is not covered by ISO 5167-1:2003, but Clause 6 of this Technical Report makes normative reference to ISO 2186.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2186, *Fluid flow in closed conduits — Connections for pressure signal transmissions between primary and secondary elements*

ISO/TR 3313:1998, *Measurement of fluid flow in closed conduits — Guidelines on the effects of flow pulsations on flow-measurement instruments*

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

ISO 5167-1:2003, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements*

ISO 5167-2:2003, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 2: Orifice plates*

ISO 5167-3:2003, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 3: Nozzles and Venturi nozzles*

ISO 5167-4:2003, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 4: Venturi tubes*

3 Terms and definitions

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

4 How the structure of this guide relates to ISO 5167:2003 (all parts)

Clause 5 of this Technical Report sets out the guidance specific to each of the four parts of ISO 5167:2003:

- 5.1 covers part 1;
- 5.2 covers part 2;
- 5.3 covers part 3;
- 5.4 covers part 4.

Subsequent subclause numbering relates to the clauses in each of the parts. Hence, 5.1.1 covers Clause 1 in part 1; 5.4.3.1.1 covers Subclause 3.1.1 in part 4.

Guidance applicable to all four parts is given in Clause 6.

5 Guidance on the use of ISO 5157:2003 (all parts)

5.1 Guidance specific to the use of ISO 5167-1:2003

5.1.1 Scope

No comments on this clause.

5.1.2 Normative references

No comments on this clause.

5.1.3 Terms and definitions

No comments on this clause.

5.1.4 Symbols and subscripts

No comments on this clause.

5.1.5 Principle of the method of measurement and computation

5.1.5.1 Principle of the method of measurement

No comments on this subclause.

5.1.5.2 Method of determination of the diameter ratio of the standard primary device

See Annex A of this Technical Report.

5.1.5.3 Computation of flowrate

The equations to be used to determine the flowrate of a measuring system are given in ISO 5167-1:2003, Clause 5. Some results of these calculations will be fixed with installation dimensions and will only need to be computed once. Other calculations will need to be repeated for every flow measurement point. Annex A gives worked examples of the iterative computations shown in ISO 5167-1:2003, Annex A.

5.1.5.4 Determination of density, pressure and temperature

5.1.5.4.1 General

No comments on this subclause.

5.1.5.4.2 Density

For details on density measurement, see 6.4.

For details on density computation, see Annex B of this Technical Report.

5.1.5.4.3 Static pressure

No comments on this subclause.

5.1.5.4.4 Temperature

The computation of temperature decrease resulting from expansion of the fluid through the primary device requires knowledge of the Joule-Thomson coefficient. The coefficient is a function of temperature, pressure and gas composition. The calculation can be carried out using an equation of state (see, in Annex B, the “detailed method” using molar composition analysis) or by the use of an approximation valid for natural gas mixtures that are not too rich, and when p and T are in the range given below. In the last case, the coefficient is a function of p and T alone.

Provided that, in the molar composition of the natural gas, methane is greater than 80 %, the temperature is in the range 0 °C to 100 °C and the absolute static pressure is in the range 100 kPa to 20 MPa (1 bar to 200 bar).

$$\begin{aligned}\mu_{\mathrm{JT}} &= 0{,}35 - 0{,}001\,42t \\ &+ \left(0{,}231 - 0{,}002\,94t + 0{,}000\,0136t^2\right)\left(0{,}998 + 0{,}000\,41p - 0{,}000\,111\,5p^2 + 0{,}000\,000\,3p^3\right)\end{aligned} \tag{1}$$

where

μ_{JT} is the Joule-Thomson coefficient, in kelvin per bar (K/bar);

t is the temperature of the fluid, in degrees Celsius (°C);

p is the absolute static pressure of the fluid, in bar.

The uncertainty was determined from the differences between this equation and the Joule-Thomson coefficient of 14 common natural gases and is given by

$$U = 0{,}066\left(1 - \frac{t}{200}\right) \qquad \text{for } p \leqslant 70 \text{ bar (7 MPa)} \tag{2}$$

and

$$U = 0{,}066\left(1-\frac{t}{200}\right)\left[1-\frac{(290-t)}{4}\left(\frac{1}{70}-\frac{1}{p}\right)\right] \qquad \text{for } p > 70 \text{ bar (7 MPa)} \qquad (3)$$

where U is the (expanded) uncertainty in the Joule-Thomson coefficient (K/bar).

NOTE If an orifice plate with $\beta = 0{,}6$ has a differential pressure $\Delta p = 0{,}5$ bar, the uncertainty in the Joule-Thomson coefficient corresponds to an uncertainty in flowrate in the range from 0,001 % to 0,009 %, depending on the temperature, the pressure and the gas composition.

5.1.6 General requirements for the measurements

5.1.6.1 Primary device

5.1.6.1.1 No comments on this subclause.

5.1.6.1.2 No comments on this subclause.

5.1.6.1.3 Table 1, whilst not exhaustive, lists materials most commonly used for the manufacture of primary devices.

Table 1 — Steels commonly used for the manufacture of primary devices

	AISI	BS 970	AFNOR	DIN
Stainless steels	304	304-S15	Z6CN18-09	1.4301
	316	316-S16	Z6CND17-11	1.4401
High elastic limit stainless steel	420	420-S37	Z30C13	

Table 2 gives the mean linear expansion coefficient, elasticity moduli and yield stresses for the materials of Table 1 according to their AISI designation.

Table 2 — Characteristics of commonly used steels

AISI designation	Mean linear expansion coefficient between 0 °C and 100 °C K^{-1}	Elasticity modulus Pa	Yield stress Pa
304	17×10^{-6}	193×10^{9}	215×10^{6}
316	16×10^{-6}	193×10^{9}	230×10^{6}
420	10×10^{-6}	200×10^{9}	494×10^{6}

The values given in Table 2 vary with both temperature and the treatment process of the steel. For precise calculations, it is recommended that the data are obtained from the manufacturer.

When the primary device under operating conditions is at a different temperature from the one at which the diameter "d" was determined (this temperature is referred to as the reference or calibration temperature), the expansion or contraction of the primary device should be calculated. The corrected diameter "d" to be used in the computation of diameter ratio and flowrate should be calculated using Equation (4), assuming there is no restraint due to the mounting:

$$d = d_0[1 + \lambda_d(T - T_0)] \tag{4}$$

where

d is the primary device diameter in flowing conditions;

d_0 is the primary device diameter at reference temperature;

λ_d is the mean linear expansion coefficient of the primary device material;

T is the primary device temperature in flowing conditions;

T_0 is the reference or calibration temperature.

Where automatic temperature correction is not required in the flow computer, the uncertainty for "d" included in the overall uncertainty calculations should be increased for the change in "d" due to temperature variation (see ISO 5167-1:2003, 8.2.2.4). An initial calculation may show that this additional uncertainty is small enough to be considered negligible.

5.1.6.2 Nature of the fluid

No comments on this subclause.

5.1.6.3 Flow conditions

5.1.6.3.1 No comments on this subclause.

5.1.6.3.2 If there is a likelihood of such a change of phase, a way of overcoming the problem is to increase the diameter ratio, so that the differential pressure is reduced.

5.1.6.3.3 No comments on this subclause.

5.1.7 Installation requirements

5.1.7.1 General

The following list of inspection equipment is not exhaustive, but provides a basis for inspection control:

- calipers (thickness, diameters);
- internal micrometer (diameters);
- micrometer (thickness);
- gauge block, feeler gauge (relative position, absolute standard for checking micrometers);
- protractor (angles);
- profile measuring apparatus (edge);
- straight edge rule (flatness);
- three point bore gauge (internal diameter).

Only instruments which may be calibrated to primary standards should be used if optimum accuracy is required.

5.1.7.1.1 No comments on this subclause.

5.1.7.1.2 No comments on this subclause.

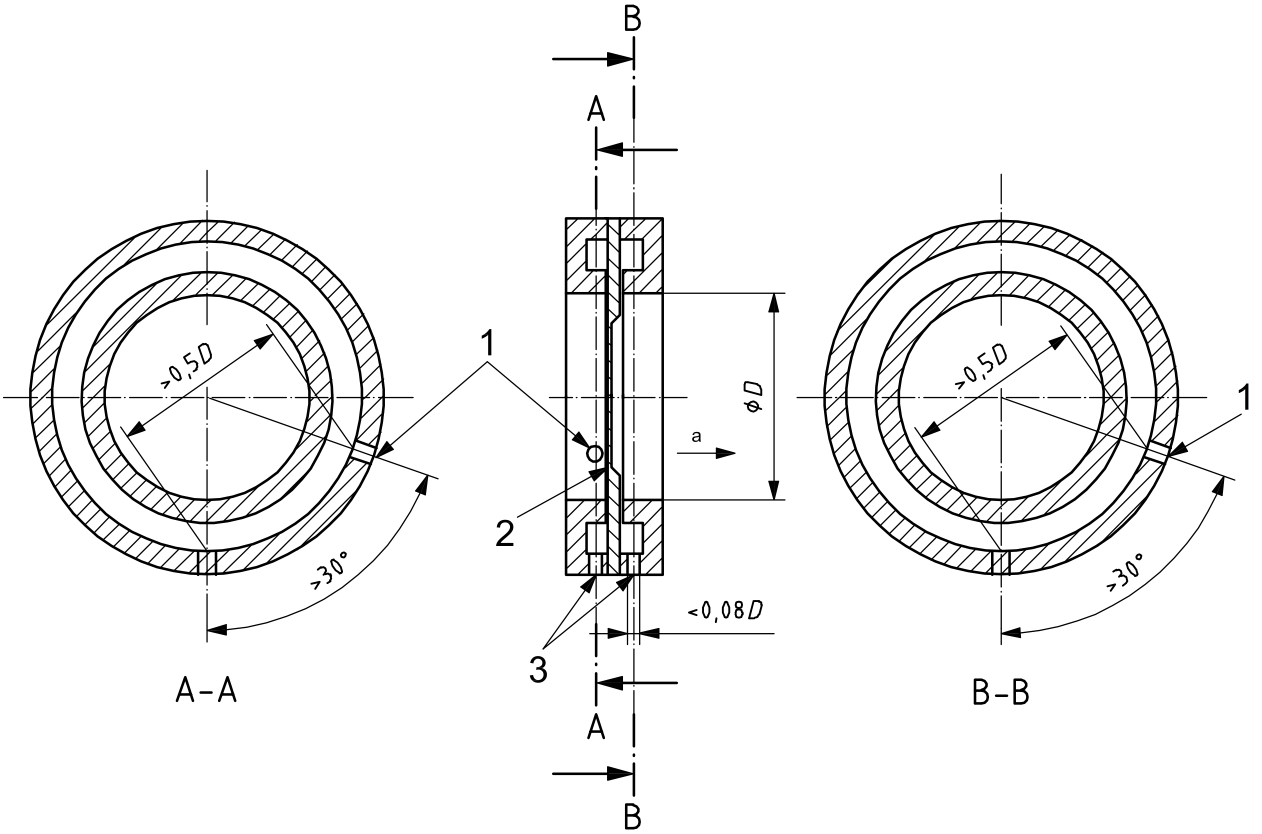
5.1.7.1.3 No comments on this subclause.

5.1.7.1.4 No comments on this subclause.

5.1.7.1.5 No comments on this subclause.

5.1.7.1.6 The requirements in this subclause of ISO 5167-1, where drain or vent holes are located near to the primary device, are illustrated in Figure 1. This figure illustrates the importance of placing the drain or vent hole in the annular chamber where one is used. It should be noted that the location of a drain or vent hole relative to a pressure tapping is of greater importance where there is no annular chamber and the drain or vent hole enters the pipe itself.

It should be realized that the flowing fluid may cause deposition, corrosion or erosion of the inner wall of the pipe. The installation may therefore not conform to the requirements of ISO 5167-1. Internal inspection of the pipe should be carried out at intervals appropriate to the conditions of application.



Key

1 pressure tapping

2 orifice plate

3 drain holes and/or vent holes

[a] Flow direction.

Figure 1 — Location of drain holes and/or vent holes

5.1.7.1.7 This subclause is intended to ensure a reliable measurement of temperature. Although the flowing temperature is not a quantity directly involved in the equation for calculating flowrate, it is an important parameter since it may be used to calculate "d" and "D" plus critical process parameters under flowing conditions.

5.1.7.2 Minimum upstream and downstream straight lengths

5.1.7.2.1 No comments on this subclause.

5.1.7.2.2 When designing a metering pipe installation, it is recommended that the required minimum straight lengths are determined by the maximum diameter ratio that is expected in the life of the installation.

For diameter ratios not actually shown in ISO 5167-2:2003, Table 3, ISO 5167-3:2003, Table 3 or ISO 5167-4:2003, Table 1 but which are inside the limits of the standard, it is reasonable practice to interpolate linearly between the values obtained at the nearest two diameter ratios.

If an orifice meter is designed to measure the flowrate in either direction, the minimum straight lengths of pipe on both sides of the orifice plate should conform to the minimum requirements for upstream and downstream straight lengths as specified in ISO 5167-2:2003, 6.2 and Table 3.

5.1.7.3 General requirement for flow conditions at the primary device

No comments on this subclause.

5.1.7.4 Flow conditioners

It should be noted that although swirl is generally not detectable in visual inspection of the pipe, swirl and asymmetry are sometimes visible in the coating, if present, on an orifice plate. A typical herring bone or chevron pattern that may be seen on a plate that has been in service for some time may indicate that the flow at the orifice plate may be swirling or asymmetrical. Swirl has a greater effect on measurement than any other fluid dynamic mechanism and, although straight lengths of pipe will eliminate swirl, decay may occur very slowly and the swirl may persist over considerable distances. The use of straight lengths of pipe to eliminate swirl is questionable, especially in large pipe sizes, as the decay of induced swirl from common pipe components may not be sufficient to ensure fully developed profiles within the minimum lengths required in the tables.

Flow conditioners are strongly recommended for use downstream of a metering system header and in the following circumstances:

a) where the upstream fittings or arrangement of fittings are not defined in the tables;

b) where a primary device of high β ratio is to be used for a given fitting, a flow conditioner which has passed the compliance test may reduce the upstream length necessary to achieve a good velocity profile, or may improve the velocity profile for a given straight length.

Many new flow conditioners have been developed since the previous edition of ISO 5167 published in 1991, and ISO 5167-1:2003 describes compliance testing for flow conditioners.

Various flow conditioners and straighteners are described in ISO 5167-1:2003, Annex C and ISO 5167-2:2003, Annex B, respectively. Not all of the conditioners described have been subjected to or have necessarily passed the compliance testing procedure.

5.1.8 Uncertainty on the measurement of flowrate

In 1995, ISO in cooperation with BIPM, IEC, IFCC, IUPAC, IUAP and OIML published the *Guide to the expression of uncertainty in measurement* (GUM). The content of this document and ISO 5168 should be taken into account when performing uncertainty analyses.

Any manufacturer's specification of error should be studied carefully to ensure that the limits of error are known at the measured value concerned. Some points to note include the following:

a) uncertainties are often expressed as a percentage of full scale or range;

b) uncertainties are often defined at specified reference conditions. Additional uncertainties may arise when operating conditions differ from reference conditions.

5.2 Guidance specific to the use of ISO 5167-2:2003

5.2.1 Scope

This part of ISO 5157:2003 is concerned solely with orifice plates and their geometry and installation. It is necessary to read ISO 5167-2 in conjunction with ISO 5167-1.

Orifice plate meters with three arrangements of tappings are described and specified: flange tappings; corner tappings; and D and $D/2$ tappings.

5.2.2 Normative references

No comments on this clause.

5.2.3 Terms, definitions and symbols

No comments on this clause.

5.2.4 Principles of the method of measurement and computation

The density and viscosity of the fluid can be measured (see 6.4) or calculated (see Annex B) from the gas composition. A number of computer programs are available for carrying out the calculation of density and viscosity. In the case of a compressible fluid, the isentropic exponent at working conditions is necessary for the flow calculation and this can be calculated from gas composition.

5.2.5 Orifice plates

5.2.5.1 Description

5.2.5.1.1 General

No comments on this subclause.

5.2.5.1.2 General shape

5.2.5.1.2.1 No comments on this subclause.

5.2.5.1.2.2 No comments on this subclause.

5.2.5.1.2.3 Referring to Annex C, three factors need to be taken into consideration in designing an orifice plate to avoid excessive deformation.

- First, the mounting arrangements should not impose any forces on the orifice plate which would cause the limit of 0,5 % slope given in ISO 5167-2:2003, 5.1.3.1 to be exceeded under the condition of no differential pressure.
- Secondly, the thickness of the plate, E, should be such that, taking account of the modulus of elasticity of the plate material, the differential pressure for the maximum design flowrate should not cause a 1 % slope to be exceeded. When the flowrate is reduced to zero, the plate will return to the original maximum 0,5 % slope.

- Thirdly, it is necessary to ensure that, if it is possible for differential pressures in excess of those for maximum design flowrate to be applied, plastic buckling (i.e. permanent deformation) will not occur.

For the first point, great care is needed in both the design and manufacture of the mounting arrangements. Single or double chamber mounting devices are satisfactory. When mounting orifice plates between standard flanges, the flanges shall be at 90° ± 1° to the pipe axis. The pipe sections on both sides of the orifice plate should be adequately supported to ensure that no undue strain is placed on the orifice plate.

For the second point, it should be understood that elastic deformation of an orifice plate introduces an error in the flow measurement results. As long as the deformation does not exceed the 1 % slope required by ISO 5167-2:2003, 5.1.2.3, no additional uncertainty will result. Theoretical and experimental research (see Reference [13]) indicates that the maximum change in discharge coefficient for a 1 % slope is 0,2 %. Therefore, orifice plates that conform to the 0,5 % slope specified in ISO 5167-2:2003, 5.1.3.1 can deform an additional 0,5 % slope (i.e. 0,1 % change in discharge coefficient) whilst still conforming to the requirements of this subclause. Table 3 tabulates the plate thickness to plate support diameter ratios (E/D') for various values of β and differential pressures, valid for an orifice plate manufactured from AISI stainless steel 304 or 316, and simply supported at its rim.

Table 3 — Minimum E/D' ratios for orifice plates manufactured in AISI 304 or AISI 316 stainless steel

β	Δp for maximum flowrate kPa						
	10	30	50	75	100	200	400
0,2	0,009	0,011	0,013	0,014	0,014	0,016	0,018
0,3	0,010	0,013	0,015	0,016	0,017	0,020	0,022
0,4	0,010	0,014	0,016	0,018	0,019	0,022	0,025
0,5	0,010	0,014	0,016	0,018	0,020	0,023	0,027
0,6	0,010	0,014	0,016	0,018	0,019	0,023	0,026
0,7	0,009	0,012	0,014	0,016	0,017	0,020	0,024
0,75	0,008	0,011	0,013	0,014	0,016	0,018	0,021

Table 3 is based on the use of Equation (5) when $100\,\Delta q_m/q_m$ is not to exceed 0,1 in magnitude and $E^* = 193 \times 10^9$ Pa:

$$100\frac{\Delta q_m}{q_m} = -\frac{\Delta p}{E^*}\left(\frac{D'}{E}\right)^2\left(a\frac{D'}{E} - b\right) \tag{5}$$

where

$a = \beta(13{,}5 - 15{,}5\beta)$;

$b = 117 - 106\,\beta^{1{,}3}$;

E^* is the modulus of elasticity of plate material;

D' is the plate support diameter (this may differ from pipe bore D);

E is the plate thickness.

For the third point, the maximum differential pressure (which can be greater than Δp in Table 3) that could be applied has to be determined by the designer. This could occur when the metering section is isolated and then vented to reduce it to atmospheric pressure to enable the orifice plate to be removed for inspection, or when pressurizing the metering section before putting into service.

To avoid plastic deformation (buckling), the orifice plate thickness should be such that:

$$\frac{E}{D'} > \sqrt{\frac{\Delta p}{\sigma_y}\left(0{,}681 - 0{,}651\beta\right)} \tag{6}$$

where

Δp is the maximum differential pressure determined by the designer, in pascals (Pa);

σ_y is the yield stress of the orifice plate material, in pascals (Pa).

NOTE 1 For stainless steel, $\sigma_y = 300$ MPa, but it is advisable to use a value of 100 MPa for design purposes.

The thickness of the orifice plate chosen should be whichever is the greater when determined by Equations (5) and (6), but should not exceed the 0,05D required in ISO 5167-2:2003, 5.1.5.3. Should the calculations indicate that the E required is greater than 0,05D, the designer should either reduce Δp or else introduce a stronger material.

EXAMPLE

— Equation (5):

β = 0,2

E^* = 193 GPa

Δp = 50 kPa (0,5 bar)

gives $E/D' > 0{,}013$ from Equation (5) or Table 3.

— Equation (6):

β = 0,2

σ_y = 300 MPa for stainless steel, but for design purposes it is advisable to use

σ_y = 100 MPa

Δp = 100 kPa (1 bar) (see NOTE 2)

gives $E/D' > 0{,}023$.

Consequently, E/D' should be at least 0,023.

NOTE 2 100 kPa (1 bar) is the maximum anticipated differential pressure.

5.2.5.1.3 Upstream face A

5.2.5.1.3.1 Table 4 gives values of deflection of the inner edge of the orifice corresponding to the 0,5 % slope for various pipe diameters and diameter ratios, β, assuming the deformation is rectilinear.

Table 4 — Plate flatness tolerances

β	Nominal diameter of the measuring pipe in millimetres										
	50	100	200	300	400	500	600	700	800	900	1 000
	Maximum deflection h in millimetres for 0,5 % slope										
0,20	0,10	0,20	0,40	0,50	0,80	1,00	1,20	1,40	1,60	1,80	2,00
0,25	0,09	0,19	0,38	0,56	0,75	0,94	1,13	1,31	1,50	1,69	1,88
0,30	0,09	0,18	0,35	0,52	0,70	0,88	1,05	1,22	1,40	1,57	1,75
0,35	0,08	0,16	0,32	0,49	0,65	0,81	0,97	1,14	1,30	1,46	1,63
0,40	0,07	0,15	0,30	0,45	0,60	0,75	0,90	1,05	1,20	1,35	1,50
0,45	0,07	0,14	0,27	0,41	0,55	0,69	0,82	0,96	1,10	1,24	1,38
0,50	0,06	0,13	0,25	0,38	0,50	0,63	0,75	0,88	1,00	1,13	1,25
0,55	0,06	0,11	0,22	0,34	0,45	0,56	0,67	0,79	0,90	1,01	1,13
0,60	0,05	0,10	0,20	0,30	0,40	0,50	0,60	0,70	0,80	0,90	1,00
0,65	0,04	0,09	0,18	0,26	0,35	0,44	0,52	0,61	0,70	0,79	0,88
0,70	0,04	0,07	0,15	0,22	0,30	0,38	0,45	0,52	0,60	0,67	0,75
0,75	0,03	0,06	0,13	0,19	0,25	0,31	0,38	0,44	0,50	0,56	0,63
Reference [13].											

5.2.5.1.3.2 The roughness criterion in this subclause may not be adequate to ensure that the edge sharpness requirements of ISO 5167-2:2003, 5.1.7.2 can be achieved. It is recommended that $Ra \leqslant 10^{-5}d$ should be used. The roughness of the orifice bore should conform to the same criterion.

5.2.5.1.3.3 It is very important that the bevelled side of the plate (if applicable) is located downstream. If the plate is inserted with the bevel upstream, the flowrate can be as much as 20 % underestimated. It should be normal practice to mark the plate, if practical, to indicate the upstream face in such a way that the marking can be seen when the plate is installed.

One common method of identifying the upstream face where the orifice plate is installed between flanges is to install a “paddle plate” where the critical details are engraved on the handle which extends from the flange joint.

In no circumstances should the upstream face of the orifice plate within diameter “D” be indented by any marking.

5.2.5.1.4 Downstream face B

No comments on this subclause.

5.2.5.1.5 Thicknesses E and e

No comments on this subclause.

5.2.5.1.6 Angle of bevel

No comments on this subclause.

5.2.5.1.7 Edges G, H and I

5.2.5.1.7.1 No comments on this subclause.

5.2.5.1.7.2 The last paragraph of this subclause requires the edge radius to be measured should there be any doubt that it conforms to the requirements of ISO 5167-2:2003, 5.1.7.1 and 5.1.7.2. In those exceptional cases, some suitable techniques are given below.

a) Casting method (see Reference [8])

A replica of the edge is produced using a casting technique. The casting is made in two stages, firstly with a coloured cold-forming plastic which takes up a negative form of the orifice plate edge, and then backed with a semi-transparent epoxy resin taking the place of the orifice plate. The completed casting is cut into two halves exposing the replica of the orifice plate edge, polished and photographed with magnification. The edge condition can then be measured.

b) Lead foil impression method (see Reference [8])

An impression of the edge is made by pressing lead foil, 0,1 mm thick, onto the orifice plate edge. The lead foil is held in a micrometer controlled inspection gauge and pressed onto the edge to give an indentation 0,12 mm deep. The indentation is examined using a projection microscope or similar equipment where the image is magnified, and a tracing of the outline is drawn. The edge condition can then be measured.

c) Paper-recording roughness method (see Figure 2)

This instrument records on a magnified scale the movements of a tracing stylus. To obtain an enlarged reproduction of the orifice edge, the paper speed should be chosen equal to the driving velocity times the magnification of the transverse movements. To establish the correct edge radius of the orifice, the tip radius of the stylus has to be subtracted from the edge radius measured from reproduction and divided by the degree of magnification. It should be noted that the finite dimensions of the stylus, such as tip angle, tip radius and stylus length, can invalidate the measurement or conceal irregularities on the edge.

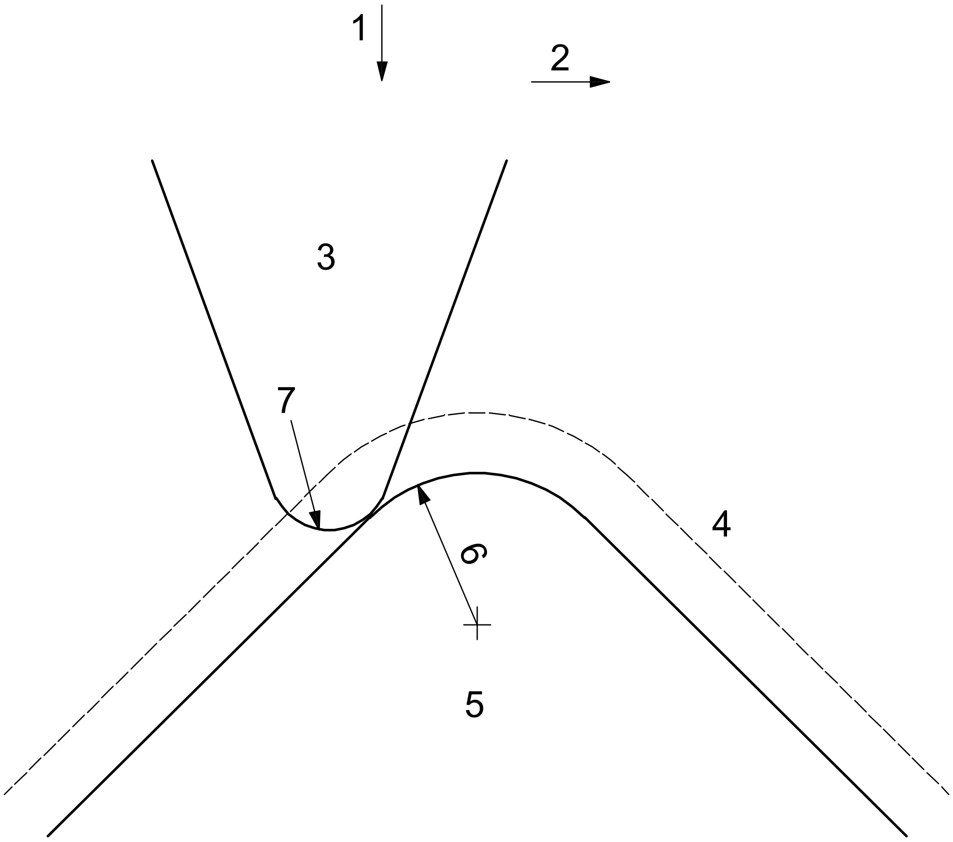
When edge sharpness is to be measured, it should be in at least 4 positions, equally spaced around the bore. When a defect is visible to the naked eye, the edge sharpness should also be measured at this point.

Interpretation of the edge profile, whatever the reproduction technique, is a matter of expert judgement. Standard machining practice can cause the profile to be very irregular, even though the orifice plate conforms to all the requirements for dimensions and surface roughness.

All edges lying within the shaded region of Figure 3, with an additional margin for surface roughness, can be considered as acceptable. Some surface roughness is tolerable in accordance with ISO 5167-2:2003, 5.1.3.2, but very irregular edges should be rejected.

A simple way of estimating the actual edge radius is by comparing the profile with curves (see examples in Figure 4) reproduced on a transparent foil.

Edge sharpness measurement is a specialist activity. There are laboratories in many countries that are capable of measuring edge sharpness to the standard required in ISO 5167-2:2003, 5.1.7.2. See Reference [8].



Key

1 recorded movement
2 driving movement
3 stylus
4 traced path
5 square edge
6 R = edge radius
7 radius

Figure 2 — Paper-recording roughness method

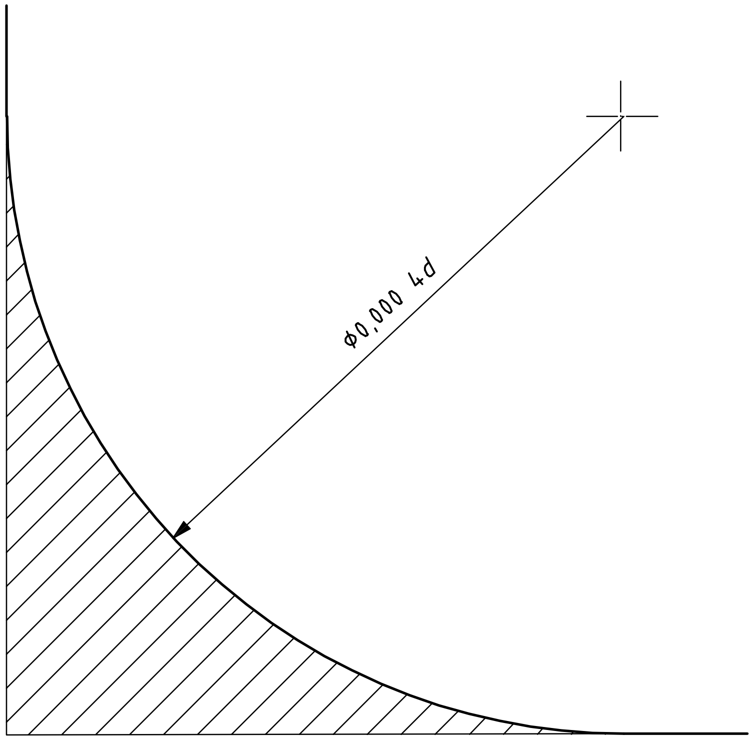


Figure 3 — Maximum edge radius

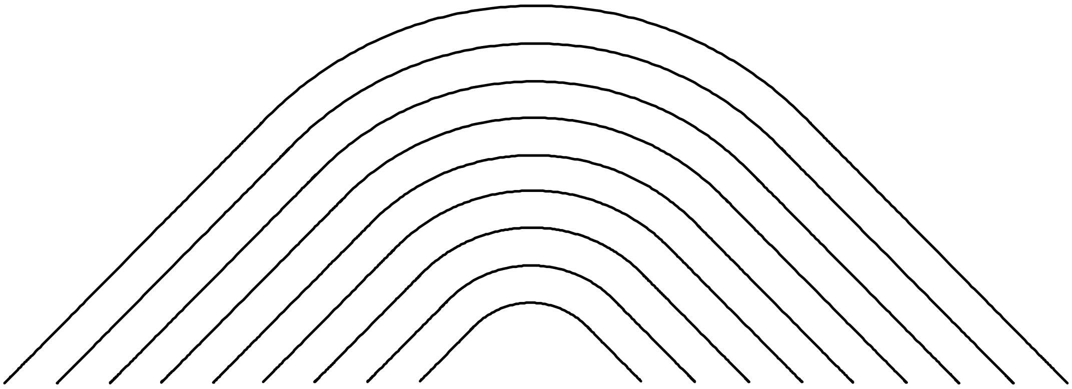


Figure 4 — Edge radius curves

5.2.5.1.7.3 No comments on this subclause.

5.2.5.1.7.4 No comments on this subclause.

5.2.5.1.8 Diameter of orifice, d

5.2.5.1.8.1 Because of the uncertainty of the discharge coefficient, and strict requirements on eccentricity, pipe roughness and upstream straight lengths, the user is advised to remain below a diameter ratio, β, of 0,6 for the most accurate measurements.

5.2.5.1.8.2 No comments on this subclause.

5.2.5.1.8.3 To enable the requirements of this subclause (i.e. 0,05 % difference) to be shown to have been met, it is necessary to measure or compare with an uncertainty of at most 0,02 %.

5.2.5.1.9 Bidirectional plates

5.2.5.1.9.1 A symmetrical plate is intended to be used for the measurement of a fluid that may flow in either direction. Such a plate should not be bevelled.

The thickness, E, of the plate should then not be greater than $0{,}02D$. As a consequence, symmetrical plates should only be used with low values of differential pressure to prevent deformation (see ISO 5167-2:2003, 5.1.2.3).

5.2.5.1.9.2 The appropriate tappings for the direction of flow should be used.

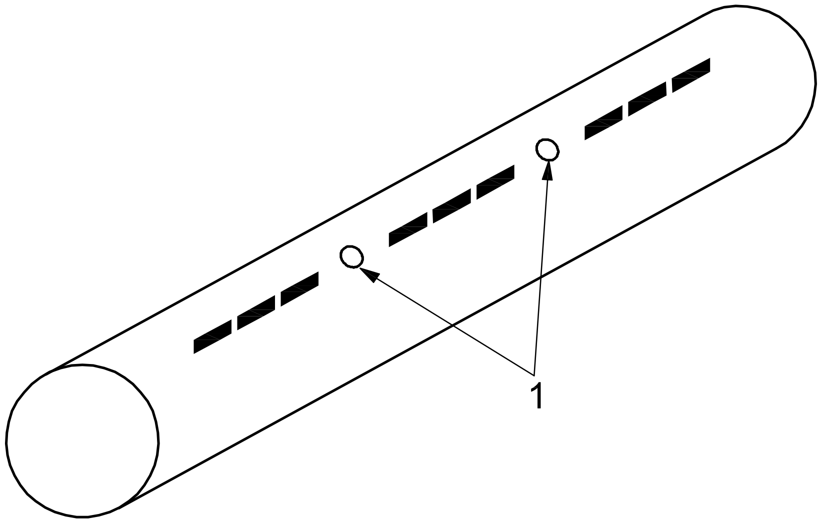
5.2.5.1.10 Material and manufacture

Subclause 5.1.6.1.3 gives some information on the most commonly used materials and their characteristics.

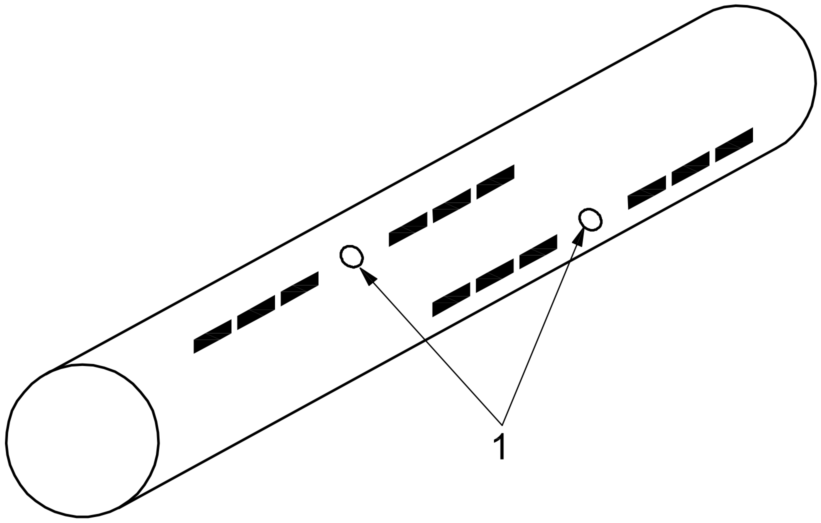
5.2.5.2 Pressure tappings

This subclause means that pressure tappings have to be installed as follows: at least one upstream tapping and one downstream tapping of the same type, i.e. D and $D/2$, flange or corner (see ISO 5167-2:2003, 5.2.1). Tappings of several types may be installed at the same location. In such cases, each type of tapping (each “set”) will be totally independent from the others: the various sets should not interfere in any way and failure to comply with this will result in an inaccurate measurement.

This implies that, on the same side of the orifice plate, several tappings should not lie on the same axial plane (see Figure 5). Moreover, if they are of different types (e.g. flange and D and $D/2$), they should be offset by at least 30°. If they are of the same type (e.g. all flange), then no guidance on the acceptable offset in terms of angle is given. No tappings should affect the readings of any other tappings.



a) Example of incorrect positioning



b) Example of correct positioning

Key

1 pressure tappings

Figure 5 — Relative position of pressure tappings of different types

5.2.5.3 Coefficients and corresponding uncertainties of orifice plates

No comments on this subclause.

5.2.5.4 Pressure loss, $\Delta \varpi$

Figure 5 in ISO 5167-2:2003 does not take account of frictional pressure losses in the pipe.

ΔT, as shown, is appropriate for a gas metering system.

5.2.6 Installation requirements

5.2.6.1 General

No comments on this subclause.

5.2.6.2 Minimum upstream and downstream straight lengths for installation between various fittings and the orifice plate

No comments on this subclause.

5.2.6.3 Flow conditioners

No comments on this subclause.

5.2.6.4 Circularity and cylindricality of the pipe

NOTE To conform to the given specifications, the pipe lengths adjacent to the primary device may have to be specially machined. As no significant diameter difference may exist between the various lengths of the measuring pipe (ISO 5167-2), the ones adjacent to the primary device may have to be made of a thicker pipe so that the correct internal diameter can be obtained after machining a length of 2 pipe diameters upstream of the primary device. This method will result in a measuring pipe having homogeneous dimensions.

5.2.6.4.1 A check should be made so that, over a length of $2D$ upstream of the primary device, any diameter measured in any plane does not vary by more than 0,3 % from the mean diameter previously obtained by ISO 5167-2:2003, 6.4.2.

In addition to the diameters measured in three cross-sections to establish "D", additional diameters should be measured in at least each of two different cross sections at locations dependent on the device to be installed:

— $0{,}5D$ and $2D$ for orifice plates with D and $D/2$ pressure tappings;

— D and $2D$ for orifice plates with corner and flange tappings.

In those cases where few cross-sections are used, a check should be made that no systematic variation of the measured diameters can be found.

5.2.6.4.2 The value of "D", corrected for thermal expansion (see below), is that used for the computation of the diameter ratio. This value of "D" is also used as the basis for establishing the circularity of the pipe over a length of at least $2D$ upstream and downstream of the primary device (see ISO 5167-2:2003, 6.4).

The distance to each of the measurement locations is expressed in terms of "D", which is not known before taking measurements at the prescribed locations. For the purpose of establishing the position of these locations, it is permissible to take "D" as equal to the nominal bore of the pipe.

Figure 6 gives an example for orifice meters where diameters are measured in only three different cross-sections:

— A_1, B_1, C_1 for orifice plates with corner tappings;

— A_2, B_2, C_2 for orifice plates with flange tappings;

— A_3, B_3, C_3 for orifice plates with D and $D/2$ tappings.

In any case, individual diameters should be measured with an accuracy of at least 0,1 %, as the overall tolerance is 0,3 % (see ISO 5167-2:2003, 6.4.1).

When the measuring pipe under flowing conditions is at a significantly different temperature from the one at which diameter D_0 was determined (this temperature is referred to as the reference or calibration temperature), the expansion or contraction of the pipe should be taken into account in the computation of diameter ratio and flowrate, using Equation (7):

$$D = D_0[1 + \lambda_D(T - T_0)] \tag{7}$$

where

D is the diameter of the pipe in flowing conditions;

D_0 is the diameter of the pipe at reference temperature;

λ_D is the mean linear expansion coefficient of the pipe material;

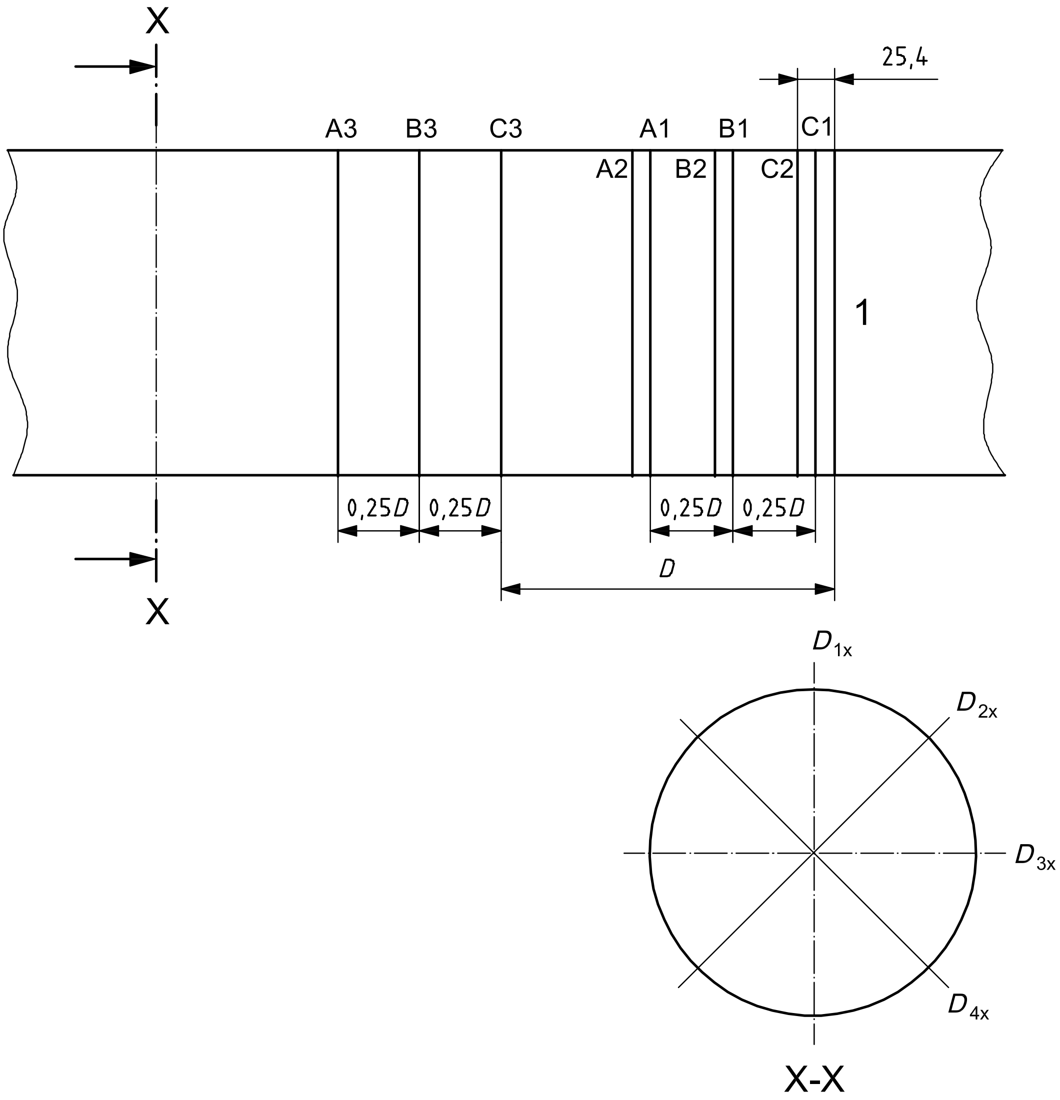
T is the pipe temperature in flowing conditions;

T_0 is the reference or calibration temperature.

The value for λ_D should be obtained from the manufacturer of the measuring pipe.

Where automatic temperature correction is not required in the flow computer, the uncertainty for "D" included in the overall uncertainty should be increased for the change in "D" due to temperature variation (see ISO 5167-1:2003, 8.2.2.4). An initial calculation may show that this additional uncertainty is small enough to be considered negligible.

Dimensions in millimetres



Key

1 plate upstream face

Internal diameter D to be used in flowrate computation:

$$D = \frac{1}{12}\left[\sum_{i=1}^{4} D_{iA_n} + \sum_{i=1}^{4} D_{iB_n} + \sum_{i=1}^{4} D_{iC_n}\right]$$

$n = 1$ for corner tappings

$n = 2$ for flange tappings

$n = 3$ for D and $D/2$ tappings

Figure 6 — Measurement of internal diameter, D

5.2.6.4.3 It shall be noted that measuring the internal diameter at the ends of each section of pipe is not sufficient to ensure conformity with ISO 5167-2:2003, 6.4.3. In addition, a check should be made to determine that the different sections of pipe are properly mounted and do not have a step in excess of the limits given in ISO 5167-2 when connected together. See Figure 7.

The use of self-centring pipe joints is recommended. Consideration should be given to the use of tongue and groove flanges, male and female flanges, dowel pins or spigot and recess.

Check that the maximum internal step "e" between any two adjacent sections of pipe (A and B) more than two pipe diameters upstream of the primary device does not exceed the required value in ISO 5167-2:2003, 6.4.3, where D is the mean pipe diameter computed over 0,5D (see Figure 6).

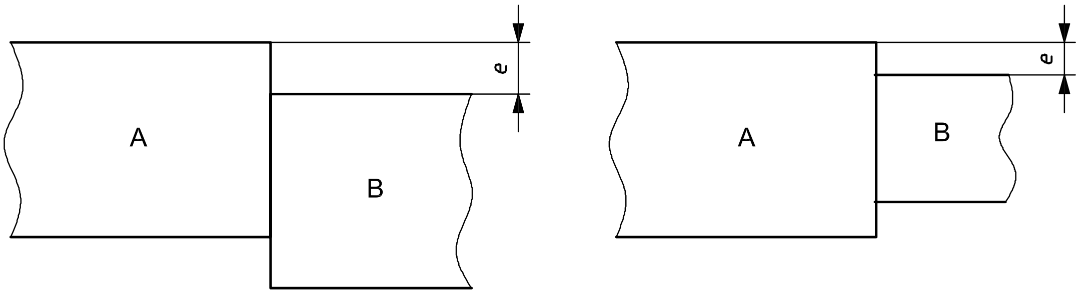


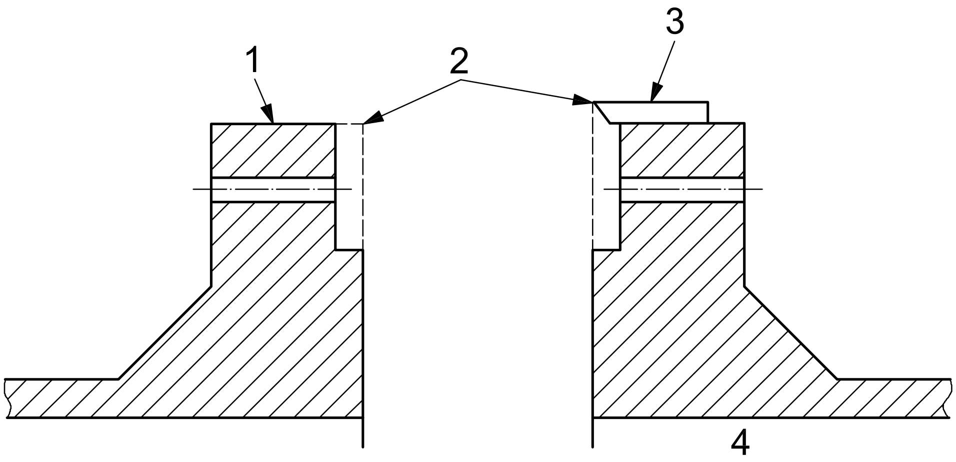
Figure 7 — Inspection of measuring pipe sections

It is possible to determine the step between coupled pipe lengths with sufficient accuracy by fixing external reference points whilst the pipe is uncoupled. Reference points can be on the extension of a matching piece or plane and should be constructed in pairs, just over the joint, one on each side of it. Four or six pairs of reference points equally spaced around the circumference of the pipe joint will usually be adequate.

The distance from the pipe wall to the reference point should be measured while uncoupled. To determine the position of a reference point in space on the extension of a plane [Figure 8 a), left hand side], the plane should be extended by a sliding reference piece.

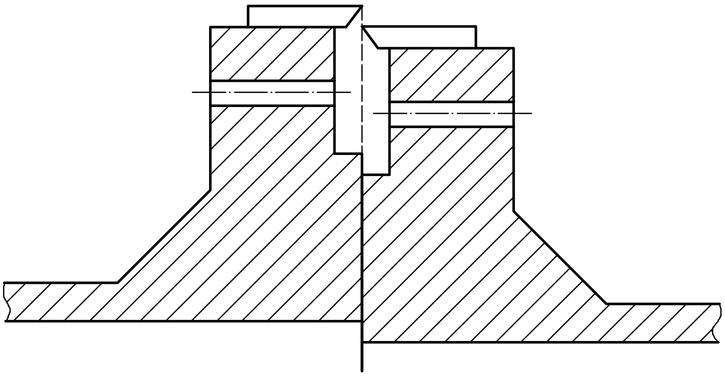
Once coupled, the distance between two reference points of a pair should be measured with a micrometer. To bridge the gap, the micrometer is best fixed in a smooth plane fitting piece sliding over an equally smooth plane. Two or more measurements are then needed to determine the distance between reference points.

If the pipe joints are self-centring, then the external reference points are not needed. Careful measurement of the pipe bore and centring device will produce equally accurate results. Examples are given in Figure 8.

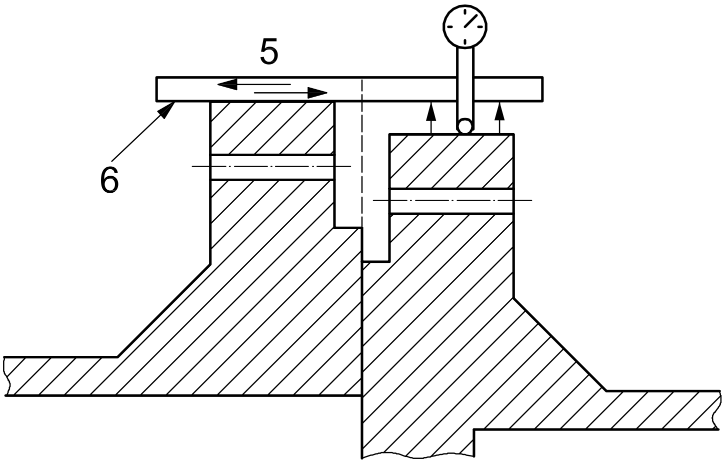


a) Some possible constructions of reference points

Figure 8 *(continued)*



b) Direct measurement of distance between reference points



c) Indirect measurement of distance between reference points

Key

1	smooth plane
2	reference points
3	fixed reference piece
4	inside pipe wall
5	sliding reference piece
6	smooth plane

Figure 8 — Measurement of steps between pipe lengths

If a flow conditioner is included upstream of the orifice plate, then the pipes on either side of the conditioner should be in conformity with ISO 5167-2:2003, 6.4.3 and a method of aligning the pipes and centring the flow conditioner should be used.

5.2.6.4.4 No comments on this subclause.

5.2.6.4.5 No comments on this subclause.

5.2.6.4.6 No comments on this subclause.

5.2.6.5 Location of orifice plate and carrier rings

5.2.6.5.1 No specific comments on this subclause.

5.2.6.5.2 Table 5 and Figure 9 show the maximum distance e_c between the centre-line of the orifice and the centre-line of the pipe on the upstream and downstream sides, in the direction parallel with the axis of the pressure tappings, as a function of a diameter ratio, β, and of the pipe diameter, D, for no additional error.

Table 5 — Maximum distance e_c between the orifice centre-line and the centre-lines of upstream and downstream pipe sections in the direction parallel with the axis of the pressure tappings, in millimetres

β	D mm							
	100	150	200	300	400	500	600	700
0,20	2,41	3,62	4,82	7,23	9,65	12,06	14,47	16,88
0,25	2,29	3,44	4,59	6,88	9,18	11,47	13,76	16,06
0,30	2,11	3,16	4,21	6,32	8,43	10,54	12,64	14,75
0,35	1,86	2,79	3,72	5,58	7,43	9,29	11,15	13,01
0,40	1,57	2,36	3,15	4,72	6,29	7,87	9,44	11,01
0,45	1,29	1,93	2,57	3,86	5,15	6,43	7,72	9,01
0,50	1,03	1,54	2,05	3,08	4,10	5,13	6,15	7,18
0,55	0,81	1,21	1,61	2,42	3,22	4,03	4,83	5,64
0,60	0,63	0,94	1,26	1,88	2,51	3,14	3,77	4,40
0,65	0,49	0,73	0,98	1,47	1,96	2,45	2,94	3,43
0,70	0,38	0,57	0,77	1,15	1,53	1,92	2,30	2,68
0,75	0,30	0,45	0,60	0,91	1,21	1,51	1,81	2,11

5.2.6.6 Method of fixing and gaskets

To avoid flow measurement errors due to incorrect centring, great care should be given to the design of the system holding the primary element in the pipe.

To conform to the requirements of centring and fixing the primary device, it may be necessary, in many practical situations, to design a special fitting to suit the line size, type of fluid, pressure and temperature fluctuations of the fluid, ease of maintenance and operation, required accuracy and the system already in existence.

If the primary device can be made an integral part of the measuring pipe, the resulting installation can be defined precisely, enabling flow measurements to be highly reproducible.

Other arrangements use pairs of flanges (slip-on or weld-neck) or special proprietary fittings. Annex C illustrates recommended arrangements for orifice plates, which are equally valid for nozzles. When using flanges, it is good practice to provide a pair of jacking screws in diametrically opposite positions.

Gaskets are cheap and easy to produce but they shall not protrude into the pipe at any point. It is recommended that gaskets are not thicker than 0,03D. It is inevitable therefore that a recess is formed at this point. The depth of the recess does not affect flow measurement, but it is necessary to maintain adequate gasket material to ensure a leak-proof joint.

O-ring seals are easy to use and give a tight, smooth joint if manufactured correctly.

Ring joints (self-centring and sealing) may produce a gap, depending upon the standard employed, and a recess between sections. Provided the gap does not exceed 13 mm, tests have shown that flow measurement will not be affected.

Care should always be taken to avoid unacceptable flexibility of the primary device mounting with respect to the eccentricity and tapping point location tolerance (ISO 5167-2:2003, 6.5.3).

It should be stressed that good metering requires maintenance of the primary device within the tolerances of the standard, thus necessitating inspection of the device from time to time. With some types of mounting for orifice plates, it is impracticable to inspect the device and the installation without dismantling the pipework. Devices enabling easy withdrawal and re-insertion of orifice plates to known tolerances may be the only practicable solution.

See Reference [16].

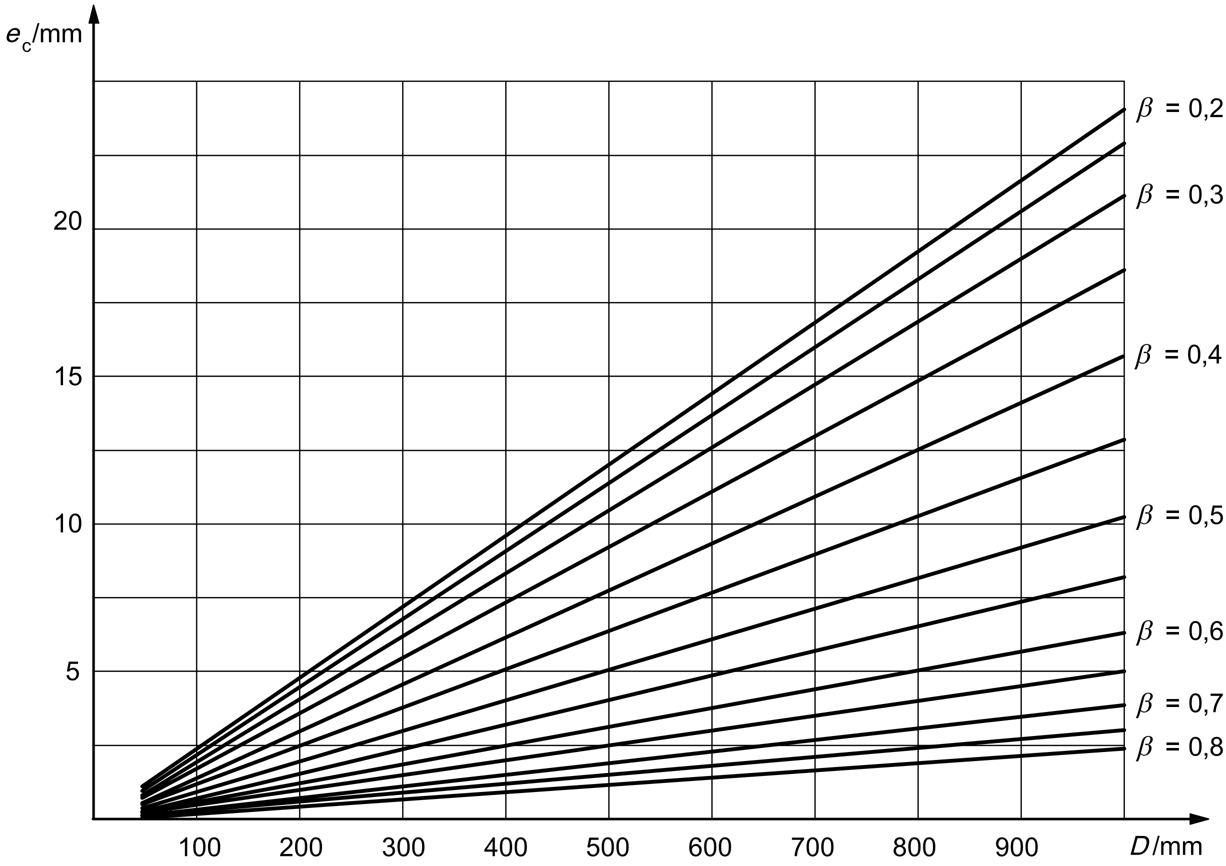


Figure 9 — Maximum distance e_c between orifice centre-line and the centre-lines of upstream and downstream pipe sections in the direction parallel to the axis of the pressure tappings, as a function of the pipe diameter, D, and the diameter ratio, β

5.3 Guidance specific to the use of ISO 5167-3:2003

5.3.1 Scope

No comments on this clause.

5.3.2 Normative references

No comments on this clause.

5.3.3 Terms and definitions

No comments on this clause.

5.3.4 Principles of the method of measurement and computation

No comments on this clause.

5.3.5 Nozzles and Venturi nozzles

5.3.5.1 ISA 1932 nozzle

No comments on this subclause.

5.3.5.2 Long radius nozzles

For a set of modern low-ratio nozzles with $Ra \approx 10^{-5}\,d$, the discharge coefficients are much closer to the value of C as given by ISO 5167-3:2003, 5.2.6.2 than would have been expected from ISO 5167-3:2003, 5.2.7.1.

See Reference [13].

5.3.5.3 Venturi nozzles

5.3.5.3.1 General shape

No comments on this subclause.

5.3.5.3.2 Material and manufacture

No comments on this subclause.

5.3.5.3.3 Pressure tappings

5.3.5.3.3.1 No comments on this subclause.

5.3.5.3.3.2 No comments on this subclause.

5.3.5.3.3.3 There should be equal angles between the centre-lines of adjacent tapping points.

5.4 Guidance specific to the use of ISO 5167-4:2003

5.4.1 Scope

No comments on this clause.

5.4.2 Normative references

No comments on this clause.

5.4.3 Terms and definitions

No comments on this clause.

5.4.4 Principles of the method of measurement and computation

No comments on this clause.

5.4.5 Classical Venturi tubes

5.4.5.5 Discharge coefficient, C

For high Re_D, even within the criteria in ISO 5167-4:2003, and for very accurate measurement, calibration is advisable.

6 Information of a general nature relevant to the application of ISO 5167:2003 (all parts)

6.1 Secondary instrumentation

6.1.1 General

The definition of primary/secondary devices is stated in the Introduction to ISO 5167-1:2003.

6.1.2 General requirements concerning installation of secondary instruments

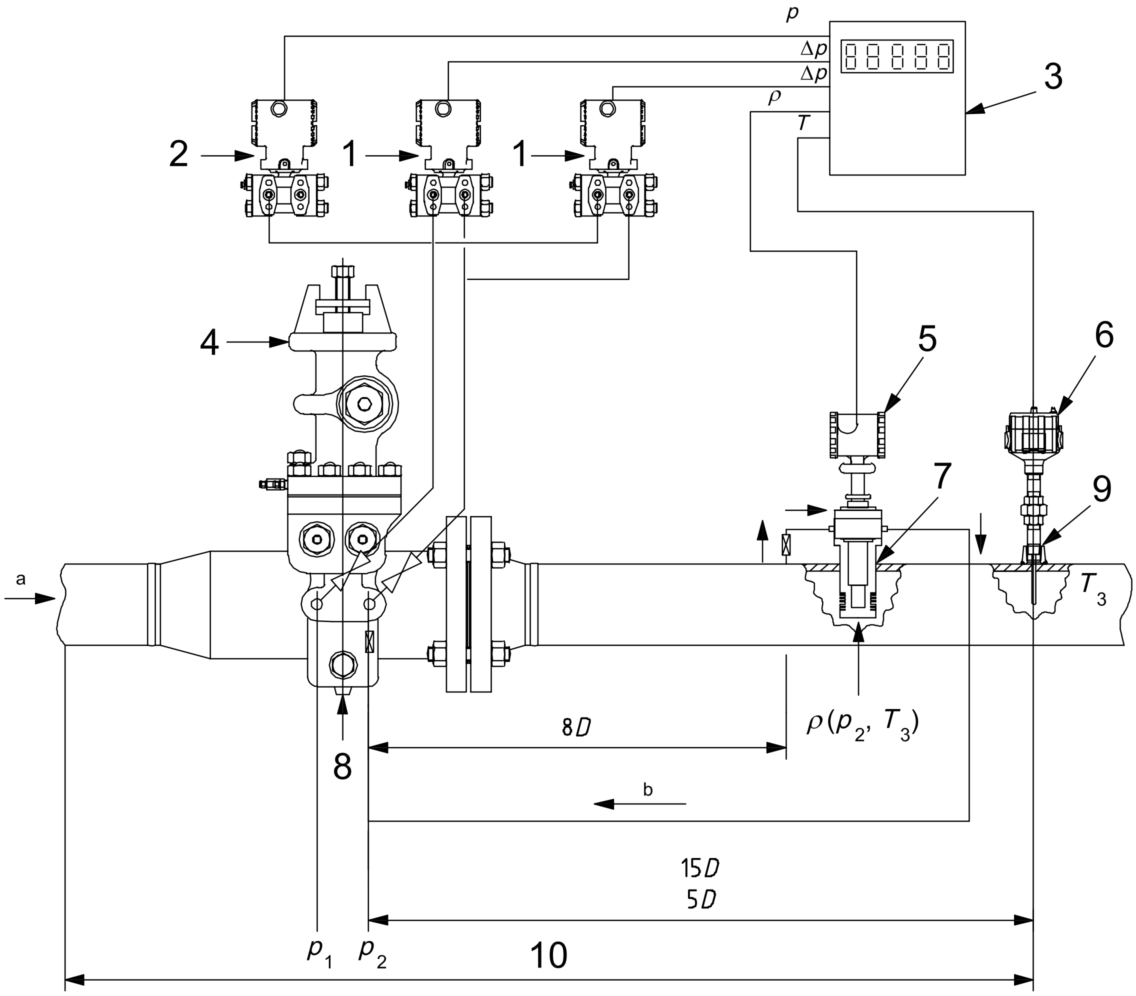
A typical orifice-plate measuring system is shown in Figure 10. When installing the instruments, careful attention should be given to the manufacturer’s specifications. The following general rules should be followed to avoid significant errors in the performance of the secondary instrumentation close to the primary element.

a) The instrumentation should be installed so that no mechanical stress is imparted by the method of mounting or the connection to the impulse pipes.

b) The installation should be free from mechanical vibration within the limits of the manufacturer's specification.

c) The pressure signal connection line shall not have a resonant frequency within the band width of pipeline noise (see ISO 5167-1:2003, 6.3.1).

d) The instruments should be placed in an enclosure where the temperature is controlled if the environmental conditions are sufficiently variable to introduce significant errors into the secondary instrumentation.



Key

1	differential pressure transmitter
2	pressure transmitter
3	flow computer
4	orifice fitting
5	density meter
6	temperature transmitter
7	pocket
8	orifice plate
9	temperature sensor connection
10	meter tube per international standard

[a] Flow direction.

[b] Sample flow.

Figure 10 — Typical metering device installation

6.2 Measurement of pressure and differential pressure

6.2.1 General

For a complete treatment of the subject of pressure-signal transmission, reference should be made to ISO 2186. However, some of the problems that demand special care are briefly mentioned below.

6.2.2 Connections for pressure signal transmissions between primary and secondary elements

6.2.2.1 General

The pressure pipes (impulse lines) connecting the tappings of the primary device to the manometer or the pressure difference meter should be arranged so that no back pressure or false pressure difference is set up by the following:

a) a temperature difference between the two pressure pipes;

b) the presence of gas bubbles, liquid droplets or solid deposits in either or both pressure pipes;

c) the congealing or freezing of the liquid in the pressure pipes.

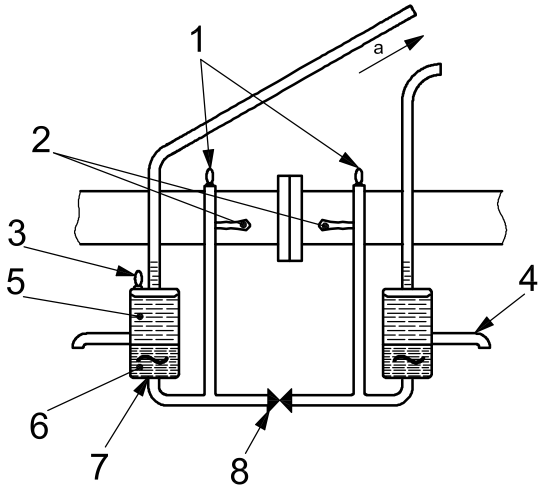
These requirements are met by the following:

- attending to the location of the meter and the size and run of the pressure pipes;
- providing gas vents and liquid catchpots or water seals;
- employing a sealing liquid of suitable properties to transmit pressure from the fluid in the pipe to the liquid in the manometer or instrument (see Figure 11 and Figure 12). (This method is not used much these days, but is still valid.)

6.2.2.2 Isolating valves (see ISO 2186)

In general:

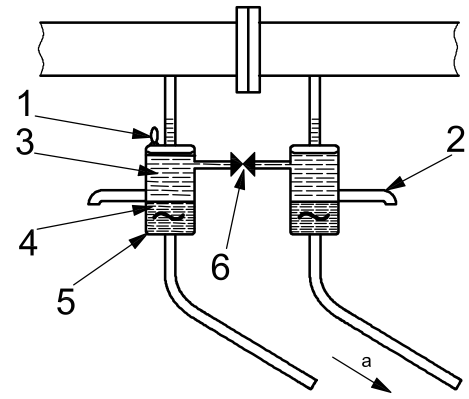
- Suitable isolating valves should be provided in the pressure pipes. The choice and location of the valves is the responsibility of the designer.
- A ball valve should be used for fluids liable to form a sediment.



Key

1	gas vents
2	pressure tappings and valves
3	filling connection
4	level-determining connection
5	sealing liquid
6	metered liquid
7	sealing pot
8	equalizing valve
a	To differential pressure transmitter.

Figure 11 — Sealing chambers — Metered fluid heavier than sealing fluid



Key

1	filling connection
2	level-determining connection
3	metered liquid
4	sealing liquid
5	sealing pot
6	equalizing valve
a	To differential pressure transmitter.

Figure 12 — Sealing chambers — Metered fluid lighter than sealing fluid

6.2.2.3 Condensation chambers

For specific fluids and conditions, such as steam, special connection arrangements, condensation chambers, etc. may be required. See ISO 2186 for details.

6.2.3 Pressure measurement devices

6.2.3.1 General

The accurate measurement of the differential pressure generated across a primary element is fundamental to the calculation of flowrate in a circular cross-section conduit employing orifice plates, nozzles or Venturi tubes.

In the case of orifice plates, for the measurement of gas or where higher accuracy is required for liquids, it is necessary to determine the absolute static pressure of the fluid at the upstream pressure tappings. In addition to the calculation of the expansibility factor, the static pressure is required to determine, as appropriate, the downstream to upstream corrections for process parameters such as temperature and measured density.

When density is calculated using an equation of state, the sensitivity of the static pressure measurement is greater and the need to measure this parameter accurately becomes more acute. In many instances, gauge pressure transmitters are employed to measure the pressure of the fluid at the upstream pressure tappings. The absolute static pressure of the fluid is required for the flowrate and referral calculations and can be calculated from gauge and ambient pressure measurements. Instead of measuring the ambient barometric pressure it is common to add the conventional reference pressure of 101,325 kPa (1,01325 bar) to the measured gauge pressure. However, when variations in atmospheric pressure result in a 0,1 % change in mass flow, it is recommended that gauge pressure instruments are replaced with absolute pressure instruments.

6.2.3.2 Pressure transducers

The differential pressure across the primary device is most commonly measured using an electronic (or, more rarely, a mechanical) transducer connected via the impulse lines to the upstream and downstream pressure tappings. The connection to the upstream tapping may be routed to the differential pressure and the static pressure transducers when both units are installed as part of a metering device as illustrated in Figure 10.

The choice of pressure transducer depends upon a number of factors which include the following:

a) the required accuracy of the measurement system;

b) whether the measurement is to be made continuously or intermittently;

c) the characteristics of the flowing fluid;

d) the data acquisition system including the computation device;

e) the required mounting and location for the transducer.

Mechanical pressure transducers, whilst less common with the advent of flow computers, are still used in many process applications. These units consist of an elastic element which converts energy from the pressure system to a displacement in the mechanical measuring system.

The more commonly used electronic pressure transducers incorporate an electric element which converts the pressure to an electrical signal which can be easily amplified, corrected, transmitted and measured.

EXAMPLE Examples of some electronic pressure transducers are

- piezoelectric pick-up devices,
- strain gauges,
- slide wire potentiometers,
- differential capacitance devices, and
- variable reluctance devices.

The declared accuracy and operating characteristics of the electronic pressure transmitters vary considerably from type to type but with the advent of the “smart transmitters”, operating in digital mode, uncertainties of $< 0,1$ % of the upper range value are claimed. Typical characteristics of electronic pressure transducers are given in Table 6.

NOTE Table 6 should be regarded as a simple guide. Quoted values are orders of magnitude.

It should be noted that differential-pressure transducers may be sensitive to changes in both static pressure and ambient temperature, unless automatic compensation arrangements are included within these units.

Table 6 — Characteristics of electrical pressure transducers

Parameter	**Type**				
	Variable reluctance	**Capacitive**	**Bonded strain gauge**	**Thin film strain gauge**	**Piston gauge**
Uncertainty % of full range	< 1	< 0,2	0,5	0,25	0,1 % of measured value
Max. pressure range (difference)	2 000 kPa bar (20 bar)	7 500 kPa (75 bar)	30 000 kPa (300 bar)	30 000 kPa (300 bar)	8 000 kPa (80 bar)
Acceptable over-range pressure	× 2,5	× 1,5	× 1,5	× 2	× 1,5
Full scale output (V)	0,1	1 V/200 Ω	< 0,03	< 0,03	10^4 pts digital
Resonance frequency (Hz)	< 10	100	< 5 000	10 000	1
Temperature range (°C)	−20 to 100	−25 to 90	−35 to 90	−50 to 120	10 to 30

6.2.3.3 Pressure calibrators

As with all secondary instrumentation, the pressure transducers (differential and static pressure) should be calibrated at regular intervals for optimum accuracy. There are a number of devices currently available for this function, the selection of which will be dependent upon the application of the metering devices and the types of transducer in service.

Those generally available are pressure balances, manometers, piezo-resistive sensors and precision Bourdon gauges. Some pressure calibrators, notably those operating on the pressure balance principle, can prove extremely difficult to operate in a non-stable environment. The performance of some of the most common calibration devices is indicated in Table 7.

NOTE Table 7 should be regarded as a simple guide. Quoted values are orders of magnitude.

Table 7 — Characteristics of precision pressure-measuring devices

Type	Range kPa (bar)	Uncertainty
Pressure balance (deadweight tester)	0,05 to 50 000 (0,000 5 to 500)	0,01kPa to 0,05 % of reading (0,1 mbar to 0,05 % of reading)
Servo manometer	0,5 to 400 (0,005 to 4,0)	Corresponding to 0,025 mm of liquid column height
Precision Bourdon gauge	0,05 to 100 000 (0,000 5 to 1 000)	0,1 % of full scale

6.2.3.4 Calibration of pressure transducers

To reduce the effects of ambient temperature changes to a minimum, it is recommended that the differential and static pressure transmitters be installed in temperature-controlled enclosures.

Static pressure transducers are usually calibrated *in situ* against an appropriate pressure calibrator selected for the specific function.

Differential pressure transmitters are often calibrated at atmospheric pressure, again using a calibrator which is deemed suitable for the purpose. For optimum accuracy, a transmitter should ideally be calibrated at operating pressure. It is common practice to use a high-static deadweight tester for this application.

As previously stated, a high-static calibration may not be possible due to less than ideal environmental conditions or background vibration at the worksite. If this is the case, a correction for static pressure shift effect should be applied either mathematically or via an interim calibration option such as “footprinting”.

The “footprinting” method referred to above involves the off-line calibration of the transducer in a controlled environment and the subsequent production of an atmospheric “footprint” which is used as a datum at the worksite for the periodic checking of the transducer against test equipment which is less environmentally sensitive than a high-static deadweight tester.

6.2.3.5 Damping of pressure signals

See Annex B of ISO/TR 3313:1998.

6.3 Measurement of temperature

6.3.1 General

The temperature at the upstream pressure tapping is needed in order to determine the density and viscosity of the fluid and to apply correction for thermal expansion of the device and the pipe.

The temperature of the fluid should preferably be measured downstream of the primary device.

6.3.2 Fundamentals of measuring the temperature of a moving fluid

Since any immersion temperature probe only measures its own temperature, the problem is to ensure that the representative temperature in the fluid is the same as the temperature at the measuring probe. Heat can be transferred by conduction, convection and radiation.

Except for great temperature differences, most of the heat is transferred from the fluid to the temperature probe by conduction and convection.

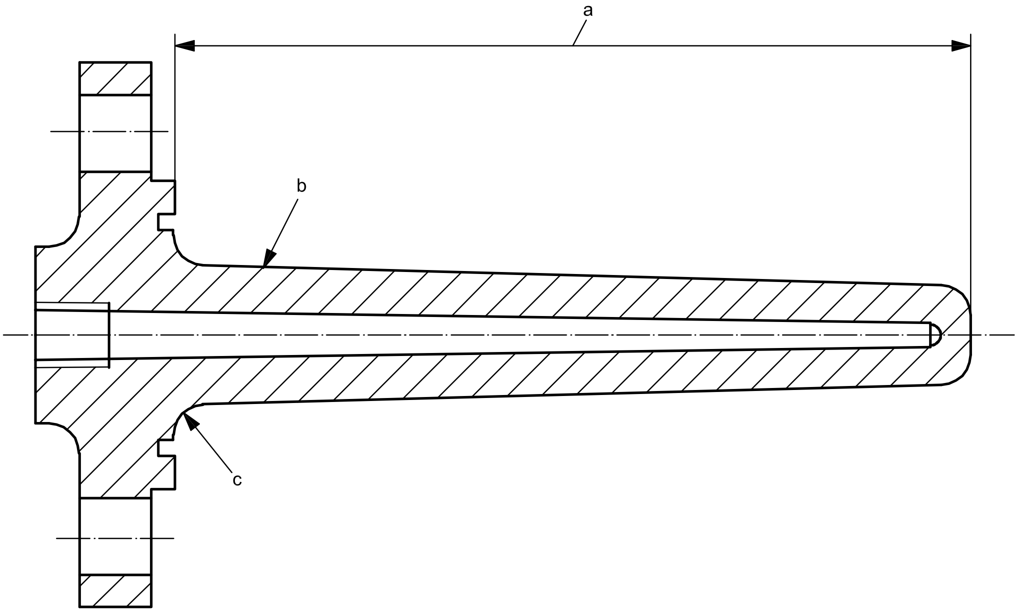
When the probe is inserted into the moving fluid, the boundary layer will tend to resist the transfer of heat to the probe and, at the same time, heat will be lost to the surroundings via the probe. The latter effect can be reduced by using thin wire leads and applying thermal insulation.

It may be necessary to mount the thermometer probe in a thermowell to protect the probe from the adverse effects of “corrosion”, vibration and excessive pressures, as well as to insulate it from electrically conductive liquids. The use of thermowells gives easy access to the probe unit. See Figure 13.

Temperature measurement in gases is more difficult than in liquids because of

- the relativity poor heat transfer between the gas and the probe, as compared with the transfer of heat between the probe and its surroundings, and
- the possibility of rapid fluctuations in temperature within the gas.

If it is not practical to insert the thermometer probe into a thermowell and if the heat transfer from the gas to the pipe wall is good, then a sensing device clamped to the wall may be used. This arrangement is not recommended for high-accuracy applications.



Key

^{a} As this length is important, it is essential that it is checked.

^{b} Forging.

^{c} Radius carefully designed to minimize stresses.

Figure 13 — Example of thermowell design

6.3.3 Sensor installation

See ISO 5167-1:2003, 5.4.4.1.

6.3.4 Precautions for accurate measurement

6.3.4.1 Sensor position and installation configuration

In general, the sensor or thermometer should be mounted perpendicular to the pipe wall, as illustrated in Figure 14 a). Severe vibration of the probe can result from the fluid flow around the inserted probe, using this installation. Care should be used in locating this probe.

This insertion depth of the sensor (N in Figure 14, measured from the inner wall) should be such that the sensor is in the middle third of the pipe. This is not always possible for smaller and larger pipes.

6.3.4.2 Use of radiation shield

The effect of thermal radiation can be reduced by developing a piping arrangement to move the thermowell out of the direct sight line of the radiating body. A highly polished thermowell will reflect a maximum of radiant energy.

6.3.4.3 Electrical isolation of the temperature transducer

Electrical isolation prevents disturbances due to variations in the insulation resistance of the sensing elements. These are caused by high temperature in the case of thermocouples, and by moisture and other electrolytic impurities penetrating into the junction box in the case of resistance bulbs. The choice between an isolated transducer and one without isolation is determined by the operating conditions. If exceptional reliability and accuracy are required from the measurement, isolation is recommended. If the conditions remain reasonably constant and the measuring point is not particularly critical, transducers, without isolation, can be used with a considerable saving in cost.

6.3.5 Restrictions on thermowells

When positioning and installing thermowells, the following provisions should be observed.

a) Where a number of thermowell pockets are to be found in close proximity to each other, care should be taken not to install them in line. This is to prevent the downstream probes being subjected to unduly high stresses as a result of vortex shedding and vibrations. The problems of vortex shedding can be minimized by spacing the thermowell pockets radially around the pipe.

b) The immersion length of the well has to be at least ten times the diameter of the well to minimize the risk of conduction error.

c) For smaller pipes, where dimension N [in Figure 14 a)] becomes larger than 3/4 of the nominal inside diameter of the pipe, the positions illustrated in Figure 14 b) and Figure 14 c) should be used.

d) For larger diameter pipes, where thermowell lengths exceed 100 mm, strength and vibration calculations are required if high density fluids are being measured. Air between the element and well is a very poor conductor of heat and results in measurement errors due to stem conduction. The second effect is an increase in the response time of the element. Liquid filling has been used to fill the empty space. Some heat transfer greases have been used; these materials are widely used in the electronics industry. Problems are associated with the fact that these greases have little or no lubricating effects and in fact are reported to cause threaded connections to seize together. The greatest improvement in heat transfer between the thermowell and the sensitive element is obtained by closely controlling the tolerances of the element’s outside diameter and the well’s inside diameter, ensuring the minimum extra clearance. Another method is to use a spring-loaded contact between the sensor and the well.

e) Undue projection of the well outside the pipe should be avoided.

f) The part of the thermometer projecting outside the pipe should be insulated if the temperature of the fluid differs from that of the ambient air. The adjacent pipe walls should be insulated in accordance with ISO 5167-1:2003, 6.1.9.

g) The mouth of the well should be closed to minimize loss of heat by convection, especially at high temperature.

h) Care should be taken regarding external temperature conditions including heat transfer due to radiation and ambient temperature.

6.3.6 Additional precautions in the case of fluctuating temperatures

If the temperature of the fluid is not constant, the accuracy of measurement depends also on the rate of heat transfer from the fluid to the temperature-sensitive element. The following precautions should be taken to reduce the time lag in response:

- the wall of the well should have a moderately high thermal conductivity and the surface in contact with the fluid should be kept clean;
- the temperature-sensitive portion of the thermometer should be small in size and of low mass and of low heat capacity.

6.3.7 Devices for temperature measurement

There are a wide variety of temperature-measuring devices based on different operating principles. Among the most common are liquid-in-glass thermometers, thermocouples and resistance thermometers.

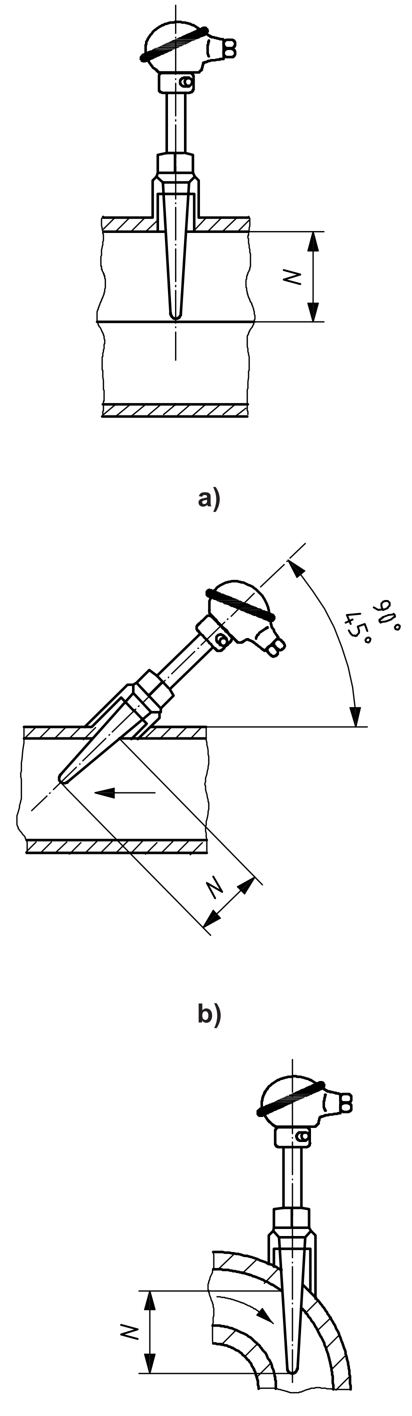
The choice of thermometer shall be based on knowledge of the measured media, the temperature range and the accuracy and reliability required. Some of the main characteristics of various thermometers are summarized in Table 8.

NOTE 1 Table 8 should not be regarded as complete, but rather as a simple guide. Quoted values are orders of magnitude. See also IEC 60584 for thermocouples and IEC 60751 for industrial platinum resistance thermometer sensors.

NOTE 2 Temperature sensors tend to be sensitive to mechanical vibration.

Table 8 — Main characteristics of different types of temperature sensors

Type	**Materials**	**Range** °C	**Uncertainty** °C	**Comments**
Liquid-in-glass	Mercury	−39 to 600	0,05	Toxicity; fragile
Liquid-in-glass	Alcohol	−100 to 50	0,1	Fragile
Thermocouples	Pt-Rh/Pt	0 to 1 500	1	
Thermocouples	Cu/Const	−200 to 350	0,5	
Thermocouples	Fe/Const	−200 to 600	1,5	
Thermocouples	Chromel/Alum	−200 to 1 000	1,5	
Resistance	Pt	−200 to 600	< 0,2	
Resistance	Ni	−100 to 200	0,5	
Resistance	Cu	−100 to 200	0,5	
Thermistor	Semi-conduct	−200 to 200	0,2	



a)

b)

c)

Figure 14 — Installation of immersion temperature probe

6.4 Determination of density

6.4.1 General

The density of the fluid can be either measured directly or calculated from the knowledge of static pressure, temperature and characteristics of the fluid using an equation of state at the chosen reference plane.

The density of liquid at flowing conditions may be determined from measurement or from reference sources and corrected to the temperature at flowing conditions. The variation with pressure is so slight that it usually may be neglected, depending on the application. Special care should be taken when working with fluids near the point of vaporization.

The density of gas varies with temperature, pressure and composition. For moist gas, the density also varies with the amount of water vapour present. Large errors can occur if sampling is used and the gas composition changes or the temperature drops below the saturation temperature, causing the formation of liquids.

The most common techniques used for density measurement are the force balance and vibrating element density meters. The fundamental characteristics of different density meters are given in Table 9.

NOTE Table 9 should be regarded as a simple guide. Quoted values are orders of magnitude.

Table 9 — Characteristics of densitometers

Type	Range kg/m^3	Span kg/m^3	Uncertainty %
Continuous weighing	400 to 2 500	250 (max.)	0,1 % to 0,3 % of measured value
Centrifugal (gas only)	1 200 (max.)	Variable	0,5 % of span
Vibration vane	0 to 400 (gases)	0,01 (min.)	0,1 % of span
		0,1 (max.)	
	300 to 1 200 (liquid)	0,1 (min.)	
		0,3 (max.)	
Vibrating tube	0 to 400 (gases)	as range	0,1 % of span
	600 to 1 600		

6.4.2 Installation of density transducers

Most of the factors relevant to the satisfactory installation of density transducers are identical to those for other field instruments; however, as the density transducer is essentially a sampling system, the installation shall also ensure that:

a) the pressure and temperature of the fluid in the density cell are as similar as possible to conditions at the metering device;

b) the sample fluid is as clean as possible, free from particles and single-phase;

c) the conditions in the sample cell will not be significantly affected by ambient temperature, solar radiation or wind;

d) there is a sufficient flow through the density cell to enable an adequate response to be made to changes in composition, pressure and temperature;

e) there are suitable facilities for maintenance and calibration of the transducer.

As with the installation of the temperature sensor, there is a conflict between the aim of knowing the density at the plane of the upstream pressure tapping and the installation requirements of the relevant part of ISO 5167. It is suggested that the density cell is installed downstream of the primary device either as an in-line probe or in a sample bypass. If the first alternative is chosen, the distance from the primary device to the point of installation shall be in accordance with ISO 5167-2:2003, Table 3 and ISO 5167-4, Table 1. For a nozzle or Venturi nozzle, the density cell should be located in accordance with ISO 5167-3:2003, Table 3. Figure 15 illustrates this type of installation.

The other installation method consists of bypassing or venting the fluid through the density cell. In this case the high-pressure tapping should be located at least $8D$ downstream of the primary device. The low-pressure return tapping should be located just behind the downstream face of the orifice plate. It should be ensured that the density measurement does not interfere with the flowrate measurement. Figure 16 illustrates this type of installation method. In this illustration, valve V_1 should be a needle valve, adjusted to control the flow through the densitometer in accordance with the manufacturer's instructions. Valve V_2 should be a full flow valve, such as a ball valve, fully open to ensure that there is no pressure drop between the densitometer and the low-pressure return tapping. In this "bypass" mode of operation, the density of the gas (ρ_m) is measured at p_2 (downstream tapping pressure) and T_3 (downstream recovered temperature). Equation (8) is an example of an equation that may be used to calculate the upstream density:

$$\rho_1 = \frac{\rho_\mathrm{m} p_1 T_3 Z_{(p_2,T_3)}}{p_2 T_1 Z_{(p_1,T_1)}} \tag{8}$$

where

ρ_1 is the upstream density (at p_1,T_1);

ρ_m is the measured density (at p_2,T_3) from the densitometer in bypass mode;

p_1 is the upstream pressure;

p_2 is the pressure at the downstream pressure tapping;

T_1 is the upstream temperature;

T_3 is the measured temperature at the downstream recovery point;

$Z_{(p_1,T_1)}$ is the compressibility at p_1, T_1;

$Z_{(p_2,T_3)}$ is the compressibility at p_2, T_3.

Listed below are some advantages and disadvantages of both installations.

Advantages of an in-line probe:

1) Temperature and pressure are always at flowing conditions at the point of measurement, but temperature and pressure still need correction.

2) The method is suitable for both large and small pipelines.

3) The probe can be removed while the line is in service if fitted with an isolating valve.

4) The method minimizes contamination by condensates.

Disadvantages of an in-line probe:

1) There is always the danger of the seal not holding with the result that the probe could be ejected from the line or leakage around the housing may develop. Added safety precautions shall be taken to ensure safe operation.

2) A relatively long response time to changes in gas density occurs at low flowrates or static pressure changes.

3) The probe is not easily removed from or inserted into the line when under pressure, if not fitted with an isolating valve.

4) Main flow may be affected, causing a change in the orifice discharge coefficient.

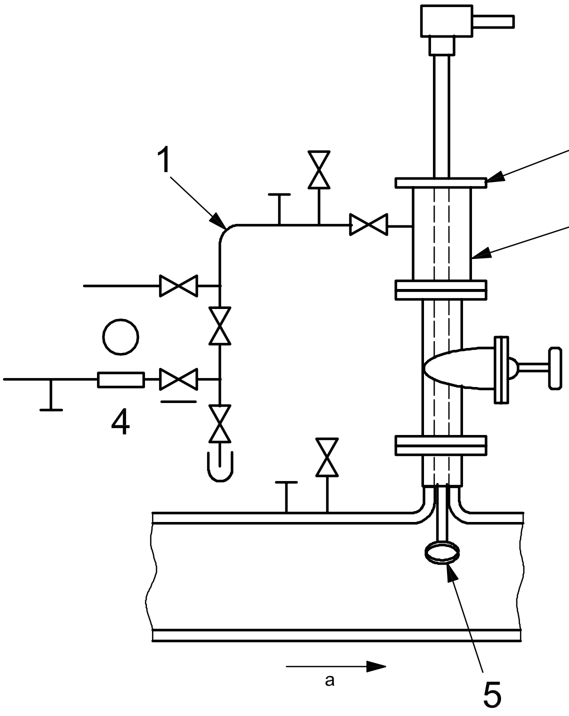
5) There is no check facility on sample flow through the transducer.

Advantages of a sample bypass probe:

1) Filtering or maintaining a filter in the stream if needed is easy.
2) The flowrate can be adjusted to comply with the accuracy of the instrumentation needed.
3) Access for maintenance and testing is easy.

Disadvantages of a sample bypass probe:

1) Large thermal mass may cause poor response time to temperature changes.
2) Temperature and pressure could vary from flowing conditions, resulting in measurement error. Both side stream and transducers shall be provided with thermal insulation.
3) Condensation can occur in the instrumentation and affect the accuracy of the density reading. A condensate trap may be necessary.

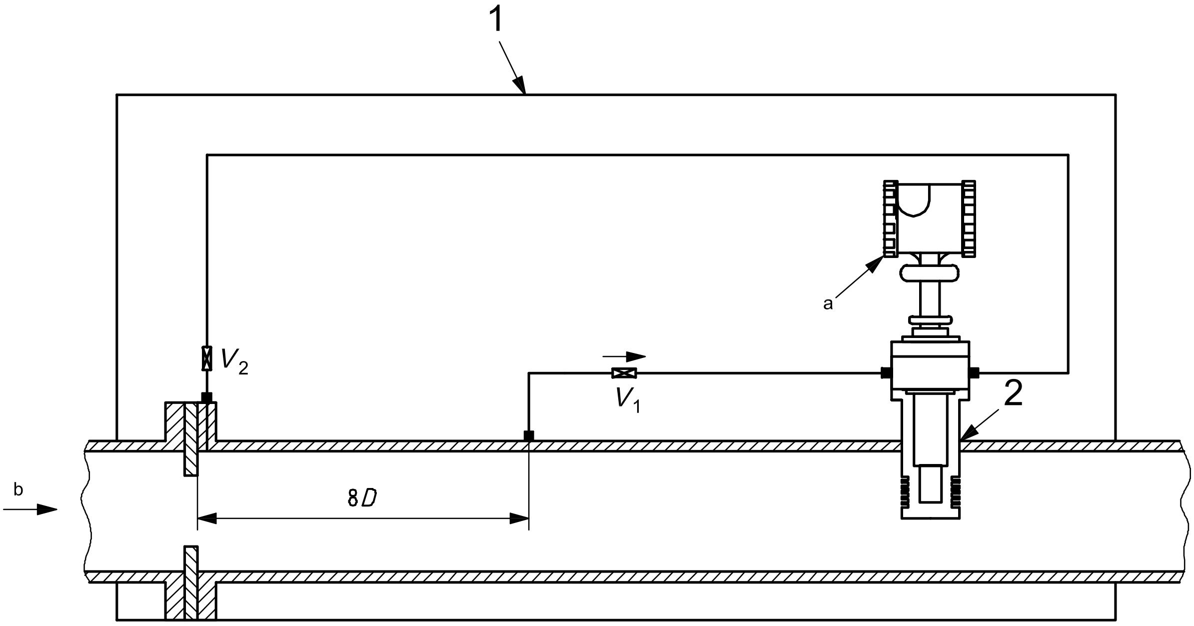


Key

1 sampling system for proving purposes only
2 seal
3 seal housing
4 flow meter
5 retractable probe

[a] Flow.

Figure 15 — Direct-insertion-type density meter



Key

1 thermal lagging

2 top of pipe

[a] To readout electronics.

[b] Flow.

Figure 16 — Installation showing density meter installed in sample bypass meter mounted in pocket

6.4.3 Additional method for the determination of the density of gas

The density of the gas can be computed from the real gas equation of state [ISO 5167-1:2003, 5.4.2].

When the composition and the temperature and pressure of the gas are known, the only unknown variable is the compressibility factor. When the compressibility factor of the gas is not known from published tables, the value has to be found from experiments. The more common techniques used are the expansion method and the weighing method. Accuracy of the compressibility factor in the range 0,1 % to 0,2 % can be obtained (see Annex B).

6.4.4 Special consideration concerning gas density

If high accuracy is required, introduce a correction to compensate for the fact that the fluid entering the density transducer is not at the condition of the upstream pressure tapping. This correction shall be made from knowledge of the density variation caused by a change in pressure and/or temperature. An estimate of the correction can be made from the real gas equation of state (see Annex B) and use of the Joule-Thomson coefficient.

6.4.5 Special considerations concerning liquid density

For less accurate liquid density determination, it can be assumed that pressure has little influence on the density. It is normally accurate enough to measure the temperature of flowing conditions (see 6.3) and find the density at that temperature from tables. This is satisfactory as long as the composition is constant and within the specification in the tables.

When the liquid contains dissolved solids or gases, the specific gravity should be determined if accurate results are required.

The pyknometer method can be used for checking continuous density measurements.

6.5 Electrical supply and electrical installations

6.5.1 Potentially explosive atmospheres

Reference should be made to IEC 60079-0:2007 for general requirements.

NOTE It is possible that reference should also be made to other parts of the IEC 60079 series.

6.5.2 Cabling

The specification for the cabling of electrical instrumentation will be defined by the instrumentation design engineer and will be influenced by the type of instrument in question. Nevertheless, the following simple rules can be given:

a) signal cables should be as short as possible;

b) shielded cables which are earthed only at one point should be used;

c) weak signals should be amplified before they are transmitted through the cables;

d) power cables should be separated from instrument cables and should only cross instrumentation lines at right angles;

e) signal lines should be shielded from electrical lines.

6.5.3 Electronic equipment

The installation of electronic equipment should be carried out in accordance with the Code of Practice appropriate for the intended use.

Annex A
(informative)

Principles of measurement and computation

A.1 Formulae

A.1.1 General

In all formulae, d, D and β refer to actual flowing conditions. In particular, when the flowing temperature differs from the temperature at which these dimensions were measured (usually 20 °C), the values shall be corrected for thermal expansion (see ISO 5167-1:2003, 5.4.4.1).

An explanation of the symbols used can be found in ISO 5167-1:2003, Clause 4.

A.1.2 Formulae common to all devices

Mass flowrate:

$$q_m = [1-\beta^4]^{-0,5} C\varepsilon \frac{\pi}{4} d^2 [2\Delta p \rho_1]^{0,5} \tag{A.1}$$

Volume flowrate:

$$q_{V1} = \frac{q_m}{\rho_1} \quad \text{or} \quad q_{VR} = \frac{q_m}{\rho_R} \tag{A.2}$$

where

$$\rho_1 = \rho_R \frac{p_1 T_R Z_R}{p_R T_1 Z_1} \tag{A.3}$$

Subscript “1” refers to the flow condition at the upstream pressure tapping cross-section.

Subscript “R” refers to given conditions of pressure and temperature.

Reynolds number:

$$Re_D = \frac{V_1 D}{\nu_1} = \frac{4 q_m}{\pi D \mu_1} = \frac{4 q_{V1}}{\pi D \nu_1} \tag{A.4}$$

A.1.3 Limits of use of primary devices

The formulae given for C and ε in all parts of ISO 5167 for the various primary devices can be applied only when certain quantities lie within given limits.

These limits of use are recalled in Table A.1.

A.2 Example of computation

A.2.1 General

Four detailed examples are shown below which deal with a compressible fluid and the discharge coefficient depending on β and Re_D.

As will be seen later, it may be convenient to consider the discharge coefficient C as the sum of two terms, $C = C_\infty + C_{Re}$, where C_∞ is the discharge coefficient obtained for an infinite Reynolds number. Table A.2 shows the formulae giving C_∞ and C_{Re} for each type of device.

Reference should be made to the table of iterative computations in ISO 5167-1:2003, Annex A.

Depending on the quantity which is to be calculated, additional equations derived from Equation (A.1) may be useful. Table A.3 shows the equation needed in the four types of problem usually encountered together with the quantities which have to be known to perform the calculations.

In all examples, 10-digit numbers are listed which is much more accurate than can be justified for practical purposes, but which can be helpful when checking the accuracy of the computer programs.

In each case, the aim is to solve an equation $f(X) = X$; so if X_i is the ith approximation to the true answer δ_1 can be defined as $f(X_i) - X_i$ and the iterative algorithm in Annex A of ISO 5167-1:2003 becomes

$$X_{n+1} = X_n - \frac{\left[f(X_n) - X_n\right](X_n - X_{n-1})}{f(X_n) - X_n - f(X_{n-1}) + X_{n-1}} \qquad \text{(A.5)}$$

An initial value, X_1, is required; then $X_2 = f(X_1)$; then the above equation can be used for $n = 2$, …

Equation (A.5) can be rewritten as

$$X_{n+1} = (1 - E_n) f(X_n) \qquad \text{(A.6)}$$

where

$$E_n = \frac{(f(X_n) - X_n)\left[f(X_{n-1}) - f(X_n)\right]}{f(X_n)\left[X_n + f(X_{n-1}) - f(X_n) - X_{n-1}\right]} \qquad \text{(A.7)}$$

Then, given an initial value, X_1, Equation (A.6) can be used for subsequent iterations with $E_1 = 0$ and Equation (A.7) for $n = 2$, …

Table A.1 — Limits of use

Type of device	d mm	D mm	β	Re_D	Roughness Criteria
Corner tappings orifice plate D and $D/2$ tappings orifice plate	$\geqslant 12{,}5$	$50 \leqslant D \leqslant 1\,000$	$0{,}10 \leqslant \beta \leqslant 0{,}75$	$Re_D \geqslant 5\,000$ for $0{,}10 \leqslant \beta \leqslant 0{,}56$ $Re_D \geqslant 16\,000\beta^2$ for $\beta > 0{,}56$	See ISO 5167-2:2003, Tables 1 and 2
Flange tappings orifice plate	$\geqslant 12{,}5$	$50 \leqslant D \leqslant 1\,000$	$0{,}10 \leqslant \beta \leqslant 0{,}75$	$Re_D \geqslant 5\,000$ and $Re_D \geqslant 170\beta^2 D$*	See ISO 5167-2:2003, Tables 1 and 2
ISA 1932 nozzle	—	$50 \leqslant D \leqslant 500$	$0{,}30 \leqslant \beta \leqslant 0{,}80$	$70\,000 \leqslant Re_D \leqslant 10^7$ for $0{,}30 \leqslant \beta \leqslant 0{,}44$ $20\,000 \leqslant Re_D \leqslant 10^7$ for $0{,}44 \leqslant \beta \leqslant 0{,}80$	See ISO 5167-3:2003, Table 1
Long-radius nozzle	—	$50 \leqslant D \leqslant 630$	$0{,}20 \leqslant \beta \leqslant 0{,}80$	$10^4 \leqslant Re_D \leqslant 10^7$	$R_a/D \leqslant 3{,}2 \times 10^{-4}$
Rough-cast convergent Venturi tube	—	$100 \leqslant D \leqslant 800$	$0{,}30 \leqslant \beta \leqslant 0{,}75$	$2 \times 10^5 \leqslant Re_D \leqslant 2 \times 10^6$	$R_a < 10^{-4}\,d$** $R_a < 10^{-4}\,D$***
Rough-welded convergent Venturi tube	—	$200 \leqslant D \leqslant 1\,200$	$0{,}40 \leqslant \beta \leqslant 0{,}70$	$2 \times 10^5 \leqslant Re_D \leqslant 2 \times 10^6$	$R_a < 10^{-4}\,d$** $R_a \approx 5 \times 10^{-4}\,D$***
Machined convergent Venturi tube	—	$50 \leqslant D \leqslant 250$	$0{,}40 \leqslant \beta \leqslant 0{,}75$	$2 \times 10^5 \leqslant Re_D \leqslant 1 \times 10^6$	$R_a < 10^{-4}\,d$** ***
Venturi nozzle	$\geqslant 50$	$65 \leqslant D \leqslant 500$	$0{,}316 \leqslant \beta \leqslant 0{,}775$	$1{,}5 \times 10^5 \leqslant Re_D \leqslant 2 \times 10^6$	See ISO 5167-3:2003, Table 2

Key

* Where D is in millimetres.

** Throat roughness criterion.

*** Convergent section roughness criterion.

NOTE For all devices, $\Delta p/p_1 \leqslant 0{,}25$ when used with compressible fluids.

Table A.2 — C_∞ and C_{Re} for orifice plates for $D > 71{,}12$ mm: $C = C_\infty + C_{Re}$

Type of device	Equations	Equation number
Orifice plates	$C_\infty = C_{\infty,\text{corner}} + C_{\infty,L}$ $C_{\infty,\text{corner}} = 0{,}5961 + 0{,}0261\beta^2 - 0{,}216\beta^8$ $C_{\infty,L} = (0{,}043 + 0{,}080\mathrm{e}^{-10L_1} - 0{,}123\mathrm{e}^{-7L_1})\frac{\beta^4}{1-\beta^4}$ $-0{,}031(M'_2 - 0{,}8M'_2{}^{1{,}1})\beta^{1{,}3}$	(A.8.1)
	$C_{Re} = 0{,}000\,521\left(\frac{10^6\beta}{Re_D}\right)^{0{,}7} + (0{,}018\,8 + 0{,}006\,3A)\beta^{3{,}5}\left(\frac{10^6}{Re_D}\right)^{0{,}3}$ $-0{,}11A(0{,}043 + 0{,}080\mathrm{e}^{-10L_1} - 0{,}123\mathrm{e}^{-7L_1})\frac{\beta^4}{1-\beta^4}$	(A.8.2)
	L_1, M_2' and A are as defined in ISO 5167-2:2003, 5.3.2.1.	

Table A.3 — Iteration equations

Known parameters	Quantities to be computed	Equations	Equation number
$d \quad D \quad \Delta p$	q_m	$f(q_m) = CK_q$	(A.9.1)
		$K_q = \left(1-\beta^4\right)^{-0{,}5} \varepsilon \frac{\pi}{4} d^2 \sqrt{2\Delta p \rho_1}$	(A.9.2)
$q_m \quad \Delta p \quad D$	β	$f(\beta) = (1 + C^2\varepsilon^2 K_\beta)^{-0{,}25}$	(A.9.3)
		$K_\beta = \frac{\Delta p \rho_1}{8}\left(\frac{\pi D^2}{q_m}\right)^2$	(A.9.4)
$d \quad D \quad q_m$	Δp	$f(\Delta p) = K_{\Delta p}\varepsilon^{-2}$	(A.9.5)
		$K_{\Delta p} = \frac{8\left(1-\beta^4\right)}{\rho_1}\left(\frac{q_m}{\pi C d^2}\right)^2$	(A.9.6)
$q_m \quad \Delta p \quad \beta$	D	$f(D) = K_D C^{-0{,}5}$	(A.9.7)
		$K_D = \left[\frac{8\left(1-\beta^4\right)}{\Delta p \rho_1 \beta^4}\left(\frac{q_m}{\pi\varepsilon}\right)^2\right]^{0{,}25}$	(A.9.8)

A.2.2 Determination of D — Example

See Figure A.1 for an example of a flowchart.

Assume an orifice plate metering facility using flange taps has to be designed for the following conditions:

— fluid:	steam
— maximum flowrate:	1 kg·s^{-1}
— maximum diameter ratio:	0,65
— maximum pressure differential:	0,5 × 10^5 Pa (500 mbar)
— pressure:	10 × 10^5 Pa (10 bar)
— temperature:	773,15 K (500 °C)

— $\lambda_d = 16 \times 10^{-6}$ K^{-1}

— $\lambda_D = 11 \times 10^{-6}$ K^{-1}

Use the following typical data:

— $\rho_1 = 2{,}825\ 1$ kg·m^{-3}

— $\mu_1 = 28{,}5 \times 10^{-6}$ Pa·s

— $\kappa = 1{,}276$

The exit criterion chosen is 10^{-6} (0,000 1 %). The calculation procedure is then:

*** Assessing starting values

1) ε, applying equation for expansibility [ISO 5167-2:2003, 5.3.2.2]:

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

$\varepsilon = 0{,}983\ 201\ 997\ 0$.

For manual calculations using a calculator with a memory, it is useful to store the value of β^4, since it is required in a number of the subsequent equations

2) K_D, applying Equation (A.9.8): $K_D = \left[\frac{8\left(1-\beta^4\right)}{\Delta p \rho_1 \beta^4}\left(\frac{q_m}{\pi\varepsilon}\right)^2\right]^{0{,}25}$

$K_D = 0{,}072\ 295\ 778\ 11$

In each case, p_1, T_1, ρ_1, U_1, K shall also be known.

3) Applying Equation (A.8.1) for corner tappings:

$$C_{\infty,\text{corner}} = 0{,}596\ 1 + 0{,}026\ 1\beta^2 - 0{,}216\beta^8$$

$C = C_{\infty,\text{ corner}} = 0{,}600\ 244\ 522\ 0$

For all the other devices, C_∞ could be readily calculated at this stage.

4) The starting value of D is obtained from Equation (A.9.7): $f(D) = K_D\, C^{-0,5}$

$D_1 = f(D) = 0{,}093\,314\,435\,6$

5) Reynolds number from Equation (A.4):

$Re_D = 478\,758{,}419\,9$

NOTE For most practical purposes, it is possible to stop the calculation here, since the final result will not be significantly different from D_1 and will be eventually rounded up to the next commercially available pipe diameter.

The final result obtained by the complete computation would be:

$D = 0{,}092\,707\,108\,61$

From the previous calculation of D, the nearest commercially available pipe diameter, $D = 0{,}102$ m, would be selected by the designer of the metering station.

A.2.3 Computation of β — Example

Refer to Figure A.2 for an example of a flowchart.

It is now necessary to calculate the orifice diameter d for the same conditions as in A.2.2, i.e.

— fluid:	steam
— maximum flowrate:	1 kg·s^{-1}
— maximum pressure differential:	$0{,}5 \times 10^5$ Pa (500 mbar)
— pressure:	10×10^5 Pa (10 bar)
— temperature:	773,15 K (500 °C)
— pipe diameter at ambient:	$D_0 = 0{,}102$ m

- $\lambda_d = 16 \times 10^{-6}$ K^{-1}
- $\lambda_D = 11 \times 10^{-6}$ K^{-1}
- $\rho_1 = 2{,}825\,1$ kg · m^{-3}
- $\mu_1 = 28{,}5 \times 10^{-6}$ Pa·s
- $K = 1{,}276$

The exit criterion being still 10^{-6}, the calculation would be:

*** Assessing starting values:

1) D is obtained from Equation (7): $D = D_0\,[1 + \lambda_D\,(T - T_0)]$

$D = 0{,}102\,538\,560\,0$

2) Re_D, from Equation (A.4): $Re_D = \dfrac{4q_m}{\pi D \mu_1}$

$Re_D = 435\,690{,}453\,9$

3) β being unknown, it is convenient and reasonable to use $\varepsilon = 0{,}97$ as the starting value, except in the case of incompressible fluids, for which $\varepsilon = 1$.

4) β being unknown, it is convenient either

— to use a fixed starting value of C, e.g. 0,60 for orifice plates and 0,99 for all types of nozzles, or

— to use as a starting value $C = C_\infty$ (in the case of classical Venturi tubes C is a constant).

The second method is preferable when the diameter ratio β (and D for orifice plates using flange tappings) is a known parameter; in such a case, C is calculated from $C = C_\infty + C_{Re}$ in the iteration steps, where C_∞ has already been calculated.

In the case of orifice plates using flange tappings where D is not known and β is known, the starting value of C can be taken as equal to $C_{\infty,\text{corner}}$, i.e. the value of C_∞ that would be obtained for corner tappings. In the iteration steps, C has to be computed as:

$$C = C_{\infty,\text{corner}} + C_{\infty,L} + C_{Re}$$

where the last two terms have to be recalculated at each step.

In most practical cases however, it will be sufficient to assume $C = C_\infty$ and make no iteration.

5) K_β, from Equation (A.9.4): $K_\beta = \dfrac{\Delta p \rho_1}{8}\left(\dfrac{\pi D^2}{q_m}\right)^2$

$K_\beta = 19{,}264\ 708\ 61$

6) Starting value of β from Equation (A.9.3): $f(\beta) = (1 + C^2\varepsilon^2 K_\beta)^{-0{,}25}$

$\beta_1 = f(\beta) = 0{,}603\ 764\ 155\ 8$

*** First iteration step

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

$\varepsilon = 0{,}984\ 182\ 761\ 4$

8) C, from Equations (A.8.1) and (A.8.2):

$C = C_\infty + C_{Re}$

$C = 0{,}607\ 261\ 036\ 6$

9) Next value of β from Equation (A.9.3): $f(\beta) = (1 + C^2\varepsilon^2 K_\beta)^{-0{,}25}$

$\beta = f(\beta_1) = 0{,}596\ 831\ 560\ 9$

No correction being made at the first step ($E_1 = 0$), the starting value for the second step is:

$\beta_2 = f(\beta_1) = 0{,}596\ 831\ 560\ 9$

*** Second iteration step

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

$\varepsilon = 0{,}984\ 300\ 372\ 0$

11) C, from Equations (A.8.1) and (A.8.2).

$C = 0{,}607\ 076\ 664\ 5$

12) Next value of β from Equation (A.9.3): $f(\beta) = (1 + C^2\varepsilon^2K_\beta)^{-0{,}25}$

$\beta = f(\beta_2) = 0{,}596\ 879\ 546\ 2$

13) Deviation in $f(\beta_2)$ is given by: $E_2 = -\frac{1}{f(X_2)}\frac{[f(X_2) - X_2]^2}{[2X_2 - f(X_2) - X_1]}$

$E_2 = 5{,}526\ 344\ 567 \times 10^{-7}$

which is less than the exit criterion. The iteration is then stopped.

$d = \beta D$ $\quad d = 0{,}061\ 203\ 169\ 16$ m

d_0 from Equation (4): $d = d_0\ [1 + \lambda_d(T - T_0)]$ $\quad d_0 = 0{,}060\ 736\ 711\ 22$ m

A.2.4 Computation of q_m — Example

Refer to Figure A.3 for an example of a flowchart.

Assume the metering station is now used to measure a flowrate with a plate of diameter $d_0 = 0{,}061$ m in the following conditions:

- fluid: steam
- pressure differential: $0{,}481 \times 10^5$ Pa (481 mbar)
- pressure: 10×10^5 Pa (10 bar)
- temperature: 773,15 K (500 °C)
- $\rho_1 = 2{,}825\ 1$ kg·m^{-3}
- $d_0 = 0{,}061$ m
- $D_0 = 0{,}102$ m
- $\mu_1 = 28{,}5 \times 10^{-6}$ Pa·s
- $\lambda_d = 16 \times 10^{-6}$ K^{-1}
- $\lambda_D = 11 \times 10^{-6}$ K^{-1}
- $\kappa = 1{,}276$

The exit criterion being 10^{-6}, the calculation would be:

*** Assessing starting values:

1) d is obtained from Equation (4): $d = d_0\,[1 + \lambda_d\,(T - T_0)]$

   $d = 0{,}061\ 468\ 480\ 00$

2) D, from Equation (7): $D = D_0\,[1 + \lambda_D\,(T - T_0)]$

   $D = 0{,}102\ 538\ 560\ 0$

3) β, from $\beta = d/D$

   $\beta = 0{,}599\ 466\ 971\ 3$

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

   $\varepsilon = 0{,}984\ 857\ 929\ 9$

5) K_q, from Equation (A.9.2): $K_q = (1 - \beta^4)^{-0{,}5}\,\varepsilon\,\frac{\pi}{4}\,d^2\,(2\Delta p \rho_1)^{0{,}5}$

   $K_q = 1{,}632\ 671\ 123$

6) C, from Equation (A.8.1):

   $C = C_\infty = 0{,}602\ 425\ 043\ 2$

7) The starting value for q_m from Equation (A.9.1): $f(q_m) = CK_q$

   $q_{m,1} = f(q_m) = 0{,}983\ 561\ 971\ 8$

*** First iteration step

8) Reynolds number from Equation (A.4): $Re_D = \frac{4q_m}{\pi D \mu_1}$

   $Re_D = 428\ 528{,}561\ 9$

9) New estimate of C, from $C = C_\infty + C_{Re}$

   $C = 0{,}607\ 176\ 725\ 2$

10) New estimate of q_m, from Equation (A.9.1): $f(q_m) = CK_q$

   $q_m = f(q_{m,1}) = 0{,}991\ 319\ 905\ 8$

No correction being made at the first step ($E_1 = 0$), the starting value for the second step is:

$$q_{m,2} = f(q_{m,1}) = 0{,}991\ 319\ 905\ 8$$

*** Second iteration step

11) New Reynolds number from Equation (A.4): $Re_D = \dfrac{4q_m}{\pi D \mu_1}$

$$Re_D = 431\ 908{,}619\ 7$$

12) New value of C, from $C = C_\infty + C_{Re}$

$$C = 0{,}607\ 163\ 108\ 8$$

13) New value of q_m, from Equation (A.9.1): $f(q_m) = CK_q$

$$q_m = f(q_{m,2}) = 0{,}991\ 297\ 674\ 7$$

14) Deviation of $f(q_{m,2})$: $E_2 = -\dfrac{1}{f(X_2)} \dfrac{[f(X_2) - X_2]^2}{[2X_2 - f(X_2) - X_1]}$

$$E_2 = -6{,}408\ 057\ 577 \times 10^{-8}$$

which is less than the exit criterion. The iteration is then stopped and the result is:

$$q_m = 0{,}991\ 297\ 674\ 7\ \text{kg·s}^{-1}$$

A.2.5 Determination of Δp — Example

Refer to Figure A.4 for an example of a flowchart.

Assume the pressure differential is required for the maximum flowrate of the same facility if the plate has a diameter of $d_0 = 0{,}050$ m.

—	fluid:	steam
—	flowrate:	1 kg·s^{-1}
—	pressure:	10×10^5 Pa (10 bar)
—	temperature:	773,15 K (500 °C)
—	density:	2,825 1 kg·m^{-3}

— $d_0 = 0{,}050$ m

— $D_0 = 0{,}102$ m

— $\mu_1 = 28{,}5 \times 10^{-6}$ Pa·s

— $\lambda_d = 16 \times 10^{-6}$ K^{-1}

— $\lambda_D = 11 \times 10^{-6}$ K^{-1}

— $\kappa = 1{,}276$

10^{-6} being the exit criterion, the calculation would be:

*** Assessing starting values

1) d is obtained from Equation (4): $d = d_0\,[1 + \lambda_d\,(T - T_0)]$

   $d = 0{,}050\ 384\ 000\ 00$

2) D, from Equation (7): $D = D_0\,[1 + \lambda_D\,(T - T_0)]$

   $D = 0{,}102\ 538\ 560\ 0$

3) β, from $\beta = d/D$

   $\beta = 0{,}491\ 366\ 369\ 9$

4) Re_D from Equation (A.4): $Re_D = \dfrac{4q_m}{\pi D \mu_1}$

   $Re_D = 435\ 690{,}453\ 9$

5) C, from Equations (A.8.1) and (A.8.2): $C = C_\infty + C_{Re}$

   $C = 0{,}603\ 572\ 933\ 9$

6) $K_{\Delta p}$, from Equation (A.9.6): $K_{\Delta p} = \dfrac{8(1-\beta^4)}{\rho_1}\left(\dfrac{q_m}{\pi C d^2}\right)^2$

   $K_{\Delta p} = 115\ 091{,}115\ 8$

7) ε is taken as equal to 0,97.

8) Starting value for Δp, from Equation (A.9.5): $f(\Delta p) = K_{\Delta p}\,\varepsilon^{-2}$

   $\Delta p_1 = f(\Delta p) = 122\ 320{,}242\ 1$

*** First iteration step

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

   $\varepsilon = 0{,}964\ 125\ 846\ 1$

10) Next value of Δp, from Equation (A.9.5): $f(\Delta p) = K_{\Delta p}\,\varepsilon^{-2}$

   $\Delta p = f(\Delta p_1) = 123\ 815{,}310\ 0$

No correction being made at the first step ($E_1 = 0$), the starting value for the second step is:

$\Delta p_2 = f(\Delta p_1) = 123\ 815{,}310\ 0$

*** Second iteration step

11) New value of ε: $\varepsilon = 1-\left(0{,}351+0{,}256\beta^4+0{,}93\beta^8\right)\left[1-\left(\frac{p_2}{p_1}\right)^{1/\kappa}\right]$

$\varepsilon = 0{,}963\ 680\ 936\ 9$

12) Next value of Δp, from Equation (A.9.5): $f(\Delta p) = K_{\Delta p}\ \varepsilon^{-2}$

$\Delta p = f(\Delta p_2) = 123\ 929{,}661\ 7$

13) Deviation of $f(\Delta p_2)$: $E_2 = -\frac{1}{f(X_2)}\frac{[f(X_2)-X_2]^2}{[2X_2-f(X_2)-X_1]}$

$E_2 = -\ 7{,}641\ 976\ 350 \times 10^{-5}$

For manual computation, one would stop here. The calculation is carried on to show the effect of the rapid scheme.

*** Third iteration step

14) The starting value for step 3 is obtained from: $\Delta p_{n+1} = (1 - E_n)\ f(\Delta p_n)$

$\Delta p_3 = 123\ 939{,}132\ 4$

NOTE If substitution iteration was continued [$\Delta p_{n+1} = f(\Delta p_n)$ for all steps], a total of 5 iteration steps would be necessary to conform to the exit criterion.

15) New value of ε: $\varepsilon = 1-\left(0{,}351+0{,}256\beta^4+0{,}93\beta^8\right)\left[1-\left(\frac{p_2}{p_1}\right)^{1/\kappa}\right]$

$\varepsilon = 0{,}963\ 644\ 081\ 9$

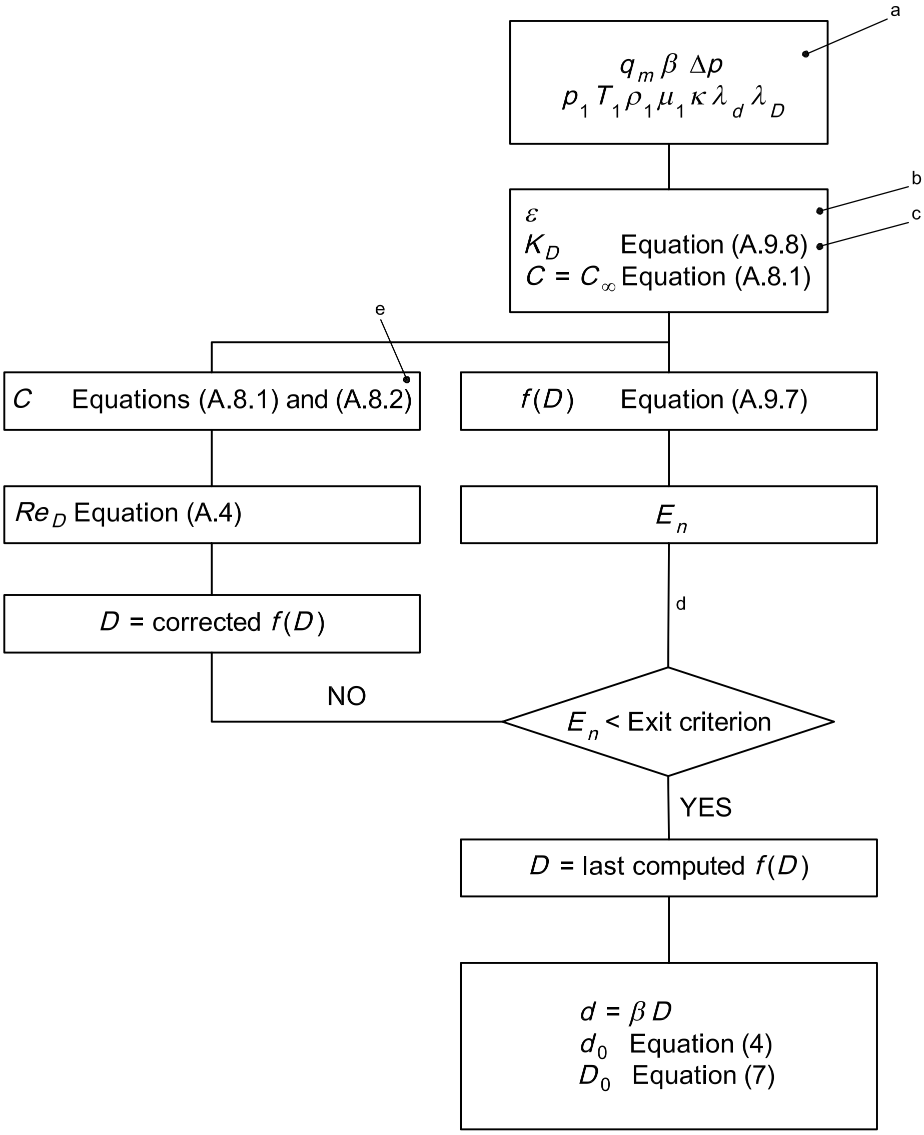
16) Next value of Δp, from Equation (A.9.5): $f(\Delta p) = K_{\Delta p}\ \varepsilon^{-2}$

$\Delta p = f(\Delta p_3) = 123\ 939{,}141\ 4$

17) Deviation on $f(\Delta p_3)$: $E_n = \frac{1}{f(X_n)}\frac{[f(X_n)-X_n][f(X_{n-1})-f(X_n)]}{[X_n+f(X_{n-1})-f(X_n)-X_{n-1}]}$

$E_3 = -\ 6{,}017\ 524\ 711 \times 10^{-9}$

The iteration is then stopped, the exit criterion being met. The result is $\Delta p = 123\ 939{,}141\ 4$ Pa.



Key

[a] ε and p_1 have to be known for compressible fluids only.

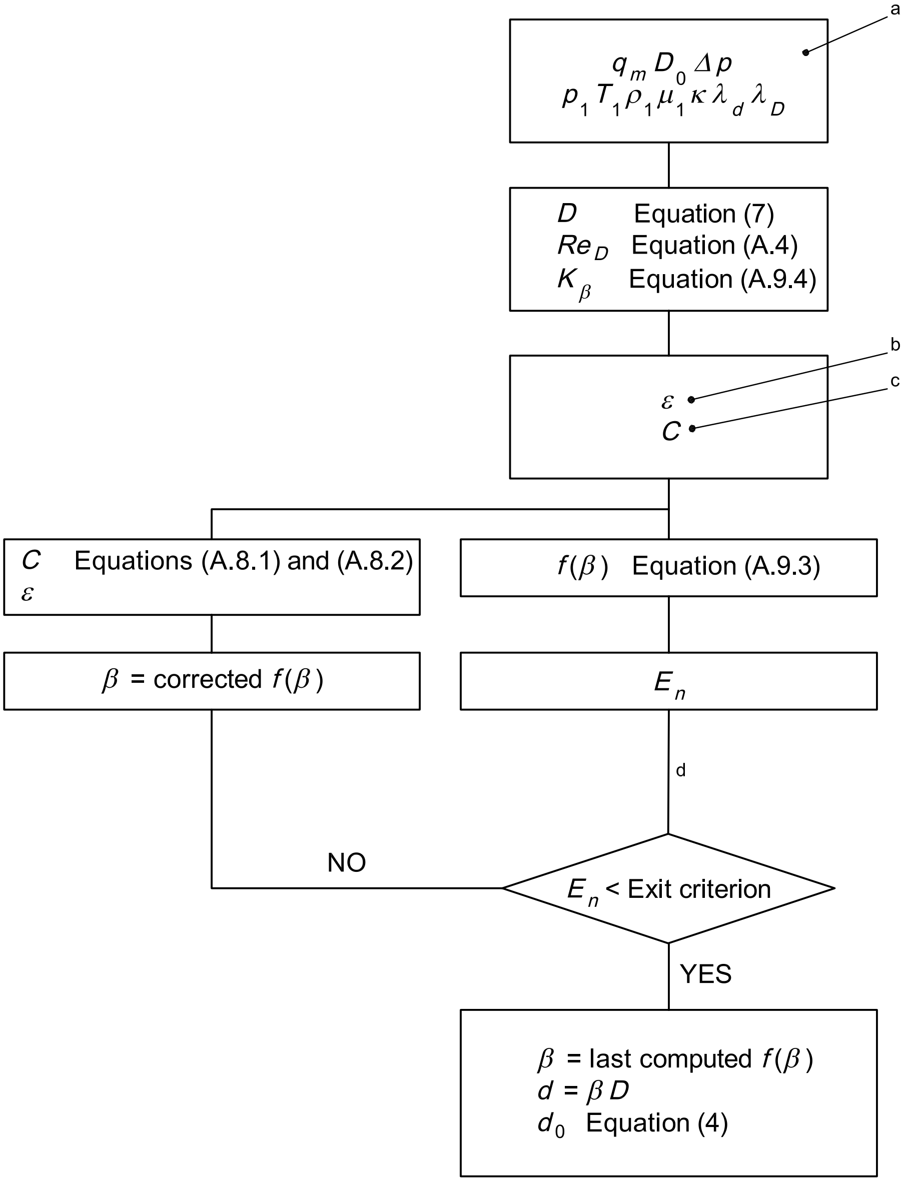
[b] For incompressible fluids, $\varepsilon = 1$.

[c] For classical Venturi tubes and Venturi nozzles, $C = C_\infty$, and no loop is necessary.

[d] For the first step, $E_1 = 0$ but proceed to “NO”, except for classical Venturi tubes and Venturi nozzles.

[e] Except for flange tapping orifice plates, only C_{Re} has to be computed here, then it is added to previously computed C_∞.

Figure A.1 — Flowchart example — Computation of pipe diameter D



Key

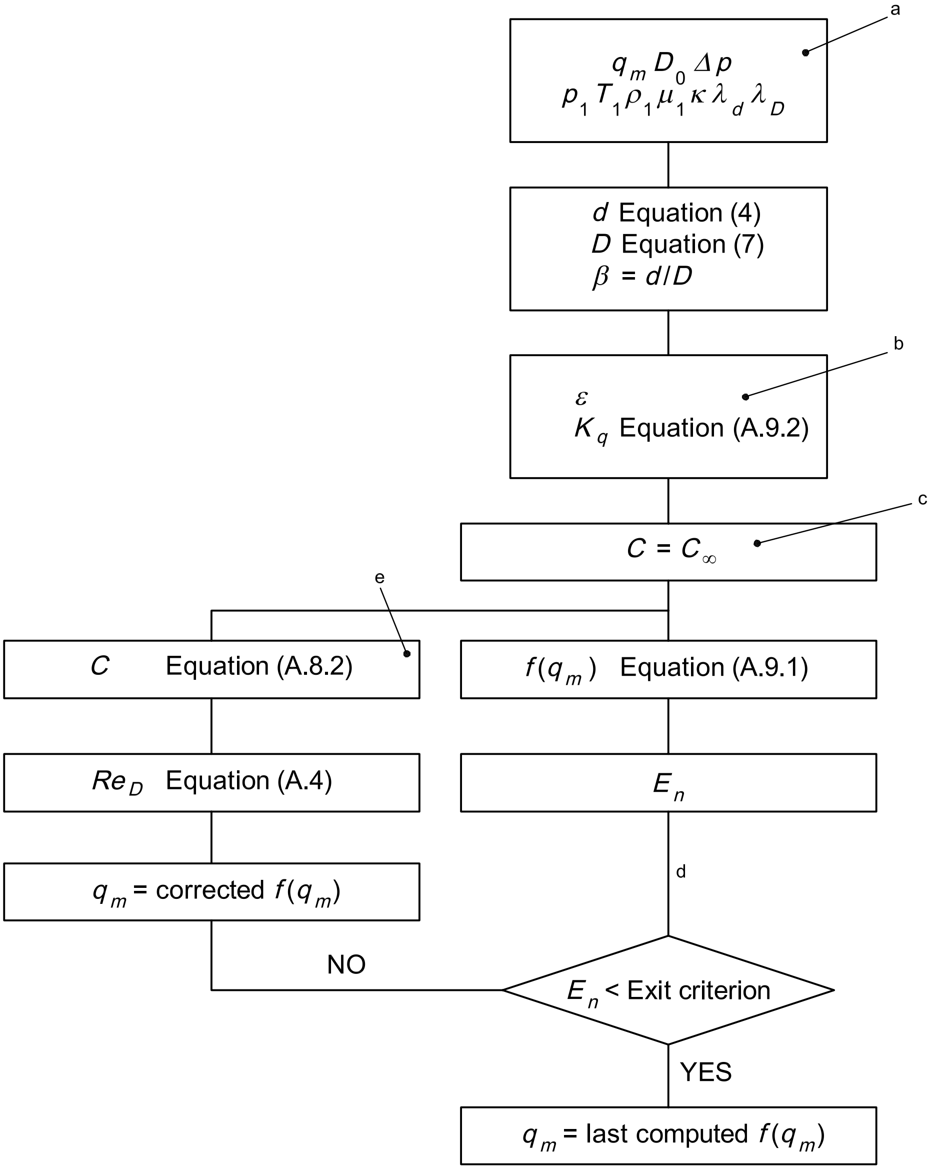
[a] ε and p_1 have to be known for compressible fluids only.

[b] For incompressible fluids, $\varepsilon = 1$ and need not be computed further again.

[c] For classical Venturi tubes, C is a constant and need not be computed further again. If in addition the fluid is incompressible, no iteration is necessary.

[d] For the first step, $E_1 = 0$ but proceed to "NO", except for Venturi tubes operated with incompressible fluids.

Figure A.2 — Flowchart example — Computation of diameter d and diameter ratio β



Key

a ε and p_1 have to be known for compressible fluids only.

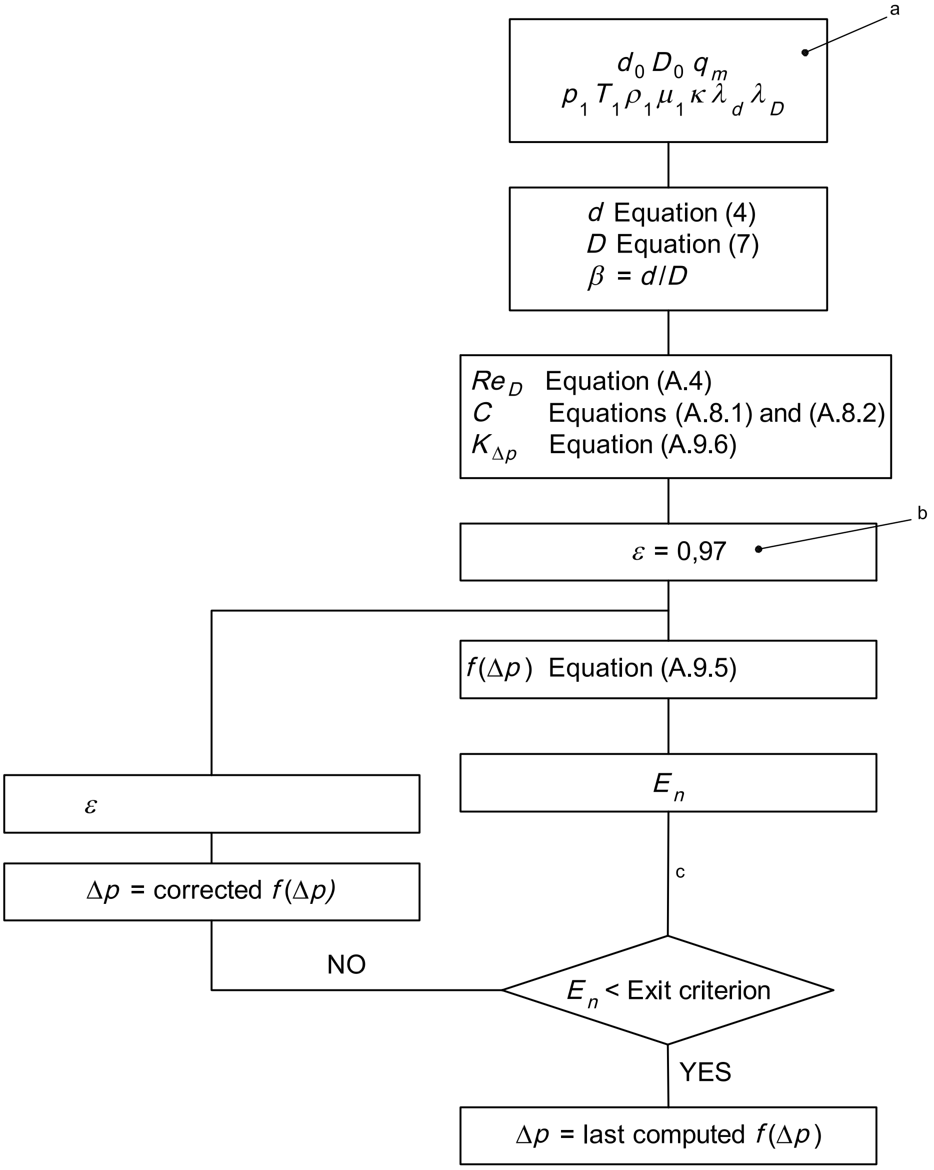
b For incompressible fluids, $\varepsilon = 1$ and need not be computed further again.

c For classical Venturi tubes and Venturi nozzles, $C = C_\infty$ and no iteration is necessary.

d For the first step, $E_1 = 0$ but proceed to "NO", except for classical Venturi tubes and Venturi nozzles.

e Only C_{Re} has to be computed here, then added to already computed C_∞.

Figure A.3 — Flowchart example — Computation of flowrate q_m



Key

[a] ε and p_1 have to be known for compressible fluids only.

[b] For incompressible fluids, $\varepsilon = 1$ and no loop is necessary.

[c] For the first step, $E_1 = 0$ but proceed to “NO”, except for classical Venturi tubes and Venturi nozzles.

Figure A.4 — Flowchart example — Computation of pressure Δp

Annex B
(informative)

Computation of compressibility factor for natural gases

B.1 Calculation of density, ρ

The density of a gas may be calculated by means of either of the following equations:

$$\rho = \frac{pM}{R_u T Z} \tag{B.1}$$

$$\rho = \frac{\rho_0 p T_0 Z_0}{p_0 T Z} \tag{B.2}$$

where

Z is the compressibility factor;

ρ is the density;

M is the molecular weight of the gas;

R_u is the universal gas constant.

The subscript $_0$ refers to a reference state of temperature and pressure.

Z is a function of the composition of the gas.

B.2 Calculation of compressibility factor, Z

Modern methods for the computation of Z aim to cover the entire range of transmission metering conditions and gas compositions. These are described in ISO 12213 [2].

ISO 12213 has three parts: 1) introduction and guidelines; 2) calculation using molar composition analysis; 3) calculation using physical properties. All of these parts were published in 2006 and are based on AGA Report Number 8 [7].

The calculation of Z using molar composition analysis, also known as the “detailed method”, uses up to 21 components and has been thoroughly evaluated for a broad range of typical natural gas pipeline temperatures, pressures and gas compositions (see Reference [9]). High accuracy measurements on five gravimetrically prepared reference natural gas mixtures were made by four leading laboratories in Europe and North America. The gas compositions were selected by European and North American pipeline company representatives, and are characteristic of a wide range of commercial natural gases found world-wide.

The calculation of Z using physical properties, known as the “gross method”, uses a simplified input data set comprising any three from superior (gross) calorific value (heating value), relative density, carbon dioxide content and nitrogen content, together with pressure and temperature. With this limited information, the equation predicts Z within the respective pressure and temperature ranges of 0 MPa to 12 MPa (0 bar to 120 bar) and 265 K to 335 K (–8 °C to 62 °C) with an accuracy of about 0,1 %, about the same as the detailed method.

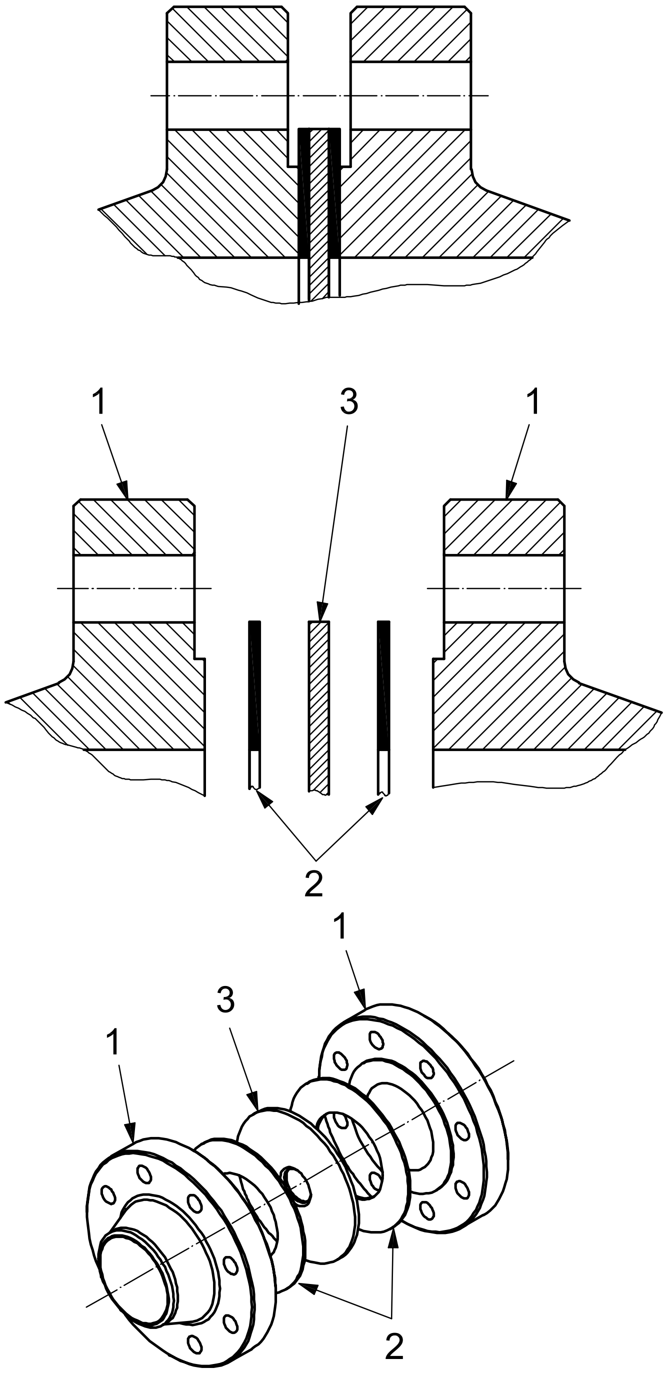
The detailed and gross calculation methods have also been published in Technical Monographs by the Groupe Européen de Recherches Gazières (GERG) and are known as the Master (or Molar) GERG-88 Virial Equation and Standard (or Simplified) GERG-88 Virial Equation (SGERG).

Consistent thermophysical property calculations over a range of pipeline operating conditions are also needed for general orifice meter calibrations using sonic nozzles and cross-meter checking. The GRI/AGA8 detail equation provides highly accurate, internally consistent derived thermophysical properties at standard pipeline operating conditions. These properties include the speed of sound, heat capacity, enthalpy, and entropy required for sonic nozzle and other metering calculations used to evaluate and calibrate orifice, turbine and ultrasonic meters. It is not recommended that the SGERG equation be used for calculating derived thermophysical properties.

Annex C
(informative)

Orifice plate assembly

Recommended orifice plate assemblies are illustrated below.



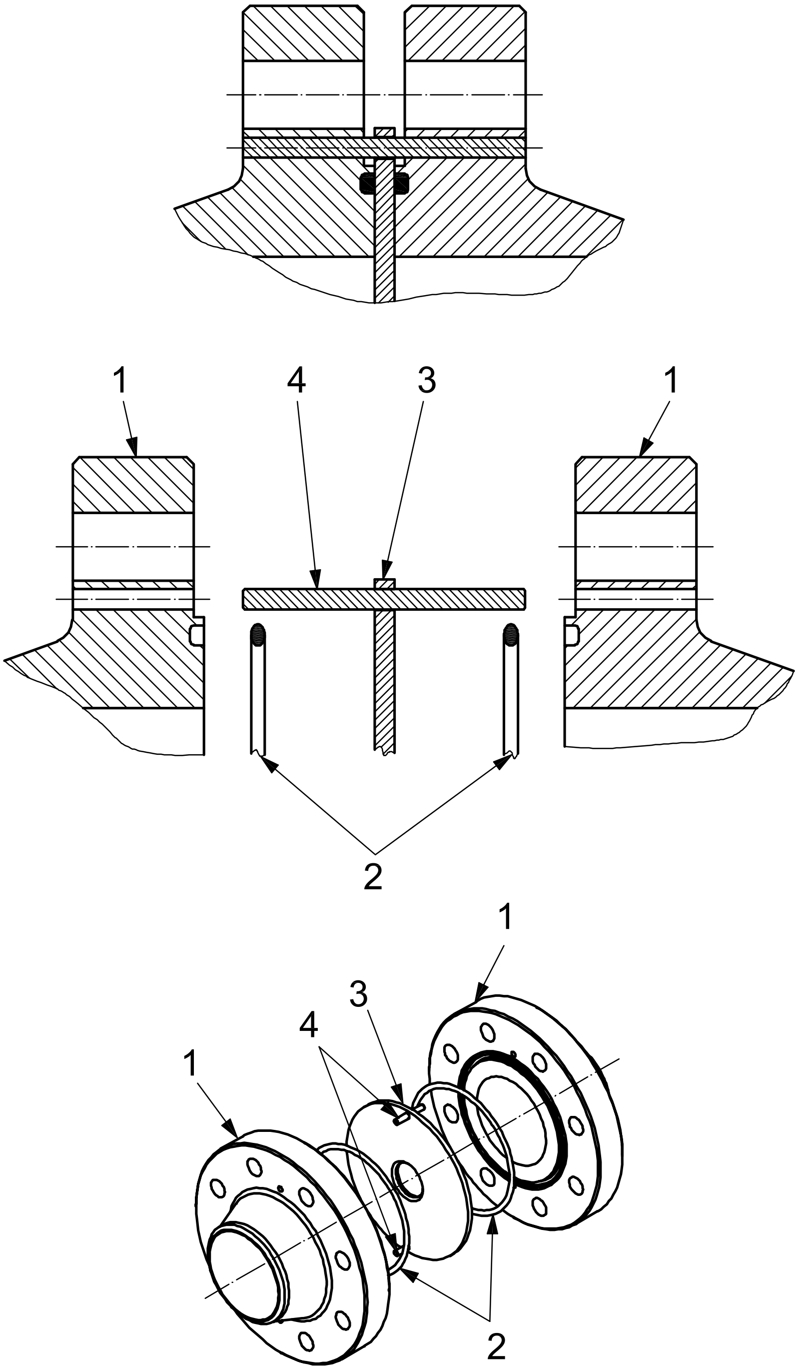
Key

1 raised face (RF) flange

2 gasket

3 orifice plate

Figure C.1 — Standard RF orifice flange assembly



Key

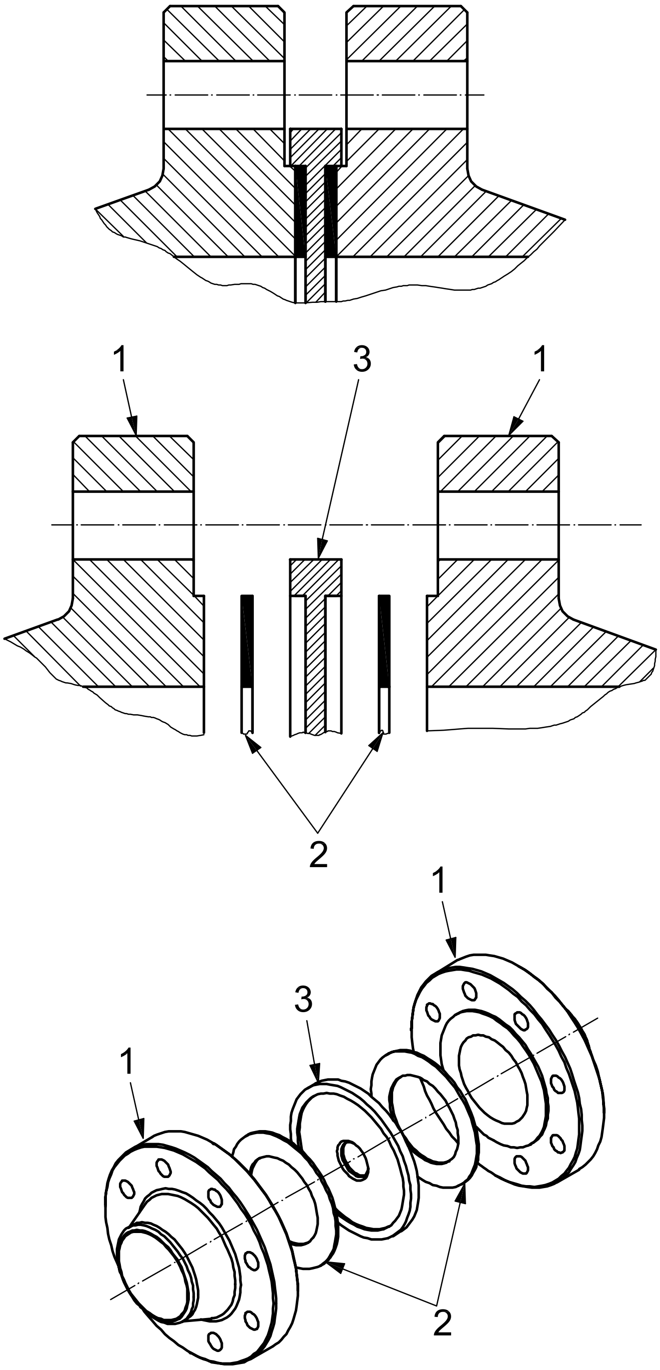
1 raised face (RF) flange

2 ‘O’ rings

3 orifice plate

4 dowel pins (for location)

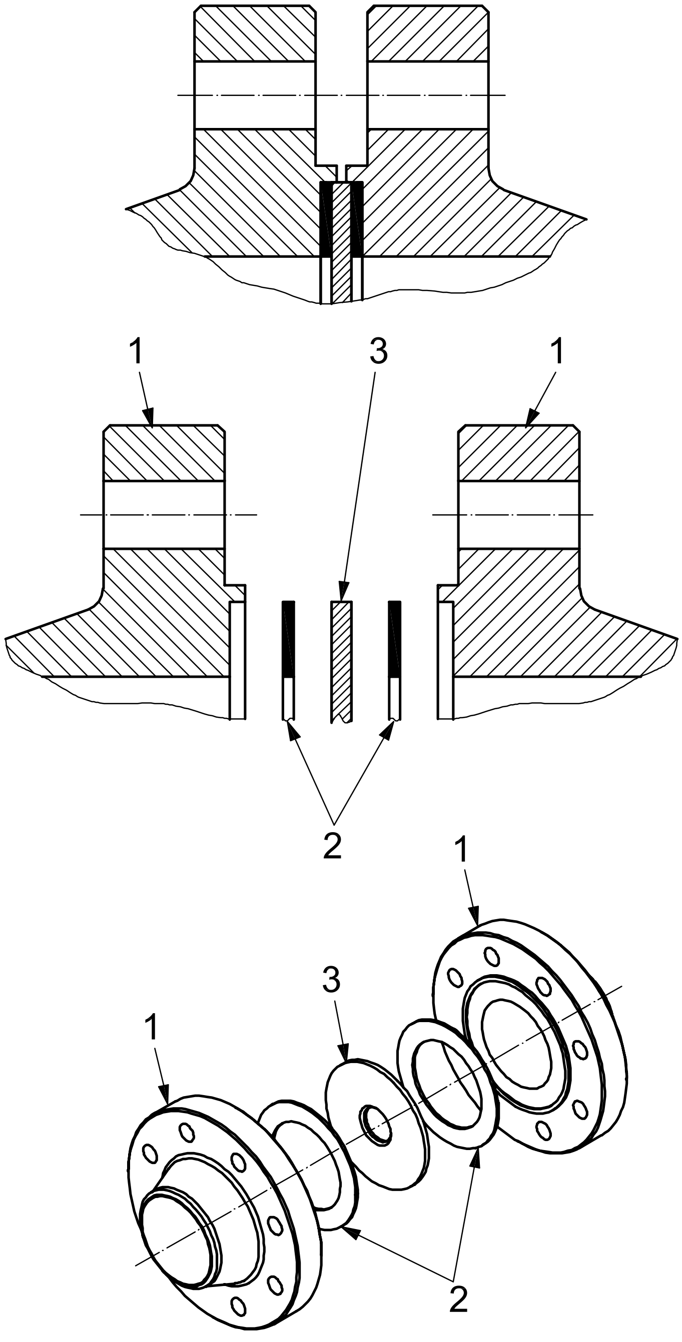
Figure C.2 — Dowelled orifice flange assembly



Key

1	raised face (RF) flange
2	gasket
3	orifice plate (locates on flange RF outside diameter)

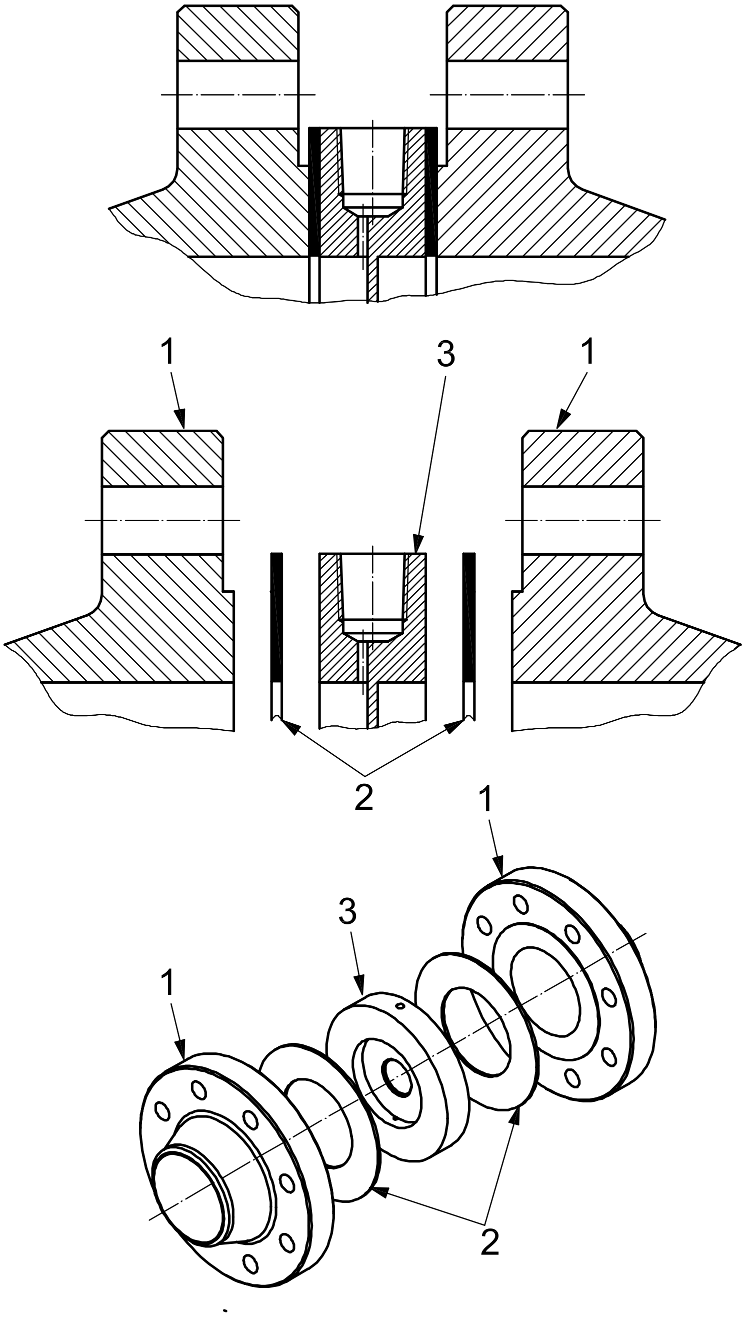
Figure C.3 — Orifice flange assembly



Key

1	raised face (RF) flange
2	gasket
3	orifice plates (locates in flange face recess)

Figure C.4 — Tongued faced orifice flange assembly



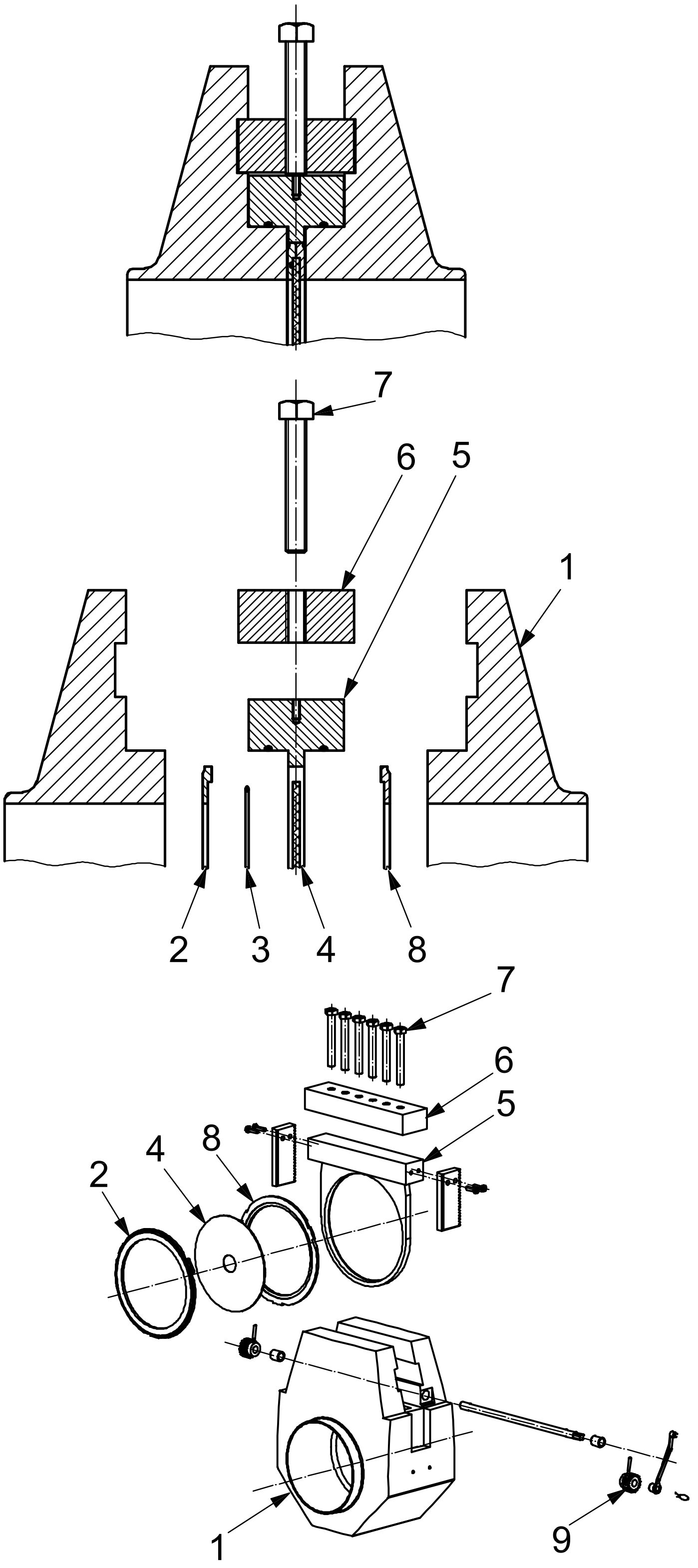
Key

1 raised face (RF) flange

2 gasket

3 integral carrier

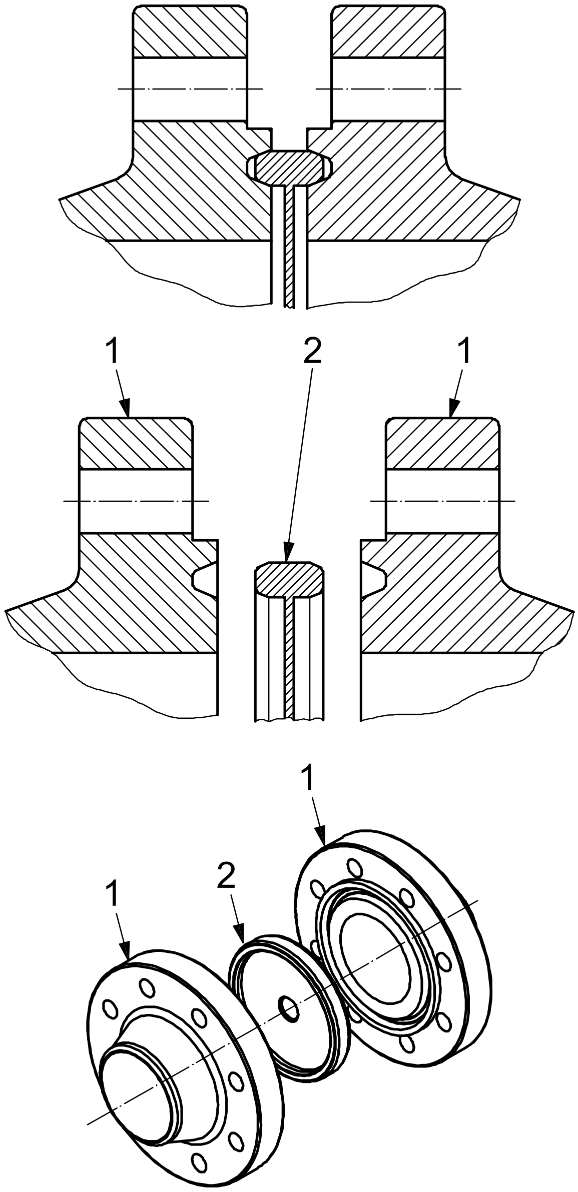
Figure C.5 — Integral carrier orifice flange assembly



Key

1	single chamber orifice body	4	orifice plate	7	locking nut
2	upstream sealring	5	sealing bar	8	downstream sealring
3	‘O’ ring	6	locking bar	9	winding mechanism to remove orifice plate

Figure C.6 — Single chamber orifice assembly

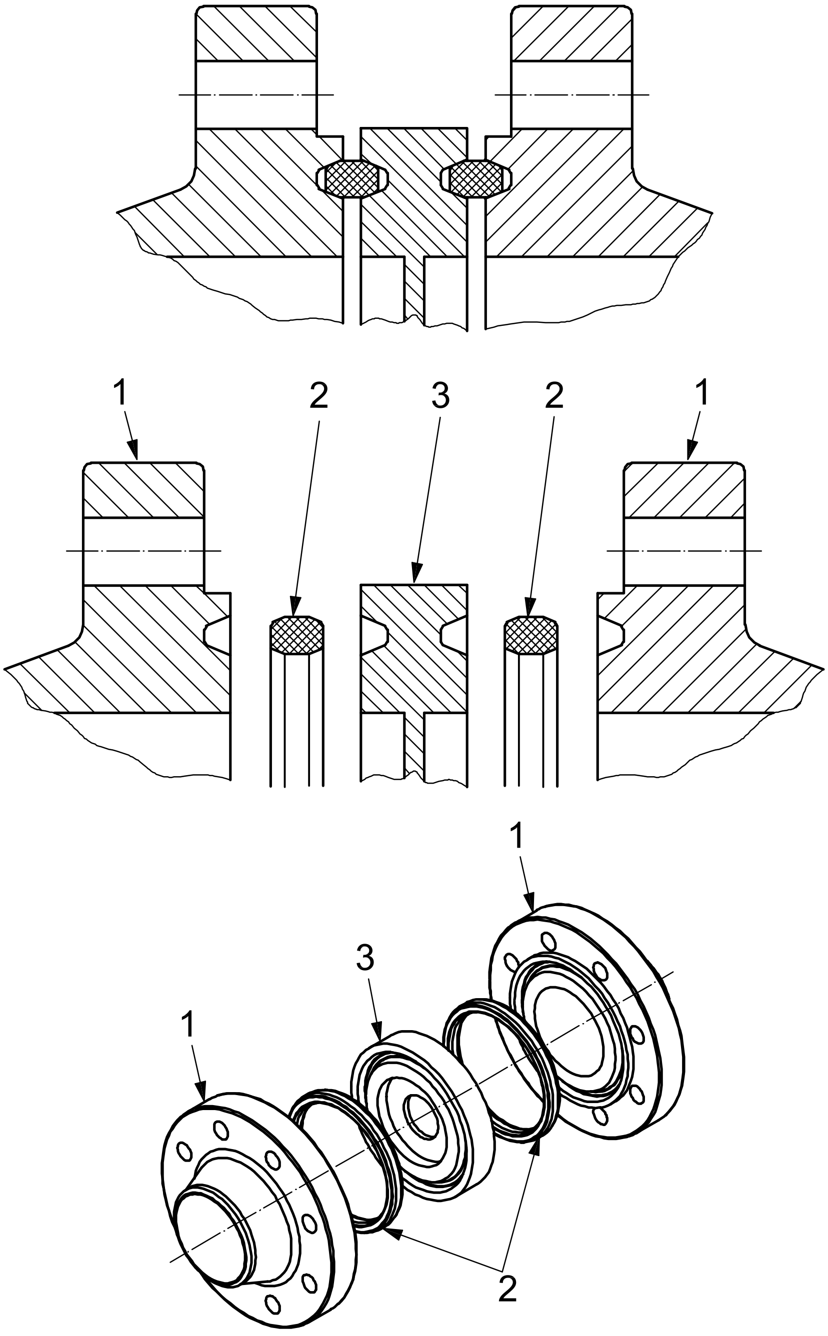


Key

1 ring type joint (RTJ) flange

2 orifice plate (integral male RTJ)

Figure C.7 — Standard RTJ orifice flange assembly



Key

1	ring type joint (RTJ) flange
2	ring type joint gasket
3	orifice plate (integral female RTJ)

Figure C.8 — Standard RTJ orifice flange assembly

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