TECHNICAL REPORT

ISO/TR 9464

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Guidelines for the use of ISO 5167-1:1991

Guide pour l'emploi de l'ISO 5167-1:1991

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Contents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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

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

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

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

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 Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 9464, which is a Technical Report of type 3, was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits,* Subcommittee SC 2, *Differential pressure methods.*

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Guidelines for the use of ISO 5167-1:1991

Section 1 - Guidance relating to specific clauses in ISO 5167-1:1991

1 Introduction

The objective of this Technical Report is to assist users of ISO 5167-1:1991. For convenience of use, it is divided into two Sections, as

Section 1 - Makes reference to specific clauses and subclauses in ISO 5167-1:1991, and provides guidance on details and interpretation of the requirements specified in ISO 5167-1:1991. The clause numbers in this Section have been arranged to be the same as the corresponding clause numbers in ISO 5167-1:1991.

Section 2 - Gives further information of a general nature, relevant to the application of ISO 5167-1:1991, but does not refer to specific clauses in ISO 5167-1:1991.

In Section 1, cross-reference is simplified by using the same clause and subclause numbering as in ISO 5167-1. To avoid confusing figures and tables of this Technical Report with those of the reference standard ISO 5167-1, references to the latter are made within square brackets, i.e. [...].

Some clauses of ISO 5167-1 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.

All quantities and constants quoted in this Technical Report are expressed in SI units.

1.1 ISO 5167-1

ISO 5167-1 is an International Standard for flow measurement based on the differential pressure generated by a constriction introduced into a circular conduit [ISO 5167-1, 5.1]. It presents a set of rules and requirements based on theory and experimental work undertaken in the field of flow measurement. Neither ISO 5167-1 nor this Technical Report give the detailed theoretical background and 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, it is practicable to achieve flow measurement within an uncertainty of approximately 1 per cent on the calculated rate of flow.

For more detailed description of the scope, reference should be made to [ISO 5167-1, clause 1].

1.2 Selection of the primary device

The constraints applicable to each of the primary devices need to be given proper consideration before determining the most suitable type for a particular application. Clause 4 of this Technical Report gives guidance. A final decision should not be made unless it is clear that, for a particular application, the appropriate requirements of the clauses and subclauses of ISO 5167-1 listed in column 1 of table 1 of this Technical Report can be fulfilled.

These paragraphs will also form the basis for preliminary design. [ISO 5167-1, Clauses 3 and 4] give definitions and symbols.

1.3 Detail design

The information necessary for detailed design, manufacture and final check is specified in the clauses and paragraphs of ISO 5167-1 listed in column 2 of table 1.

1.4 Computation

Operation of a measuring system, once installed, requires several computations to establish the resultant flow-rate. 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. The equations to be used are given in the clauses and sub-clauses of ISO 5167-1 listed in column 3 of table 1.

1.5 Secondary instrumentation

Secondary instrumentation is not covered by ISO 5167-1 but Section 2 of this Technical Report makes reference to ISO 2186, which will be required.

2 Normative references

No comments on this clause.

3 Definitions

3.1 Pressure measurement

No comments on this clause

3.2 Primary devices

No comments on this clause

3.3 Flow

No comments on this clause

4 Symbols and subscripts

For explanation of the symbols and definitions, reference is made to [ISO 5167-1, clause 4.1] which is based on ISO 4006.

5 Principle of measurement and computation : Examples

5.1 Principle of the method of measurement

No specific comments on this clause, but note that throughout this guide, ρ_2 and ε_2 may be used as alternatives to ρ_1 and ε_1 .

5.2 Determination of the diameter ratio

Refer to annex A.

5.3 Determination of the rate of flow

Refer to annex A.

5.4 Determination of the density

For more details on density measurement, see Part 2.

For more details on density computation, see 6.2.

5.4.1 No specific comments on this clause.

Table 1 : Reference clauses in ISO 5167-1

	1. Selection	2. Design	3. Computation
General	1, 2, 5.1	3.3.6	3.3, 5.1, 5.3, 11
Fluid and flow conditions	6.2, 6.3	5.4	5.4.3
Primary device	6.1	3.2, 6.1.3	
Pipe work	7.1	7.1 and 7.5 or 7.6	7.5.1.2
Minimum straight lengths	7.2 or 7.4	7.2	
Orifice plates	8.3.1, 8.4	8.1, 8.2	8.3.2, 8.3.3
ISA 1932 nozzles	9.1.6.1, 9.1.8	9.1.2 to 9.1.5	9.1.6.2, 9.1.6.3, 9.1.7
Long radius nozzles	9.2.5.1, 9.2.7	9.2.1 to 9.2.4	9.2.5.2, 9.2.5.3, 9.2.6
Classical Venturi tubes	10.1.1, 10.1.5, 10.1.9.2	10.1.2 to 10.1.4	10.1.5 to 10.1.8
Venturi nozzles	10.2.4.1, 10.2.6	10.2.1 to 10.2.3	10.2.4.2, 10.2.4.3, 10.2.5.1, 10.2.5.2

5.4.2 Temperature measurement

Within the limits of application of the international standard [ISO 5167-1, 5.4.2] it may be assumed that the downstream and the upstream temperatures of the fluid are the same. For very accurate measurements it is advisable that the actual temperature at the upstream plane is measured under flowing conditions using a temporarily installed temperature probe.

If the fluid being measured is a gas and high accuracy is required and there is a large pressure loss between the upstream pressure tapping and the location of the temperature measuring device downstream of the primary device, then it is necessary to calculate the upstream temperature from the temperature measured downstream. Experimental work has shown that an isenthalpic expansion is a reasonable approximation for orifice plates. Further work is required to check its correctness for other primary devices. To perform the calculation, the pressure loss $\Delta\omega$ should be calculated from ISO 5167-1, 8.4, 9.1.8, 9.2.8, 10.1.9.2, or 10.2.6, The corresponding temperature drop from the upstream tapping to the downstream temperature measurement location, ΔT, can be evaluated given the rate of change of T with respect to p at constant enthalpy:

$$\Delta T = \left.\frac{\partial T}{\partial p}\right|_H \Delta\omega$$

$$= \frac{R_g T^2}{p c_p} \left.\frac{\partial Z}{\partial T}\right|_p \Delta\omega$$

where T is the absolute temperature, R_g is the universal gas constant, c_p is the heat capacity at constant pressure and Z is the compressibility factor.

In the 1980 edition of ISO 5167-1 it was stated that if the measured fluid is a gas an isentropic expansion should be assumed through the primary device. This is now known to be incorrect. The complete process includes both isentropic and isenthalpic expansions between upstream of the primary device and the location at which the static pressure recovery is completed.

REFERENCE : "Performance Equations for Compressible Flow Through Orifices and Other Δp Devices : A Thermodynamic Approach", AIChe Journal, March 1986, Vol. 32, No 3.

5.4.3 No specific comments on this clause.

5.4.4 Temperature of primary device

This assumption is made when correcting the primary device dimensions for temperature changes when very accurate flow measurement is required.

6 General requirements for measurements

6.1 Material and manufacture

Table 2 whilst not exhaustive, lists materials most commonly used for orifice plate manufacture.

Table 2 : Commonly used steels for orifice plate manufacture

	AISI	BS970	AFNOR	DIN
Stainless steels	304 316	304-S15 316-S16	Z6CN18-09 Z6CND17-11	1,430 1 1,440 1
High elastic limit stainless steel	420	420-S37	Z30C13	

Table 3 gives the mean linear expansion coefficient, elasticity modulii and yield stresses for the materials of table 2 according to their AISI designation.

Table 3 : Characteristics of commonly used steels

AISI designation	10^{-6} Mean Linear Expansion Coefficient between 0 and 100°C in K^{-1}	10^{9} Elasticity Modulus in Pa	10^{6} Yield Stresses in Pa
304	17	193	215
316	16	193	230
420	10	200	494

NOTE : the figures given in table 3 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.

6.1.1 No specific comments on this clause.

6.1.2 No specific comments on this clause.

6.1.3 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 shall be taken into account in the computation of diameter ratio and flowrate using the following equation, assuming there is no restraint due to the mounting :

$$d = d_0 \left[1 + \lambda_d (T - T_0)\right] \quad (1)$$

where d : primary device diameter in flowing conditions ;

d_0 : primary device diameter at reference temperature ;

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

T : primary device temperature in flowing conditions ;

T_0 : 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 to allow for the change in "d" due to temperature variation (see ISO 5167-1, 11.2.2.3). An initial calculation may show that this additional uncertainty is small enough to be considered negligible.

6.2 Nature of the fluid

6.2.1 No specific comments on this clause.

6.2.2 Universal gas constant

The value indicated for the universal gas constant

6.2.3 Ascertaining density and viscosity of the flowing fluid

Annex B lists references for physical properties whilst annex C gives specific information for natural gases. They provide data relating to the dependence of density and viscosity on temperature and pressure.

For gases, several methods can be used to calculate density from pressure and temperature :

(a) by using tables, or equations of density versus pressure and temperature.

(b) when the molar mass M of the fluid is known, by first computing the compressibility factor Z_1, in flowing conditions, and then the density using the equation :

$$\rho_1 = \frac{p_1 M}{R T_1 Z_1} \qquad (2)$$

where R is the universal gas constant (= 8,314 50 $J.mol^{-1}.K^{-1}$)

(c) when the density at standard conditions, ρ_R is known (from calculation or measurement) for given conditions of pressure and temperature, p_R and T_R, by first computing the compressibility factors Z_1 and Z_R and then using the equation :

$$\rho_1 = \rho_R \frac{p_1 T_R Z_R}{p_R T_1 Z_1} \qquad (3)$$

For complex mixtures such as natural gas, the two latter methods are generally the only practicable ones. Annex C gives a list of the main existing methods of computation of the compressibility factor Z for a number of gas mixtures.

6.3 Flow conditions

6.3.1 No specific comments on this clause.

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.

7 Installation requirements

7.0 Inspection equipment

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.

7.1 Pipe sections adjacent to the primary device

For additional requirements for orifice plates, nozzles and Venturi nozzles, refer to [ISO 5167-1, 7.5]. For classical Venturi tubes, refer to [ISO 5167-1, 7.6].

For pipe roughness criteria, refer to the following paragraphs of [ISO 5167-1 : 8.3.1, 9.1.6.1, 10.2.4.1].

7.1.1 No specific comments on this clause.

7.1.2 No specific comments on this clause.

7.1.3 No specific comments on this clause.

7.1.4 No specific comments on this clause.

7.1.5 Internal diameter of the measuring pipe

The value of "D", corrected for thermal expansion (see below), is that used for the computation of the diameter ratio β. This value of "D" is also used as the basis for establishing the circularity of the pipe over a length of at least 2 D upstream and downstream of the primary device (see 7.5.1).

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

Figure 1 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 per cent, as the overall tolerance is 0,3 per cent (see 7.5.1).

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, referred to as the reference or calibration temperature) the expansion or contraction of the pipe shall be taken into account in the computation of diameter ratio and flow-rate, using the following equation:

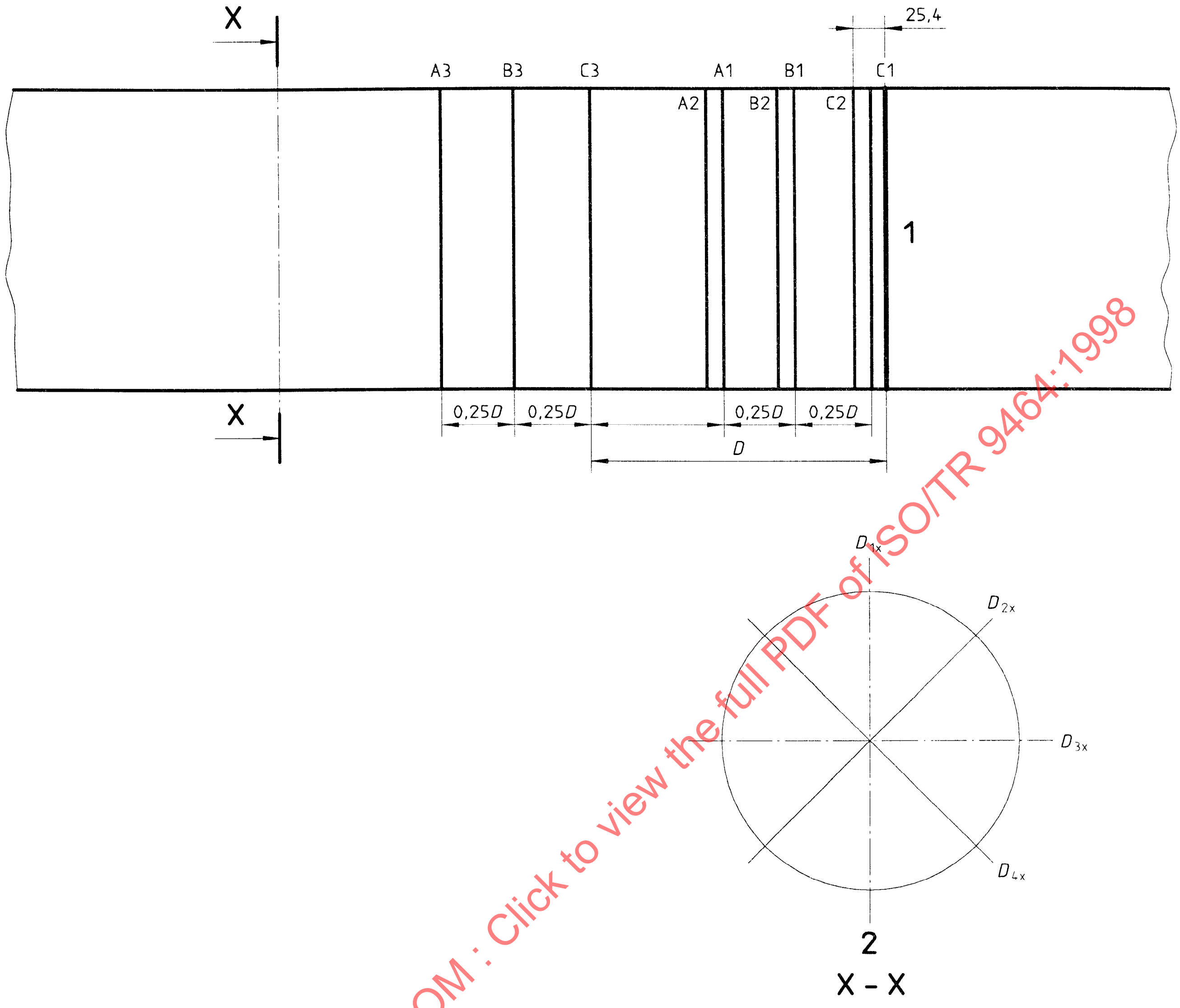
$$D = D_0 \left[1 + \lambda_D (T - T_0)\right] \qquad (4)$$

where :

D : diameter of the pipe in flowing conditions ;
D_0 : diameter of the pipe at reference temperature ;
λ_D : mean linear expansion coefficient of the pipe material ;
T : pipe temperature in flowing conditions ;
T_0 : reference or calibration temperature.

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

Dimensions in millimetres



1. Plate upstream face
2. Cross section X

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 1 : Measurement of internal diameter D

Where automatic temperature correction is not required in the flow computer the uncertainty for "D" included in the overall uncertainty should be increased to allow for the change in "D" due to temperature variation (see 11.2.2.3). An initial calculation may show that this additional uncertainty is small enough to be considered negligible.

7.1.6 No specific comments on this clause.

7.1.7 No specific comments on this clause.

7.1.8 The requirements in [7.1.8] where drain or vent holes are located near to the primary device are illustrated in Figure2. It should be realised that the flowing fluid may cause deposition, corrosion or erosion of the inner wall of the pipe. The installation may therefore not comply with the requirements of ISO 5167-1. Users should consider internal inspection of the pipe at intervals appropriate to the conditions of application.

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

7.2 Straight lengths

7.2.1 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 covered by [ISO 5167-1, table 1 or 2] but inside the limits of the standard, it is reasonable practice to interpolate linearly between the nearest table values of the closest diameter ratio and to round up to the next integer number for [table 1] and to the next half number for [table 2].

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 shall comply with the minimum requirements for upstreamstraight lengths as specified in [ISO 5167-1, 7.2 and Tables 1 and 2].

7.2.2 No specific comments on this clause.

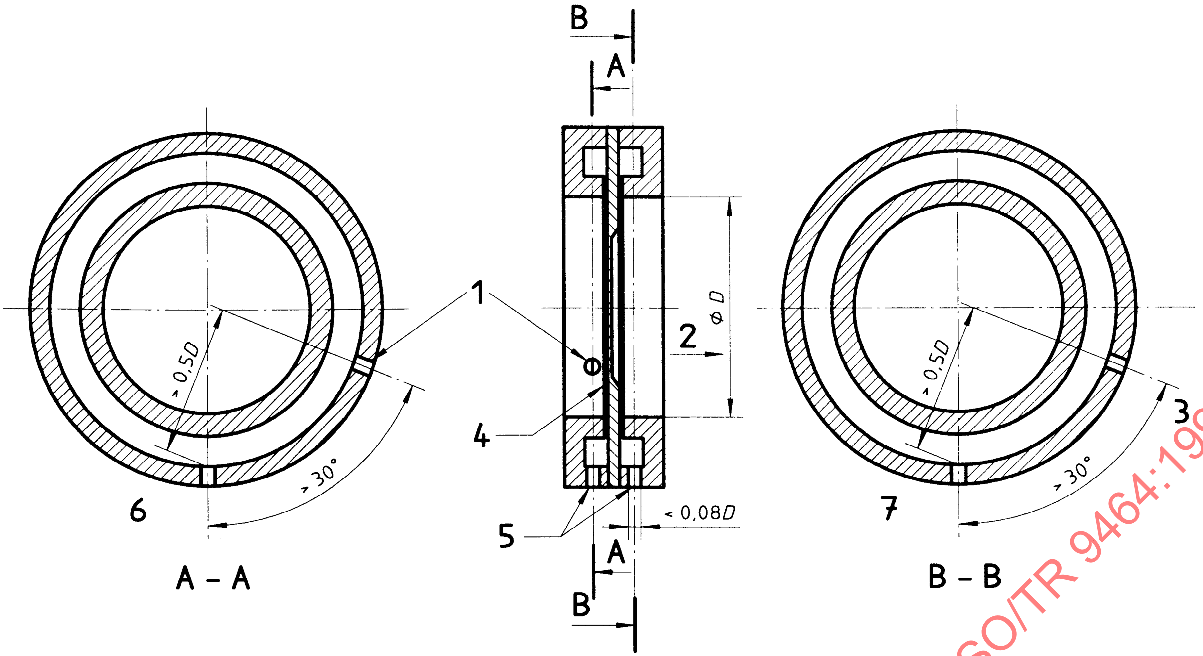
7.2.3 No specific comments on this clause.

7.2.4 No specific comments on this clause.

7.2.5 No specific comments on this clause.

7.2.6 No specific comments on this clause.

7.2.7 No specific comments on this clause.



1. Pressure tapping
2. Flow direction
3. Pressure tapping
4. Orifice plate
5. Origin holes and /or vent holes
6. Cross section A-A
7. Cross section B-B

Figure 2 : Location of drain holes and/or vent holes

7.2.8 Several upstream fittings

7.2.8 (a) No specific comments on this clause.

7.2.8 (b) The requirements of this clause define the minimum straight length between the first and second fittings in series, upstream of the primary device, except for two or more 90° bends, where the third and fourth columns of [ISO 5167-1, table 1 or 2] shall apply.

[Clause 7.4] allows the requirements of [ISO 5167-1, table 1 or 2] to be ignored if it can be demonstrated "that the flow conditions immediately upstream (of the primary device) sufficiently approach those of a fully developed profile and are free from swirl" [ISO 5167-1, 7.1.3].

Consideration should be given to disturbances in the flow conditions caused possibly by additional upstream devices before the second fitting eg. a globe valve as the third fitting would need to be sufficiently remote from the second fitting so as to present immediately upstream of this second fitting a flow condition sufficiently close to a fully developed and swirl free flow. No specific guidance is given in ISO 5167-1 but it is recommended that the separation of such fittings comply with the requirements of [ISO 5167-1, 7.2.8 (b)].

[ISO 5167-1, 7.2.8 (b) Note 10] also states that in the case of several 90° bends, the data in tables 1 and 2 can be applied, whatever the lengths between two consecutive bends.

7.3 Flow conditioners

Introduction

The use of straightening devices is only recommended where it is not practicable to install the minimum upstream straight lengths defined in [ISO 5167-1, 7.2]. Nevertheless, it should be noted that although swirl is generally not detectable in visual inspection of the pipe, it has a greater effect on measurement than any other fluid dynamic mechanism, and may persist over considerable distances. The use of straight lengths of pipe to eliminate swirl is of question, especially in large pipe sizes as the degradation of induced swirl from common pipe components may not be sufficient to ensure fully developed profiles within the minimum lengths required in the tables.

The measurement of fluid flow by means of the primary devices described in ISO 5167-1 requires "that the flow conditions immediately upstream sufficiently approach those of a fully developed profile and are free from swirl" (see [ISO 5167-1, 7.1.3]). ISO 5167-1 does permit the use of flow straighteners in two situations :

(a) where the fittings are not defined in [table 1 and 2] ;

(b) where a large diameter ratio primary device is to be used, the installation of a flow conditioner may allow shorter upstream lengths to be specified.

Scope and field of application

For a given fitting, a flow straightener may reduce the upstream length necessary to achieve a good velocity profile, or may improve the velocity profile for a given straight length.

The distance between the flow straightener and the primary device, for no additional uncertainty, is given in [ISO 5167-1, 7.3.1]. The standard does not define any relaxation permitted for any additional uncertainty, as is defined in [7.2.4] relating to the required straight lengths, although it should be noted that the DOWNSTREAM requirements may affect uncertainty.

7.3.1 No specific comments on this clause.

7.3.2 Type of straightening devices

New types of flow conditioners have been developed during recent years. These are not dealt with in ISO 5167-1 : 1991, which specifies five types of flow straigthener :

Other types of flow straighteners are not specified in ISO 5167-1 but their use would be permitted provided the requirements of [ISO 5167-1, 7.4] are met. Refer to ISO 7194 for other types of flow straightener and velocity profile measurement techniques.

7.3.2.1 Type A : Zanker

Flow straighteners which give better performances often combine the characteristics of two simple designs. Of these types, the Zanker straightener combines the "Honeycomb" and "Perforated Plate" (see also type B). Its pressure loss is approximately 5 times the dynamic pressure (ie. the loss of energy is about 5 times the kinetic energy due to flow velocity). It removes both swirl and velocity profile asymmetry.

7.3.2.2 Type B : Sprenkle

This is "Perforated plate" type and specified by :

(a) the thickness of the plate ;
(b) the ratio of the restricted flow area to the cross-sectional area of the pipe ;
(c) the pitch of the holes ;
(d) the bevel angle of the holes.

The spacing and diameters of the perforations are not designed to distibute the velocity profile in line with a fully developed velocity profile.

> NOTE : (c) is not defined in ISO 5167-1. Nevertheless it is recommended the holes to be evenly distributed over the whole cross-sectional area of the pipe.

The Sprenkle straightener specified by ISO 5167-1 incorporates a pressure loss of about 15 times the dynamic pressure. It is very efficient in removing profile asymmetry.

> NOTE : dimension "d" is shown in some versions of [ISO 5167-1, figure 1 and figure 2] as the diameter of the bevel; it should be the diameter of the perforated hole.

7.3.2.3 Type C : Tube Bundle

These are specified by :

a) the length of the bundle ;
b) the diameter of the tubes ;
c) the thickness of the tubes ;
d) a minimum number of tubes.

(c) is not specified in ISO 5167-1. It should provide sufficient strength whilst not unduly restricting the flow.

The pressure loss of the tube bundle flow straighteners as specified in ISO 5167-1 is usually low. This device eliminates practically all swirl but has little effect on the velocity profile.

7.3.2.4 Type D : AMCA

These are specified by :

a) the length of the blades ;
b) the distance between blades ;
c) the thickness of the blades.

(c) is not specified in ISO 5167-1. It should provide sufficient strength whilst not unduly restricting the flow.

The pressure loss of the AMCA flow straighteners as specified in ISO 5167-1 varies with the thickness of the blades, but is usually less than the dynamic pressure. This device eliminates practically all swirl but has little effect on the velocity profile.

7.3.2.5 Type E : Etoile

These are specified by :

a) the length of the blades ;
b) the distance between blades ;
c) the thickness of the blades.

(c) is not specified in ISO 5167-1. It should provide sufficient strength whilst not unduly restricting the flow.

The pressure loss of the Etoile flow straighteners as specified in ISO 5167-1 varies with the thickness of the blades, but is usually less than the dynamic pressure. This device eliminates practically all swirl but has little effect on the velocity profile.

7.4 No specific comments on this clause.

7.5 Additional specific installation conditions

7.5.1 Circularity of the pipe

To meet the given specifications, the pipe lengths adjacent to the primary device may have to be specially machined. As no significant diameter difference must exist between the various lengths of the measuring pipe (ISO 5167-1, 7.5.1.2 and 7.6.1.2]) the ones adjacent to the primary device may have to be made of a thicker pipe so that the proper 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.

7.5.1.1 Inspection of the upstream length of the measuring pipe

A check shall be made so that, over a length of 2 D upstream of the primary device, any diameter measured in any plane does not vary by more than 0,3 per cent from the mean diameter previously obtained (see 7.5.1.2).

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

- 0.5D and 2 D for orifice plates with D and D/2 pressure tappings and long radius nozzles ;

- D and 2 D for orifice plates with corner and flange tappings, ISA 1932 nozzles and Venturi nozzles.

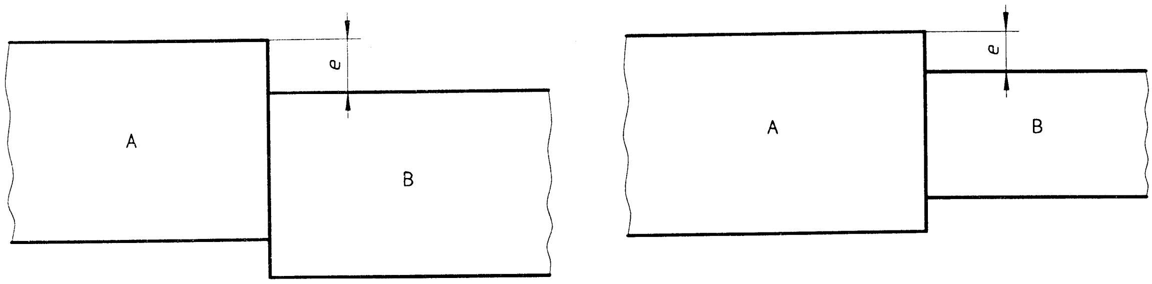
In those cases where few cross sections are used, one should check that no systematic variation of the measured diameters can be found.

7.5.1.2 No specific comments on this clause

7.5.1.3 Steps between pipe lengths

It must be noted that measuring the internal diameter at the ends of each pipe length (see figure 3) is not sufficient to ensure conformity with [ISO 5167-1, 7.5.1.3]. In addition, a check should be made to determine that the different pipe lengths are properly mounted and do not have a step in excess of ISO 5167-1 limits when connected together.

The use of self centering pipe joints is recommended. Consideration should be given to the use of tongue and groove 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 0,3% D, where D is the mean pipe diameter computed over 0,5 D - see Fig 1

Figure 3 : 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 shall 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 shall be measured while uncoupled. To determine the position of a reference point in space on the extension of a plane (figure 4(a) left hand side), the plane shall be extended by a sliding reference piece.

Once coupled the distance between two reference points of a pair shall 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 centering, then the external reference points are not needed. Careful measurement of the pipe bore and centering device will produce equally accurate results.

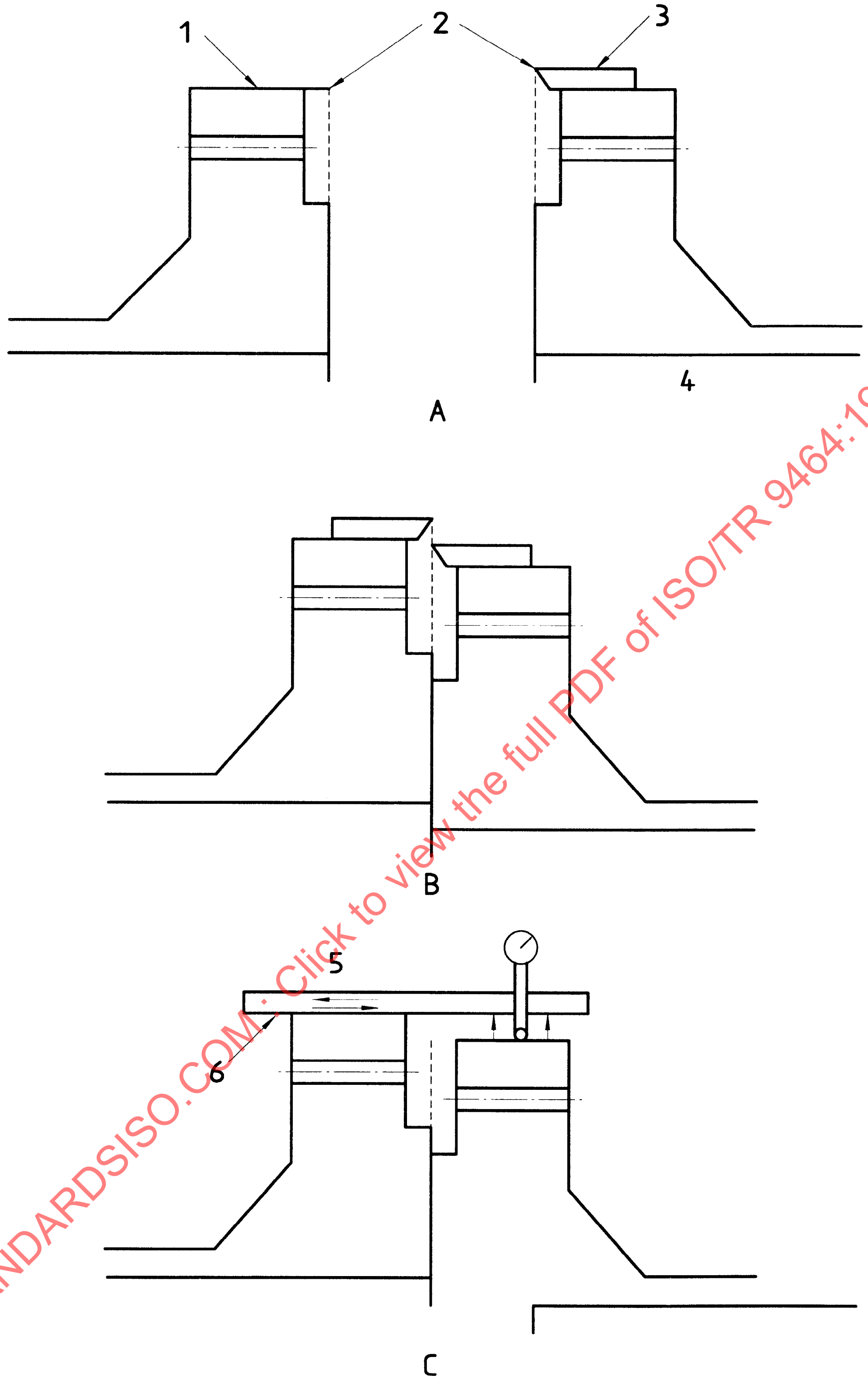
Examples are given in figure 4.

7.5.2 Location of the primary device and rings

7.5.2.1 No specific comments on this clause.

7.5.2.2 No specific comments on this clause.

7.5.2.3 Table 4 and figure 5 shows the maximum distance e_X between the centre-line of the orifice and the centre-line of the pipe on the upstream and downstream sides, as a function of a diameter ratio β and of the pipe diameter D, for no additional error.



A. Some possible constructions of reference points
B. Direct measurement of distance between reference points
C. Indirect measurement of distance between reference points

1. Smooth plane
2. Reference points
3. Fixed reference piece
4. Inside pipe wall
5. Sliding reference piece
6. Smooth plane

Figure 4 : Measurement of steps between pipe lengths

Table 4 : Maximum distance e_x between the orifice centre-line and the centre-lines of upstream and downstream pipe sections in mm

β	D in 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

7.5.3 Fixing and gaskets

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

To meet the requirements of centering 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, allowing flow measurements to be highly reproducible.

Other arrangements use pairs of flanges (slip-on or weld-on) or special proprietary fittings. Figure 6 illustrates recommended arrangements for orifice plates, which are equally valid for nozzles. When using flanges, it is good practice to provide a pair of Jack screws in diametrically opposite positions.

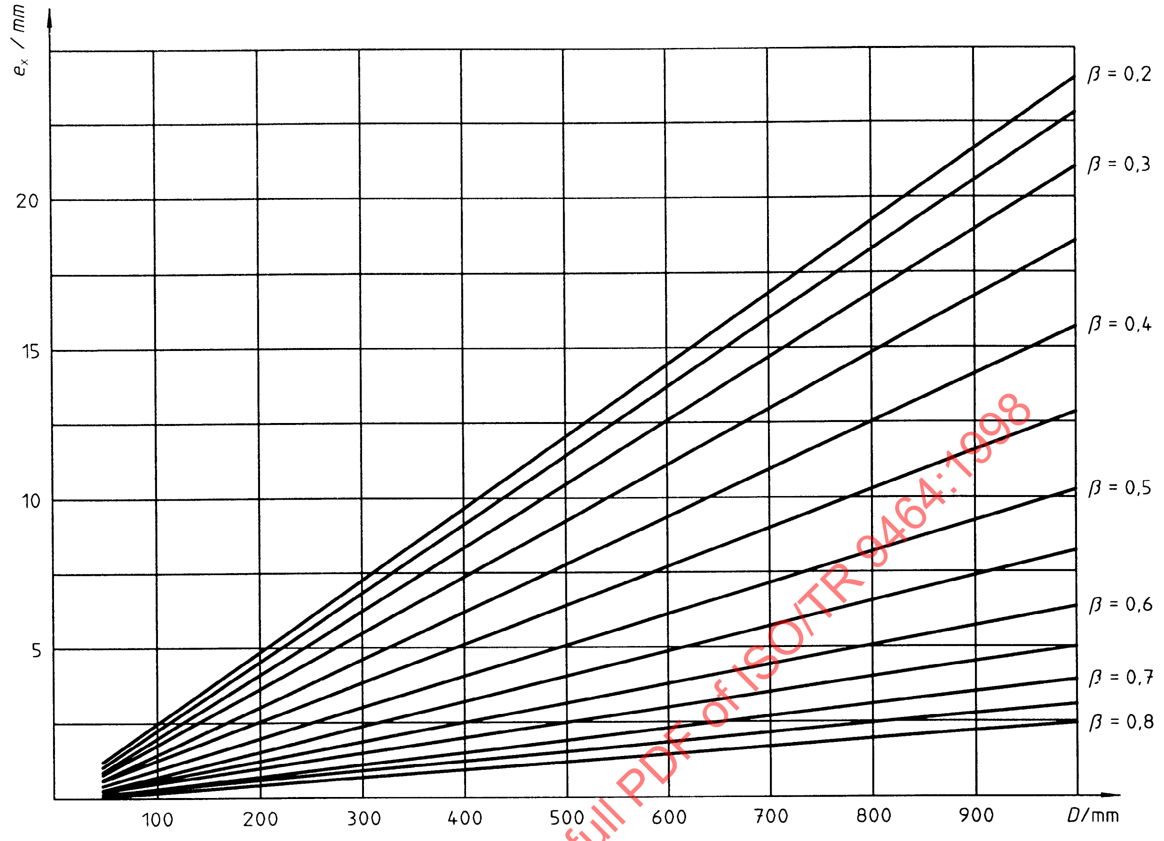


Figure 5 : Maximum distance e_x between orifice (or nozzle) centre-line and the centre-lines of upstream and downstream pipe sections as a function of the pipe diameter D and the diameter ratio β

Gaskets are cheap and easy to produce but they must not be allowed to protrude into the pipe at any point. It is recommended that gaskets are not thicker than 0,03 D. 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-centering and sealing) always produce a gap and a recess between sections. Provided the gap does not exceed that which is specified in the flange standard, flow measurement will not be affected. Tests have shown that this is true when the gap does not exceed 13 mm.

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 5167-1, 8.2.1.3].

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 allowing easy withdrawal and re-insertion of orifice plates to known tolerances may be the only practicable solution.

REFERENCES : HF ZEDAN and RG TEYSSANDIER, "The effect of recesses on the discharge coefficient of a Flange Tapped Orifice Plate", ASME Symposium on Mass Flow Measurement, 1984.

7.6 Additional specific installation requirements for classical Venturi tubes

7.6.1 Circularity of the pipe

7.6.1.1 No specific comments on this clause.

7.6.1.2 No specific comments on this clause.

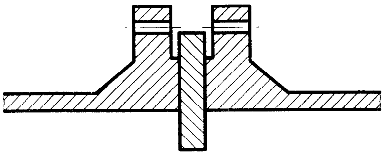
8 Orifice plates

8.1 Description

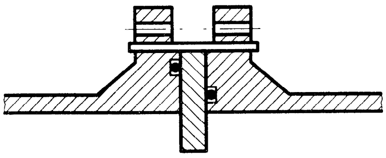
8.1.1 General shape

8.1.1.1 No specific comments on this clause.

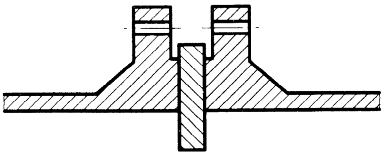
8.1.1.2 No specific comments on this clause.



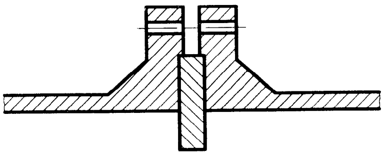
Orifice plate between raised face flanges; centering by flange bolts; sealing by gaskets; inaccurate.



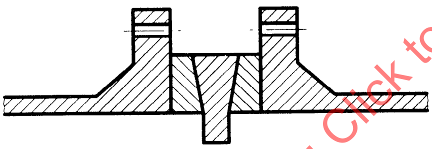
Orifice plate between raised face flanges; centering by dowel pins; sealing by O-rings or gaskets; used generally.



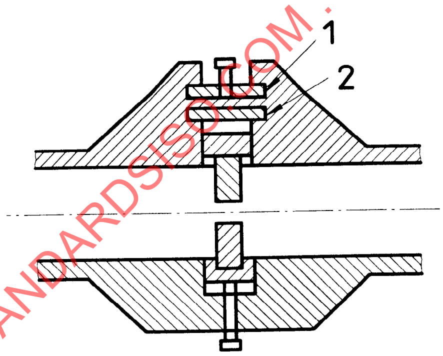
Orifice plate between flanges; centered on raised face; very accurate centering possible with great care in manufacture.



Orifice plate between flanges; centered in chambered faces; very accurate centering possible with great care in manufacture.



Sandwiched orifice plate section with integral tappings; small and medium sized meter runs with corner or flange tappings; very accurate centering possible with great care in manufacture.



Flanges or weld mounted orifice plate fitting; plate with fixed seal inserted through slit; also available with lockchamber for changing under pressure; accurate centering possible with great care in manufacture.

1. Clamping bar
2. Sealing bar

Figure 6 : Examples of orifice plate fittings

8.1.1.3 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 onto the orifice plate which would cause the limit of 0,5% slope given in [ISO 5167-1, 8.1.2.1] 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 then return to the original 0,5% slope.

Thirdly, it is necessary to ensure that if it is possible for the 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. The single or double chamber mounting devices are satisfactory. When mounting orifice plates between standard flanges, the flanges must 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 5167-1, 8.1.1.3], no additional uncertainty will result. Theoretical and experimental research (see reference at the end of 8.1.2.1) indicates that the maximum change in discharge coefficient for a 1% slope is 0,2%. Therefore orifice plates that comply with the 0,5% slope specified in [ISO 5167-1, 8.1.2.1] can be allowed to deform an additional 0,5% slope (i.e. 0,1 % change in discharge coefficient) whilst still meeting the requirements of this clause. Table 5 tabulates the plate thickness to pipe 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 5 : Minimum E/D′ ratios for orifice plate manufacture in AISI 304 or AISI 316 stainless steel

β	Δp for maximum flowrate in 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 5 is based on the use of the following expression when 100 $\Delta q_m/q_m$ = 0,1 and $E^* = 193 \times 10^9$ Pa.

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

where e = % change in discharge coefficient,

a = β (13,5 - 15,5 β),

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

E* = modulus of elasticity of plate material,

D' = plate support diameter (this may differ from pipe bore D).

E = Plate thickness

REFERENCES : R. NORMAN, MS RAWAT, P JEPSON : "Buckling and eccentricity effects on orifice metering accuracy", 1983, International Gas Research Conference.

For the third point the maximum differential pressure (which can be greater than Δp in table 5) 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 pressurising the metering section before putting into service.

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

$$\frac{E}{D'} > \sqrt{\frac{\Delta p}{\sigma_y}(0.681 - 0.651\beta)} \qquad (6)$$

where Δp : maximum differential pressure determined by the designer in Pa ;

σ_y = yield stress of the orifice plate material in Pa.

NOTE : for stainless steel σ_y = 300 x 10^6 Pa but it is advisable to use a figure of 100 x 10^6 for design purposes.

The thickness of orifice plate chosen should be whichever is the greater when determined by equations 5 and 6, but should not exceed the 0,05 D required in [ISO 5167-1, 8.1.4.3]. Should the calculations indicate that E required is greater than 0,05 D, the designer should either reduce Δp or else introduce a stronger material.

EXAMPLE :

- Equation 5 :

β = 0,2
E* = 193 x 10^9 Pa
Δp = 50 000 Pa (0,5 bar)

gives E/D' > 0,013 from equation 5 or Table 5.

- Equation 6 :

β = 0,2
σ_y = 300 x 10^6 Pa for stainless steel, but for design purposes it is advisable to use
σ_y = 100 x 10^6 Pa
Δp = 100 000 Pa (1 bar) - anticipated

gives E/D' > 0,023

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

8.1.2 Upstream face

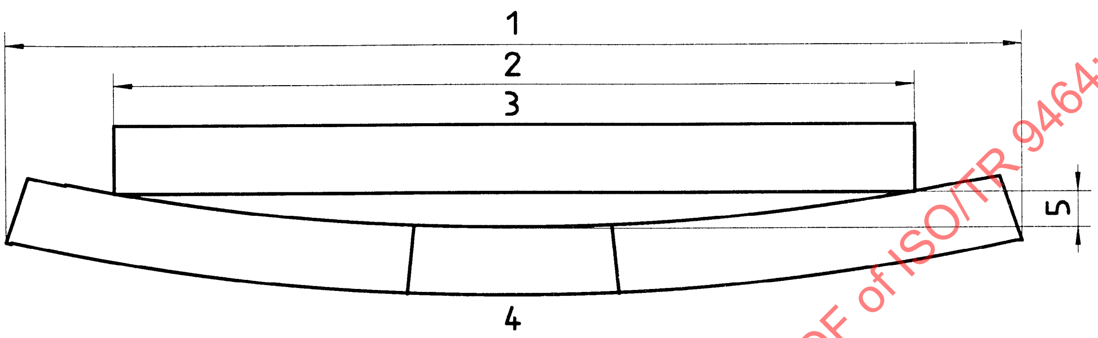
8.1.2.1 Table 6 gives values of deflection of the inner edge of the orifice corresponding to the 0,5% slope for various pipe diameters and diameter ratios, β , assuming the deformation is rectilinear.

Table 6 : Plate flatness tolerances

β	Nominal diameter of the measuring pipe in mm										
	50	100	200	300	400	500	600	700	800	900	1000
	Maximum deflection h in mm 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

Deformation of the plate is not necessarily uniform and can be localised eg. near the orifice or the periphery. ISO 5167-1 requires that the slope between any two points does not exceed 1% slope under flowing conditions. If the recommendation above for a 0,5% slope with no differential pressure is achieved, it is unlikely that this condition will arise.

The upstream face of the plate should be flat when the plate is installed in the pipe with zero differential pressure across it. Provided that it can be shown that the method of mounting does not distort the plate, this flatness may be measured with the plate removed from the pipe. Under these circumstances the plate may be considered to be flat when the maximum gap between the plate and a straight edge laid across length D, at any diameter bisecting the centre line is less than 0.005 (D-d)/2 - see Figure 7, i.e. the slope is less than 0,5% when the orifice plate is examined, prior to insertion into the meter line. As can be seen from the Figure 7, the critical area is in the vicinity of the orifice bore. The uncertainty requirements for this dimension can be met using feeler gauges.



1. Orifice plate outside diameter
2. Pipe inside diameter (D)
3. Straight edge
4. Orifice
5. Departure from flatness (measured at edge of orifice)

Figure 7 : Measurement of plate flatness

REFERENCES : R. NORMAN, MS RAWAT, P JEPSON : "Buckling and eccentricity effects on orifice metering accuracy", 1983, International Gas Research Conference.

8.1.2.2 The roughness criteria in this clause may not be adequate to ensure that the edge sharpness requirements of [ISO 5167-1, 8.1.6.2] can be achieved. It is recommended that $R_a \leq 10^{-5}$ d should be used. The roughness of the orifice bore should meet the same criteria.

8.1.2.3 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 flow-rate can be as much as 20 per cent under-estimated. 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. In no circumstances should the upstream face of the orifice plate within diameter "D" be indented by any marking.

8.1.3 No specific comments on this clause.

8.1.4 No specific comments on this clause.

8.1.5 No specific comments on this clause.

8.1.6 Edges

8.1.6.1 No specific comments on this clause.

8.1.6.2 Edge sharpness measurement

The last paragraph of this clause requires the edge radius to be measured should there be any doubt that it meets the requirements of [ISO 5167-1, 8.1.6.1 and 8.1.6.2]. In those exceptional cases, some suitable techniques are :

(a) The casting method (see references at the end of the section)

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 references at the end of the section)

An impression of the edge is made by pressing a 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 drawn. The edge condition can then be measured.

(c) Paper-recording roughness method (see figure 8)

This intrument 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, 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 meets all the requirements for dimensions and surface roughness.

All edges lying within the shaded region of figure 9 with an additional margin for surface roughness can be considered as acceptable. Some surface roughness is tolerable in accordance with [ISO 5167-1, 8.1.2.2] but very irregular edges shall be rejected.

A simple way of estimating the actual edge radius is by comparing the profile with curves (see examples in figure 10) reproduced on a transparent foil.

Edge sharpness measurement is a specialist activity. There are laboratories in many countries that are capable of undertaking edge sharpness measurement to the required standard.

REFERENCES : TJS BRAIN, J REID : "Measurement of orifice plate edge sharpness", Measurement and Control, Vol. 6, pp. 377-383.

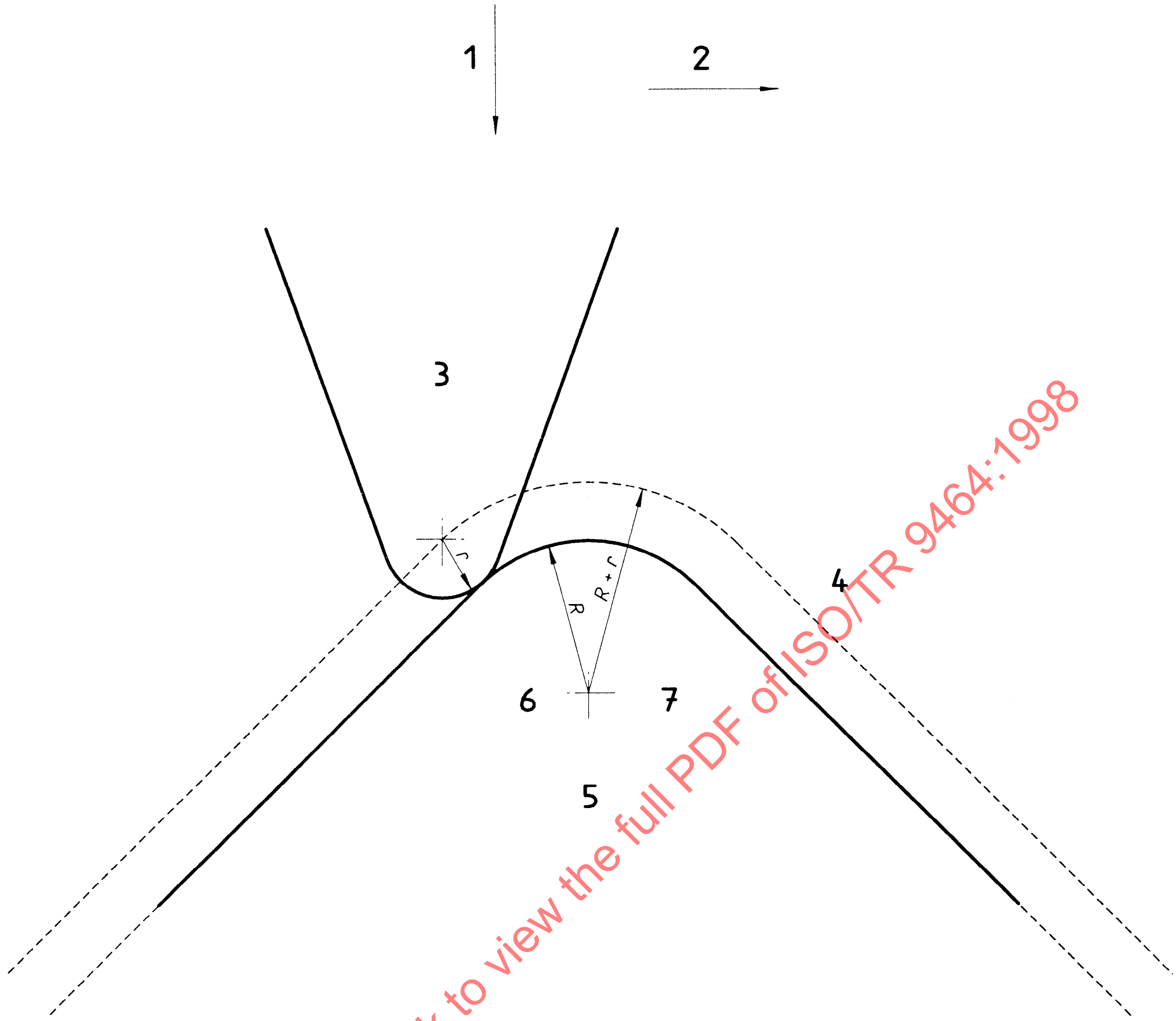
8.1.6.3 No comments at this stage

8.1.7 Diameter of orifice d

8.1.7.1 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.

8.1.7.2 No specific comments on this clause.

8.1.7.3 To enable the requirements of this clause (i.e. 0,05% difference) to be ascertained, it is necessary to measure or compare with an accuracy of at least 0,02%.



1. Recorded movement
2. Driving movement
3. Stylus
4. Traced path
5. Square edge
6. R = edge radius
7. r = tip radius

Figure 8 : Paper-recording roughness method

8.1.8 Symmetrical plate

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

The thickness E of the plate shall then not be greater than 0,02 D. As a consequence, symmetrical plates should only be used with low values of differential pressure in order to prevent deformation (see 8.1.1.3).

8.1.8.1 No specific comments on this clause.

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

8.1.9 Subclause 6.1 gives some information on the most commonly used materials and their characteristics.

8.2 Pressure Tappings

This section 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 5167-1, 8.2.1]). Tappings of several types may be installed at the same location. In such cases, each type of tapping (each "set") has to be totally independent from the others : the various sets must not interfere in any way.

This implies that on the same side of the plate several tappings must not lie on the same axial plane (see figure 11).

9 Nozzles

No specific comments on this clause.

10 Venturi tubes

10.1 Classical Venturi tubes

10.1.1 No specific comments on this clause.

10.1.2 No specific comments on this clause.

10.1.3 No specific comments on this clause.

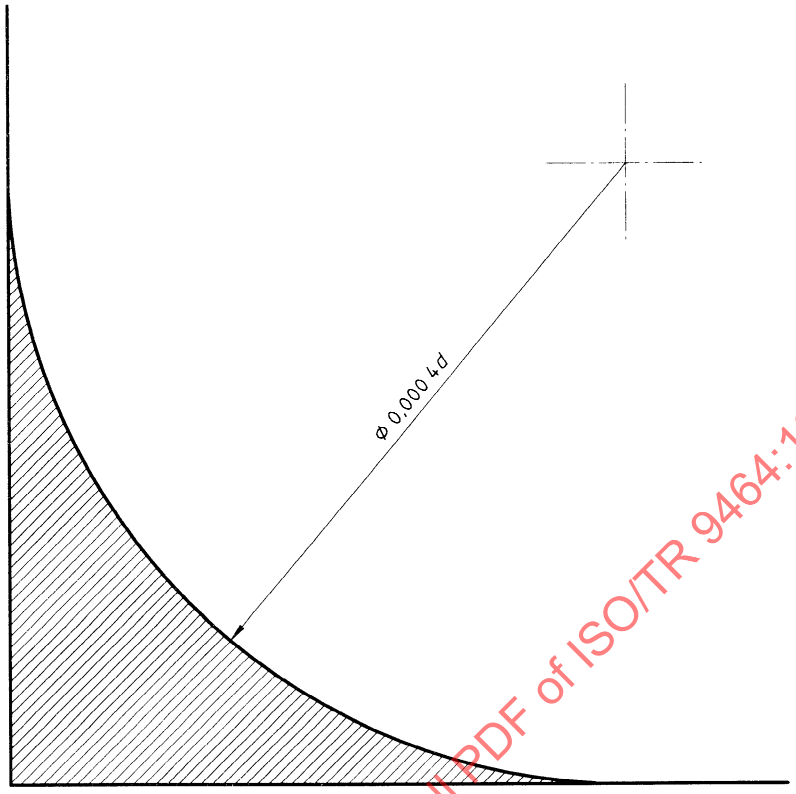


Figure 9 : Permitted edge sharpness

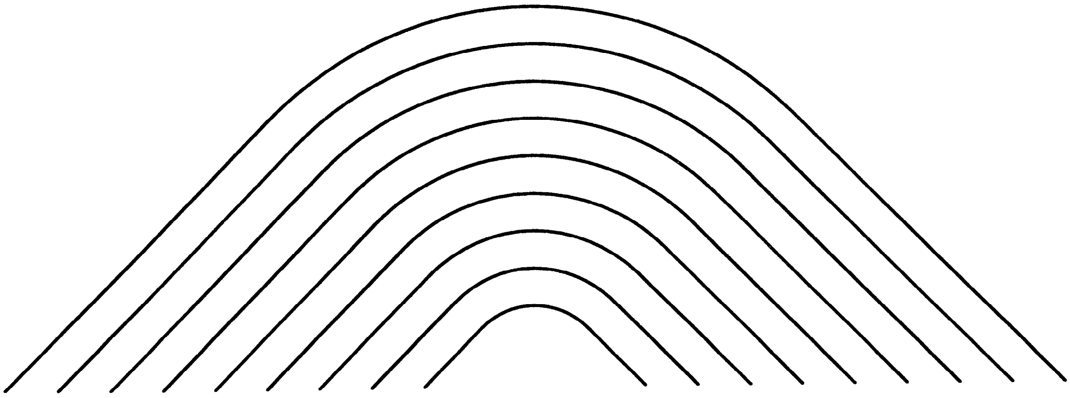


Figure 10 : Edge sharpness radius curves

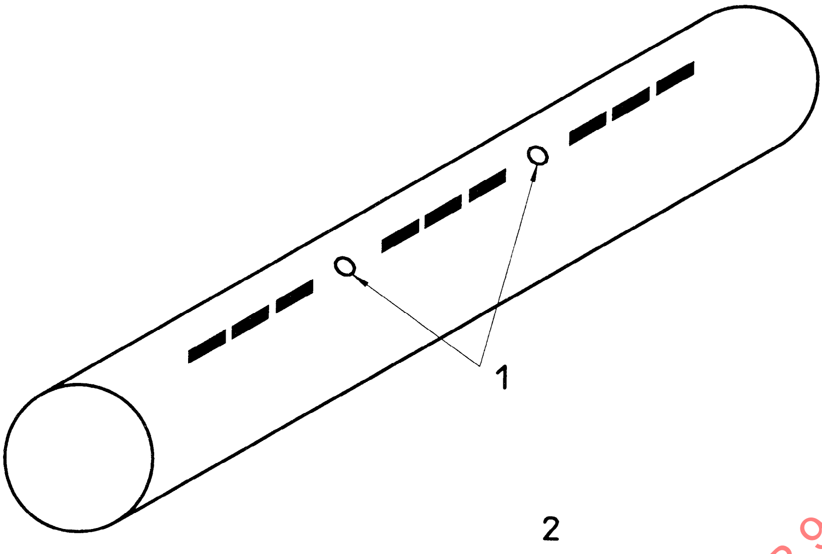
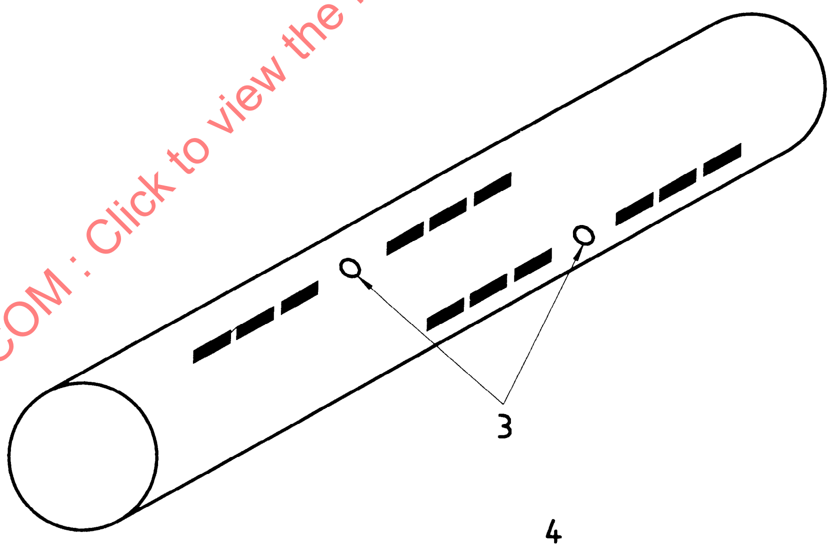


Fig 11 a : Example of wrong positioning



1. Pressure tappings
2. Wrong
3. Pressure tappings
4. Right

Fig 11 b : Example of correct positioning

Figure 11 : Relative position of pressure tappings of different types

10.1.4 Pressure tappings

10.1.4.1 No specific comments on this clause.

10.1.4.2 No specific comments on this clause.

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

10.1.5 Discharge coefficient, *C*

For high Re_D, even within the criteria in the standard, and for very accurate measurement, calibration is advisable.

10.2 Venturi nozzles

10.2.1 No specific comments on this clause.

10.2.2 No specific comments on this clause.

10.2.3 Pressure tappings

10.2.3.1 No specific comments on this clause.

10.2.3.2 No specific comments on this clause.

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

11 Uncertainties

ISO, in co-operation with BIPM, IEC, IFCC, IUPAC, IUPAP and OIML has published in 1995 the “Guide to the expression of uncertainty in measurements” (GUM). The content of the document should be taken into account when performing uncertainty analyses.

Reference can usually be made to ISO 5168, but note that ISO 5168 is currently being revised to align it with the GUM.

In a footnote ISO 5168 states "the error limits of a measuring device may be measured directly or determined from the guaranteed specifications of the manufacturer": The 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 are :

1) Uncertainties are often expressed as percentage of Full Scale or Range.

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

Section 2 - Information of a general nature, relevant to the application of ISO 5167-1

12 Secondary instrumentation

12.1 Introduction

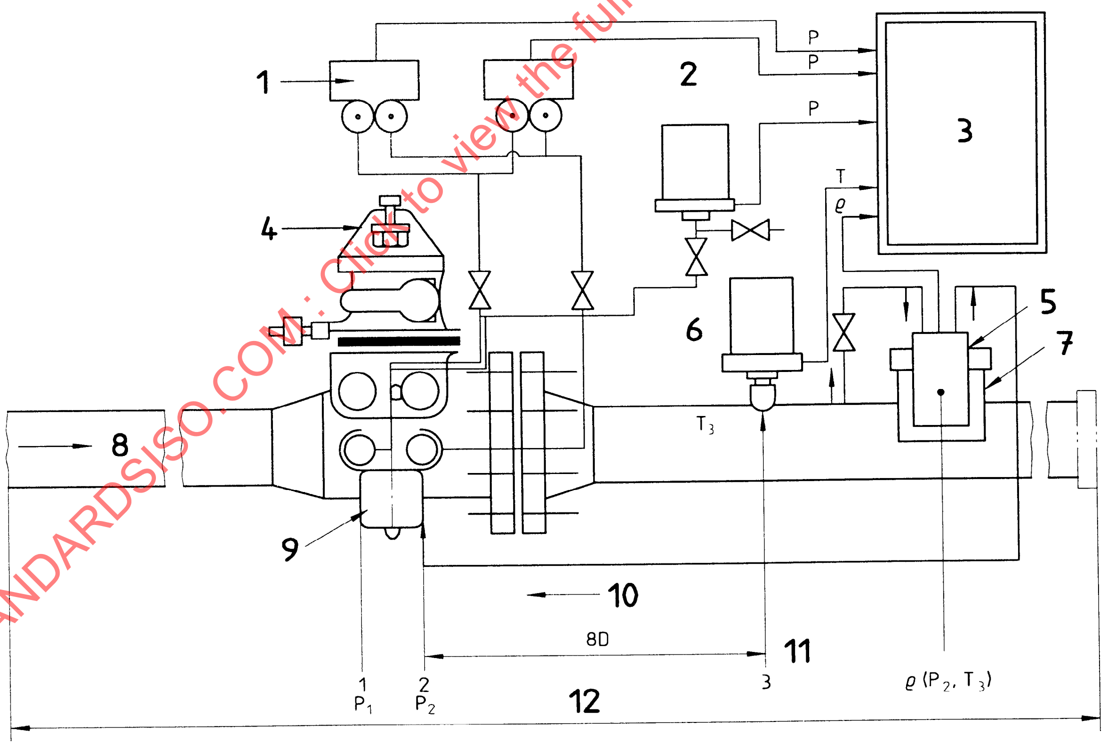
12.1.1 The definition of primary/secondary devices is stated in ISO 5167-1, clause 1.

12.1.2 General requirements concerning installation of secondary instruments

A conventional orifice plate measuring system is shown in figure 12. When installing the instruments careful attention should be given to the manufacturer's specifications. The following general rules must 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 manufacturers specification.



1. Differential pressure transmitter
2. Pressure transmitter
3. Flow computer
4. Orifice fitting
5. Density meter
6. Temperature transmitter
7. Pocket
8. Flow direction
9. Orifice plate
10. Sample flow
11. Temperature sensor connection
12. Meter tube per international standard

Figure 12 : Typical metering device installation

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

Having adjusted the calibration of the instrument with the enclosure open, it should be closed and left to stabilise before the results of the adjustment can be observed.

12.2 Measurement of pressure and differential pressure

For a complete treatment of the subject of pressure signal transmission, reference should be made to ISO 2186, "Fluid flow in closed conduits - Connections for pressure signal transmission between primary and secondary elements". However, some of the problems that demand special care are briefly mentioned below.

12.2.1 Connections for pressure signal transmissions between primary and secondary elements

12.2.1.1 General

The pressure pipes 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 :

- a temperature difference between the two pressure pipes ;

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

- the congealing or freezing of the liquid in the pressure pipes.

These requirements are met by :

- 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 ;

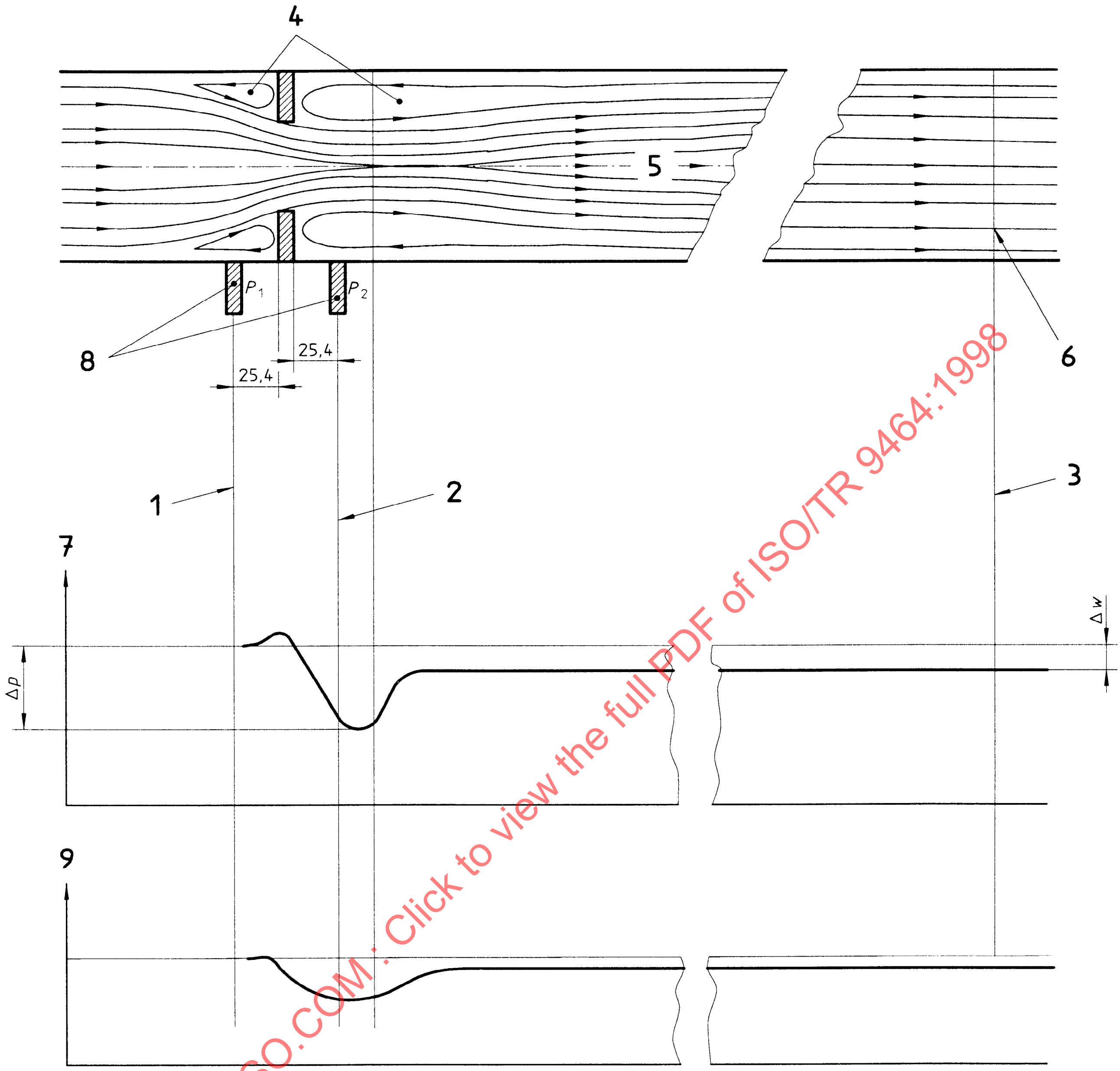
- employing a sealing liquid of suitable properties to transmit pressure from the fluid in the pipe to the liquid in the manometer or instrument. (see Figures 14 and 15)

12.2.1.2 Isolating valves (see ISO 2186, section 5)

In general :

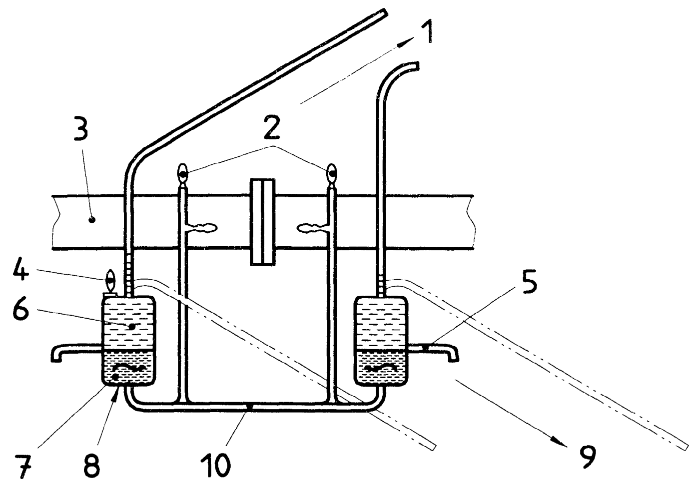
- suitable isolating valves should be provided in the pressure pipes (impulse lines). The choice and location of the valves is the responsibility of the designer.

- a ball valve should be used for fluids liable to form a sediment.



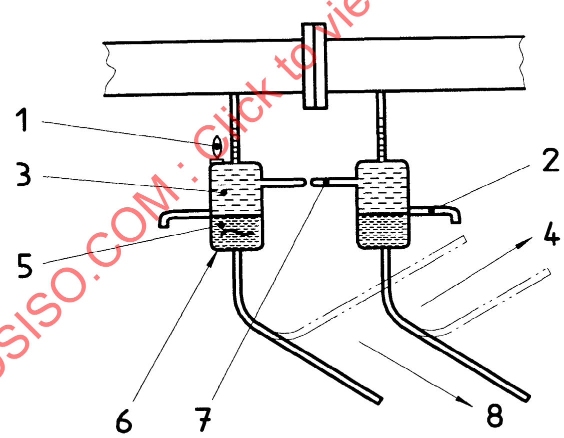
1. Plane of upstream pressure tapping
2. Plane of downstream pressure tapping
3. Plane of temperature probe location
4. Zones of recirculation
5. Direction of flow
6. Temperature transducer
7. Pressure
8. Pressure tapping points
9. Temperature

Figure 13 : Approximate profiles of flow, pressure and temperature in an orifice metering system with flange taps



1. To meter
2. Gas vents
3. Pressure tappings and valves
4. Filling connection
5. Level determining connection
6. Sealing liquid
7. Metered liquid
8. Sealing pots
9. To meter if below pipeline
10. Equalizing valve

Figure 14 : Sealing chambers - Metered fluid heavier than sealing fluid



1. Filling connection
2. Level determining connection
3. Metered liquid
4. To meter if above pipeline
5. Sealing liquid
6. Sealing pots
7. Equalizing valve
8. To meter

Figure 15 : Sealing chambers - Metered fluid lighter than sealing fluid

12.2.1.3 Condensation chambers

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

12.2.2 Pressure Measurement Devices

12.2.2.1 General

The accurate measurement of the differential pressure generated across a primary element is fundamental to the calculation of flow-rate in a circular cross-section conduit employing orifice plates, nozzles and 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 orifice plate expansibility factors, 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 accurately measure this parameter 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 flow-rate and referral calculations, in consequence the gauge pressure measurements should be converted to absolute units.

12.2.2.2 Pressure transducers

The differential pressure across the primary device is most commonly measured using a mechanical or electronic 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 12.

The choice of pressure transducer depends upon a number of factors these include:

- the required accuracy of the measurement system ;
- whether the measurement is to be made continuously or intermittently ;
- the characteristics of the flowing fluid ;
- the data acquisition system including the computation device;
- 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. Examples of mechanical pressure transducers are :

- dead-weight floating piston gauges,
- manometers,
- Bourdon tubes,
- and diaphragm gauges.

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. Examples of some electronic pressure transducers are :

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

The declared accuracy and operating characteristics of the electronic pressure transmitters varies considerably from type to type but with the advent of the "Smart Transmitters", operating in digital mode, uncertainties of < 0.1% of upper range value are claimed. Typical characteristics of electronic pressure transmitters are given in Table 7.

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 7 : 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 (differ.)	20 bar	75 bar	300 bar	300 bar	80 bar
Acceptable over-range pressure	x 2,5	x 1,5	x 1,5	x 2	x 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
NOTE : this table must be regarded as a simple guide. Quoted figures are orders of magnitude.					

12.2.2.3 Pressure calibrators

As with all secondary instrumentation, the pressure transducers (DP & static) should be calibrated at regular intervals for optimum accuracy. There are 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 8.

Table 8 : Characteristics of precision pressure measuring devices

Type	Range (bar)	Uncertainty
Pressure Balance (Deadweight Tester)	0,000 5 to 500	0,1 mbar to 0,05 % of reading
Servo Manometer	0,005 to 4,0	Corresponding to 0,025 mm of liquid column height
Precision Bourdon gauge	0,000 5 to 1 000	0,1 % of full scale

This table must be regarded as a simple guide. Quoted figures are orders of magnitude.

12.2.2.4 Calibration of pressure transducers

In order 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 purpose. For optimum accuracy a transmitter should ideally be calibrated at operating pressure. It is common practice to use a high static dead-weight 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 static shift correction should be applied either physically 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 dead-weight tester.

12.2.2.5 Damping of pressure signals (see ISO 7194 - Annex)

12.3 Measurement of temperature (see [ISO 5167-1, 3.4.2] and Code of Practice, 3.4.2.1)

12.3.1 General

The temperature at the upstream pressure tapping is required 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 shall preferably be measured downstream of the primary device.

12.3.2 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.

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,

- 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 pipewall is good, then a sensing device clamped to the wall may be used. Special consideration must be given to heat flow in this case, which is not recommended for high accuracy applications.

12.3.3 Sensor installation (see [ISO 5167-1, 5.4.2 and 5.4.3])

12.3.4 Precautions for accurate measurement

12.3.4.1 Selecting the measuring point

In general the sensor or thermometer should be mounted perpendicular to the pipewall, as illustrated in figure 16-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 16, measured from the inner wall) should be approximately 0,3 D. This is not always possible for smaller and larger pipes (see 12.3.4.4).

12.3.4.2 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.

12.3.4.3 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.

12.3.4.4 Restrictions on the thermometer well

1) 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 minimised by spacing the thermowell pockets radially around the pipe.

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

3) For smaller pipes where dimension N (in figure 16-a) becomes larger than 3/4 of the nominal inside diameter of the pipe, the positions illustrated in figures 16-b and 16-c should be used.

4) For larger diameter pipes, thermowell lengths of 75 to 100 mm are conservative. The longer insertion in higher density fluids requires strength calculations.

5) 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 to slow the time response 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.

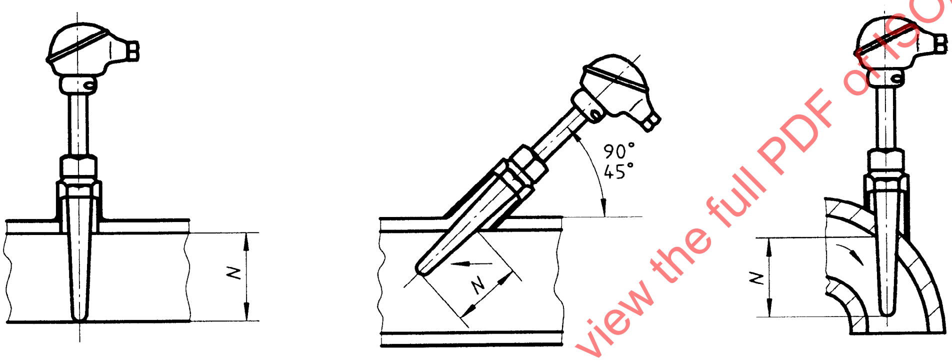


Fig 16 a Fig 16 b Fig 16 c

Figure 16 : Installation of immersion temperature probe

The greatest improvement in heat transfer between the thermowell and the sensitive element is obtained by closely controlling the tolerances on element outside diameter and well inside diameter and allowing the minimum extra clearance. Another method is to use a spring loaded contact between the sensor and the well.

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

7) 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 by more than 40 K. The adjacent pipe walls shall be insultated in accordance with [ISO 5167-1 - 6.1.9].

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

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

12.3.6 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.

12.3.7 Devices for temperature measurement

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

The choice of thermometer must 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 summarised in table 9. The table must not be regarded as complete, but rather as a guide.

Table 9 : 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
Liquid in glass	Alcohol	- 100 to 50	0,1	
Thermocouples	Pt-Rh/Pt	0 to 1500	1	
Thermocouples	Cu/Const	- 200 to 350	0,5	
Thermocouples	Fe/Const	- 200 to 600	1,5	
Thermocouples	Chromel/Alum	- 200 to 1000	1,5	
Resistance	Pt	- 200 to 600	0,3	Sensitive to mechanical vibration
Resistance	Ni	- 100 to 200	0,5	
Resistance	Cu	- 100 to 200	0,5	
Thermistor	Semi-conduct	- 200 to 200	0,2	
NOTE : this table must be regarded as a simple guide. Quoted figures are orders of magnitude. See also IEC 584 for thermocouples and IEC 751 for resistance thermometers.				

12.4 Determination of density (see [ISO 5167-1, 5.4])

12.4.1 General

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

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 the gas composition changes and the temperature drops below the saturation temperature, permitting the formation of liquids.

The most common techniques used for density measurement are the force balance and the vibrating element density meters. The fundamental characteristics of different density meters are given in Table 10.

Table 10 : 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)	1200 (Max)	Variable	0,5 % of span
Vibration vane	0 to 400 (gases)	0,01 (Min) 0,1 (Max)	0,1 % of span
	300 to 1 200 (liq)	0,1 (Min) 0,3 (Max)	
Vibrating tube	0 to 400 (gases) 600 to 1 600	as range	0,1 % of span

NOTE : this table must be regarded as a simple guide. Quoted figures are orders of magnitude.

12.4.2 Installation of density transducers

Most of the factors relative 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 must 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 is 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 ISO 5167-1. It is suggested that the density cell is installed downstream of the primary device either as an in-line probe or in a sample by-pass. If the first alternative is chosen, the distance from the primary device to the point of installation must be in accordance with [ISO 5167-1, tables 1and 2].

The other installation method consists in by-passing or venting the fluid through the density cell. In this case the high pressure tapping must be located at least 8 D downstream of the primary device. The low pressure return tapping must be located just behind the downstream face of the orifice plate. One must assure that the density measurement does not interfere with the flowrate measurement. Figure 17 illustrates this type of installation method.

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 isolating valve.

4) The method minimizes contamination by condensates.

Disadvantages of an in-line probe :

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

2) Relatively long response time to changes in gas density occurs at low flow rates or static pressure changes.

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

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

5) No check facility on sample flow through the transducer.

Advantages of a sample by-pass probe :

1) Ease of filtering or maintaining a filter in the stream if neeeded.

2) The flowrate can be adjusted to comply with the accuracy of the instrumentation needed.

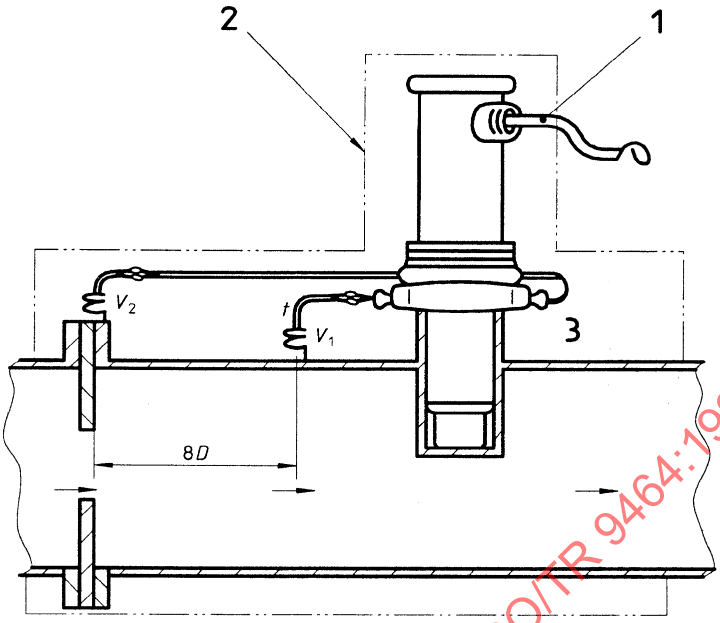
3) Easy access for maintenance and testing.

Disadvantages of a sample by-pass probe :

1) Large thermal mass may cause poor response time to temperature changes.

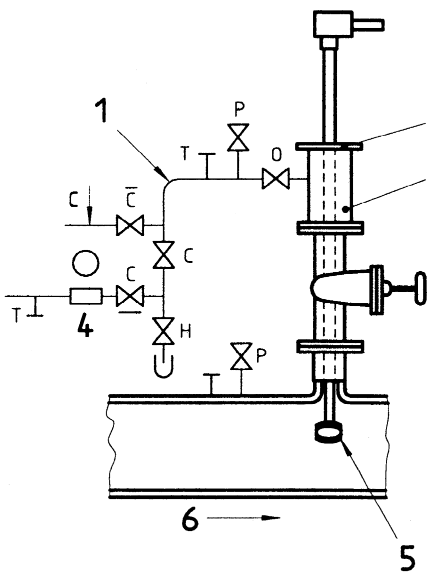
2) Temperature and pressure could vary from flowing conditions resulting in measurement error. Both side stream and transducers must be provided with thermal insultation.

3) Condensation can occur in the instrumentation and affect the accuracy of the density reading. Condensate trap may be necessary.



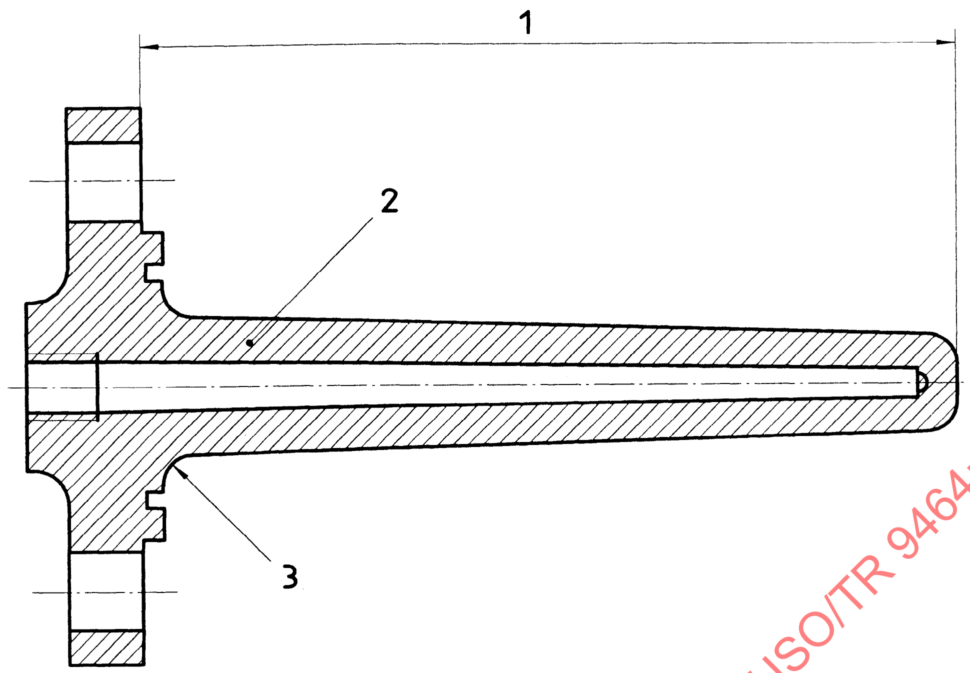
1. To readout electronics
2. Thermal lagging
3. Top of pipe

Figure 17 : Installation showing density meter installed in sample by-pass meter mounted in pocket



1. Sampling system for proving purposes only
2. Seal
3. Seal housing
4. Flow meter
5. Retractable probe
6. flow

Figure 18 : Direct insertion type density meter



1. As this length is important it must be checked
2. Forging
3. Radius carefully designed to minimise stresses

Figure 19 : Example of thermowell design

12.4.3 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 [5.4 and 6.2.3].

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 - 0,2 % can be obtained. (see Annex C).

12.4.4 Special consideration concerning gas density

If high accuracy is required, a correction must be introduced to compensate for the fact that the fluid entering the density transducer is not at the condition of the upstream pressure tapping. This correction must be made from a 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 3.4).

12.4.5 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 1.3) and find the density at that temperature from tables. This is satisfactory as long as the composition is constant and within the specification on 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.

12.5 Electrical supply and electrical installations

See IEC 79 standard for explosive atmosphere.

12.5.1 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 to be a short as possible ;

b) use shielded cables which are earthed only at one point ;

c) amplify weak signals 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 must be shielded from electrical lines.

12.5.2 Electronic equipment

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

12.6 References

1 - ISO 5167-1:1991 : Measurement of fluid by means of orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full.

2 - ISO 2186:1973 : Fluid flow in closed conduits - Connections for pressure signal transmission between primary and secondary element.

3 - The Matheson Unabridged Gas Data Book - Matheson Gas Products - 1974 - East Rutherford, New Jersey.

4 - Flow measurement engineering handbook - 3rd edition - Richard W. Miller - 1996

Annex A

Principles of measurement and computation

A.1 Formulae

NOTE : 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 must be corrected for thermal expansion (see 6.1.3 and 7.1.5).

A.1.1 Formulae common to all devices

- Mass flowrate : $q_m = \left[1-\beta^4\right]^{-0,5} C\varepsilon_1 \frac{\pi}{4} d^2 \left[2\Delta p\rho_1\right]^{0,5}$ (23)

- Volume flowrate : $q_{v1} = \frac{q_m}{\rho_1}$ or $q_{vR} = \frac{q_m}{\rho_R}$ (24)

where : $\rho_1 = \rho_R \frac{p_1 T_R Z_R}{p_R T_1 Z_1}$ (26)

Subscript "1" refers to flow condition at upstream pressure tapping cross-section.
Subscript "R" refers to given conditions of pressure and temperature.

- Reynolds number : $Re_D = \frac{U_1 D}{\upsilon_1} = \frac{4q_m}{\pi D\mu_1} = \frac{4q_{v1}}{\pi D\upsilon_1}$ (27)

A.1.2 Limits of use of primary devices

The formulae given in ISO 5167-1 for C and ε for the various primary devices can be applied only when certain quantities lie within given limits.

These limits of use are recalled in the following table A.1.

A.2 Example of computation

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 A2 shows the formulae giving C_∞ and C_{Re} for each type of device.

Reference should be made to the table of iterative computations in [Annex D] of ISO 5167-1.

According to the quantity which is to be calculated, additional equations derived from formula (23) may be useful. The following 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 figure numbers are listed which is much more accurate than can be justified for practical purposes but can be helpful when checking the accuracy of the computer programmes.

A.2.1 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 x 10^5 Pa (500 mbar),
- pressure : 10 x 10^5 Pa (10 bar),
- temperature : 773,15° K (500°C),
- λ_D = 16 x $10^{-6} K^{-1}$
- λ_d = 11 x $10^{-6} K^{-1}$,
- κ = 1,276.

Using the following typical data :

- ρ_1 = 2,825 1 $kg.m^{-3}$,
- μ_1 = 28,5 x 10^{-6} Pa.s,
- κ = 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 5167-1, 8.3.2.2] $\varepsilon = 1 - \left(0,41 + 0,35\beta^4\right)\frac{\Delta p}{\kappa p_1}$

   ε = 0,981 486 003 6.

For hand made calculations, 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 (29.8) : $K_D = \left[\frac{8\left(1-\beta^4\right)}{\Delta p \rho_1 \beta^4}\left(\frac{q_m}{\pi\varepsilon}\right)^2\right]^{0,25}$

   K_D = 0,072 358 950 12

Table A1 : Limits of use

Type of device	d (mm)	D (mm)	β	Re_D	Roughness Criteria
Corner tappings orifice plate	≥ 12,5	$50 \leq D \leq 1000$	$0,20 \leq \beta \leq 0,75$	$Re_D \geq 5000$ for $0,20 \leq \beta \leq 0,45$ $Re_D \geq 10000$ for $\beta > 0,45$	$k/D \leq 3,8 \times 10^{-4}$ or see [Table 3]
Flange tappings orifice plate D and D/2 tappings orifice plate	≥ 12,5	$50 \leq D \leq 1000$	$0,20 \leq \beta \leq 0,75$	$Re_D \geq 1250 \times 10^6 \beta^2 D$*	$k/D \leq 10 \times 10^{-4}$ or see [Table 3]
ISA 1932 nozzle	-	$50 \leq D \leq 500$	$0,30 \leq \beta \leq 0,80$	$70000 \leq Re_D \leq 10^7$ for $0,30 \leq \beta \leq 0,44$ $20000 \leq Re_D \leq 10^7$ for $0,44 \leq \beta \leq 0,80$	$k/D \leq 3,8 \times 10^{-4}$ or see [Table 4]
Long radius nozzle	-	$50 \leq D \leq 630$	$0,20 \leq \beta \leq 0,80$	$10^4 \leq Re_D \leq 107$	$k/D \leq 10 \times 10^{-4}$
Rough cast convergent Venturi tube	-	$100 \leq D \leq 800$	$0,30 \leq \beta \leq 0,75$	$2 \times 10^5 \leq Re_D \leq 2 \times 106$	$R_a < 10^{-5}$ d ** $R_a < 10^{-4}$ D ***
Rough-Welded convergent Venturi tube	-	$200 \leq D \leq 1200$	$0,40 \leq \beta \leq 0,70$	$2 \times 10^5 \leq Re_D \leq 2 \times 106$	$R_a < 10^{-5}$ d ** $R_a \approx 5 \times 10^{-4}$ D ***
Machined convergent Venturi tube	-	$50 \leq D \leq 250$	$0,40 \leq \beta \leq 0,75$	$2 \times 10^5 \leq Re_D \leq 1 \times 106$	$R_a < 10^{-5}$ d ** ***
Venturi nozzle	≥ 50	$65 \leq D \leq 500$	$0,316 \leq \beta \leq 0,775$	$1.5 \times 10^5 \leq Re_D \leq 2 \times 106$	$k/D \leq 3,8 \times 10^{-4}$ or see [Table 5]

Key: * where "D" is in "mm" ** Throat roughness criterion *** Convergent section roughness criterion

Note: For all devices, $\Delta p/p_1 \leq 0,25$ when used with compressible fluids.

Table A.2 : C_∞ and C_{Re} for orifice meters: $C = C_\infty + C_{Re}$

Type of device	Equations
Orifice plates	$C_\infty = 0{,}595\,9 + 0{,}031\,2\,\beta^{2,1} - 0{,}184\,0\,\beta^8 + C_L$ (28.1) with $C_L = a\,\beta^4\,(1-\beta^4)^{-1} - b\,\beta^3$ (28.1 (a)) $C_{Re} = 0.0029\beta^{2.5}\left(\frac{10^6}{Re_D}\right)^{0.75}$ (28.2)

Tappings	a	b
Corner tappings	$a = 0$	$b = 0$
Flange tappings with $D_0 \leq 0{,}058\,6$ m	$a = 0{,}002\,286/D_0$	$b = 0{,}000\,856/D_0$
Flange tappings with $D_0 \geq 0{,}058\,6$ m	$a = 0{,}039$	$b = 0{,}000\,856/D_0$
D and D/2 tappings	$a = 0{,}039$	$b = 0{,}015\,84$

Table A.3 : Iteration equations

Known parameters	Quantities to be computed	Equations
d D Δp	q_m	$F(q_m) = CK_q$ (29.1) $K_q = (1-\beta^4)^{-0,5}\,\varepsilon\,\frac{\pi}{4}d^2\sqrt{2\Delta p\rho_1}$ (29.2)
q_m Δp D	β	$F(\beta) = \left(1 + C^2\varepsilon^2 K_\beta\right)^{-0,25}$ (29.3) $K_\beta = \frac{\Delta p\rho_1}{8}\left(\frac{\pi D^2}{q_m}\right)^2$ (29.4)
d D q_m	Δp	$F(\Delta p) = K_{\Delta p}\varepsilon^{-2}$ (29.5) $K_{\Delta p} = \frac{8(1-\beta^4)}{\rho_1}\left(\frac{q_m}{\pi C d^2}\right)^2$ (29.6)
q_m Δp β	D	$F(D) = K_D C^{-0,5}$ (29.7) $K_D = \left[\frac{8(1-\beta^4)}{\Delta p\rho_1\beta^4}\left(\frac{q_m}{\pi\varepsilon}\right)^2\right]^{0,25}$ (29.8)

In each case, p_1, T_1, ρ_1, U_1, k must also be known.

3. C , applying equation (28.1) for corner tappings (see A.2.4.2)

C_∞ = 0,595 9 + 0,031 2 $\beta^{2,1}$ - 0,184 β^8 + C_L

C = C_∞ = 0,602 663 134 8

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

4. The starting value of D is obtained from equation (29.7) : f(D) = K_D $C^{-0,5}$

D_1 = f(D) = 0,093 208 376 55

5. Reynolds number from (27) : $Re_D = \dfrac{4q_m}{\pi D \mu_1}$

Re_D = 479 303,184 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 = 0,092 859 058 84

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.2.2 Computation of β - Example

Refer to figures 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.2.1, i.e. :

- fluid : steam,
- maximum flowrate : 1 kg.s^{-1},
- maximum pressure differential : 0,5 x 10^5 Pa (500 bar),
- pressure : 10 x 10^5 Pa (10 bar),
- temperature : 773,15° K (500°C),
- pipe diameter at ambient : D_0 = 0,102 m,
- λ_d = 16 x 10^{-6} K^{-1},
- λ_D = 11 x 10^{-6} K^{-1},
- κ = 1,276.

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

*** Assessing starting values:

1. D is obtained from equation (4) : $D = D_O [1 + \lambda_D (T - T_O)]$

   D = 0,102 538 560 0

2. Re_D, from (27) : $Re_D = \frac{4q_m}{\pi D \mu_1}$

   Re_D = 435 690,453 9

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

4. β being unknown, except for classical Venturi tubes where C is a constant, it is convenient either :

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

   - to use as a starting value $C = C_\infty$.

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 $C_{\infty, corner}$, i.e. the value of C_∞ that would be obtained for corner tappings. In the iteration steps, C has to be computed as :

$$C = C_{\infty,angle} + C_L + C_{Re}$$

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 (29.4) : $K_\beta = \frac{\Delta p \rho_1}{8}\left(\frac{\pi D^2}{q_m}\right)^2$

   K_β = 19,264 708 61

6. Starting value of β from (29.3) : $F(\beta) = [1 + C^2 \varepsilon^2 K_\beta]^{-0,25}$

   $\beta_1 = F(\beta)$ = 0,603 764 155 8