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Measurement of fluid flow by means of pressure differential devices —

Part 1:
Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full

Mesure de débit des fluides au moyen d'appareils déprimogènes —

Partie 1: Diaphragmes, tuyères et tubes de Venturi insérés dans des conduites en charge de section circulaire

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Annexes

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.

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

International Standard ISO 5167-1 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Sub-Committee SC 2, *Pressure differential devices*.

This first edition of ISO 5167-1 cancels and replaces ISO 5167:1980, of which it constitutes a technical revision.

ISO 5167 consists of the following parts, under the general title *Measurement of fluid flow by means of pressure differential devices*:

- *Part 1: Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full*
- *Part 2: Diaphragms or nozzles installed at the inlet of a conduit*

Annexes A, B, C, D and E of this part of ISO 5167 are for information only.

Measurement of fluid flow by means of pressure differential devices —

Part 1:
Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full

1 Scope

This part of ISO 5167 specifies the geometry and method of use (installation and operating conditions) of orifice plates, nozzles and Venturi tubes when they are inserted in a conduit running full to determine the flow-rate of the fluid flowing in the conduit. It also gives necessary information for calculating the flow-rate and its associated uncertainty.

It applies only to pressure differential devices in which the flow remains subsonic throughout the measuring section and is steady or varies only slowly with time and where the fluid can be considered as single-phase. In addition, each of these devices can only be used within specified limits of pipe size and Reynolds number. Thus this part of ISO 5167 cannot be used for pipe sizes less than 50 mm or more than 1 200 mm or for pipe Reynolds numbers below 3 150.

It deals with devices for which direct calibration experiments have been made, sufficient in number, spread and quality to enable coherent systems of application to be based on their results and coefficients to be given with certain predictable limits of uncertainty.

The devices introduced into the pipe are called "primary devices". The term primary device also includes the pressure tappings. All other instruments or devices required for the measurement are known as "secondary devices". This part of ISO 5167 covers primary devices; secondary devices[1] will be mentioned only occasionally.

1) See ISO 2186:1973, *Fluid flow in closed conduits — Connections for pressure signal transmissions between primary and secondary elements.*

The different primary devices dealt with in this part of ISO 5167 are as follows:

a) orifice plates, which can be used with corner pressure tappings, D and $D/2$ pressure tappings[2], and flange pressure tappings;

b) ISA 1932 nozzles[3], and long radius nozzles, which differ in shape and in the position of the pressure tappings;

c) classical Venturi tubes[4], and Venturi nozzles, which differ in shape and in the position of the pressure tappings.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 5167. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 5167 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 468:1982, *Surface roughness — Parameters, their values and general rules for specifying requirements.*

ISO 4006:1991, *Measurement of fluid flow in closed conduits — Vocabulary and symbols.*

ISO 5168:—[5], *Measurement of fluid flow — Evaluation of uncertainties.*

3 Definitions

For the purposes of this part of ISO 5167, the definitions given in ISO 4006 apply.

The following definitions are given only for terms used in some special sense or for terms the meaning of which it seems useful to emphasize.

3.1 Pressure measurement

3.1.1 wall pressure tapping: Annular or circular hole drilled in the wall of a conduit in such a way that the edge of the hole is flush with the internal surface of the conduit.

The hole is usually circular but in certain cases may be an annular slot.

3.1.2 static pressure of a fluid flowing through a straight pipeline, p: Pressure which can be measured by connecting a pressure gauge to a wall pressure tapping. Only the value of the absolute static pressure is considered in this part of ISO 5167.

3.1.3 differential pressure, Δp: Difference between the (static) pressures measured at the wall pressure tappings, one of which is on the upstream side and the other of which is on the downstream side of a primary device (or in the throat for a Venturi tube) inserted in a straight pipe through which flow occurs, when any difference in height between the upstream and downstream tappings has been taken into account.

In this part of ISO 5167 the term "differential pressure" is used only if the pressure tappings are in the positions specified for each standard primary device.

3.1.4 pressure ratio, τ: Ratio of the absolute (static) pressure at the downstream pressure tapping to the absolute (static) pressure at the upstream pressure tapping.

2) Orifice plates with *vena contracta* pressure tappings are not considered in this part of ISO 5167.

3) ISA is the abbreviation for the International Federation of the National Standardizing Associations, which was succeeded by ISO in 1946.

4) In the USA the classical Venturi tube is sometimes called the Herschel Venturi tube.

5) To be published. (Revision of ISO 5168:1978)

3.2 Primary devices

3.2.1 orifice; throat: Opening of minimum cross-sectional area of a primary device.

Standard primary device orifices are circular and coaxial with the pipeline.

3.2.2 orifice plate: Thin plate in which a circular aperture has been machined.

Standard orifice plates are described as "thin plate" and "with sharp square edge", because the thickness of the plate is small compared with the diameter of the measuring section and because the upstream edge of the orifice is sharp and square.

3.2.3 nozzle: Device which consists of a convergent inlet connected to a cylindrical section generally called the "throat".

3.2.4 Venturi tube: Device which consists of a convergent inlet connected to a cylindrical part called the "throat" and an expanding section called the "divergent" which is conical.

If the convergent inlet is a standardized ISA 1932 nozzle, the device is called a "Venturi nozzle". If the convergent inlet is conical, the device is called a "classical Venturi tube".

3.2.5 diameter ratio of a primary device used in a given pipe, β: Ratio of the diameter of the orifice (or throat) of the primary device to the internal diameter of the measuring pipe upstream of the primary device.

However, when the primary device has a cylindrical section upstream, having the same diameter as that of the pipe (as in the case of the classical Venturi tube), the diameter ratio is the quotient of the throat diameter and the diameter of this cylindrical section at the plane of the upstream pressure tappings.

3.3 Flow

3.3.1 rate of flow of fluid passing through a primary device, q: Mass or volume of fluid passing through the orifice (or throat) per unit time; in all cases it is necessary to state explicitly whether the mass rate of flow q_m, expressed in mass per unit time, or the volume rate of flow q_V, expressed in volume per unit time, is being used.

3.3.2 Reynolds number, Re: Dimensionless parameter expressing the ratio between the inertia and viscous forces.

The Reynolds number used in this part of ISO 5167 is referred to

— either the upstream condition of the fluid and the upstream diameter of the pipe, i.e.

$$Re_D = \frac{U_1 D}{\nu_1} = \frac{4 q_m}{\pi \mu_1 D}$$

— or the orifice or throat diameter of the primary device, i.e.

$$Re_d = \frac{Re_D}{\beta}$$

3.3.3 isentropic exponent, κ: Ratio of the relative variation in pressure to the corresponding relative variation in density under elementary reversible adiabatic (isentropic) transformation conditions.

The isentropic exponent κ appears in the different formulae for the expansibility [expansion] factor ε and varies with the nature of the gas and with its temperature and pressure.

There are many gases and vapours for which no values for κ have been published so far. In such a case, for the purposes of this part of ISO 5167, the ratio of the specific heat capacities of ideal gases can be used in place of the isentropic exponent.

3.3.4 discharge coefficient, C: Coefficient, defined for an incompressible fluid flow, which relates the actual flow-rate to the theoretical flow-rate through a device. It is given by the formula

$$C = \frac{q_m \sqrt{1 - \beta^4}}{\frac{\pi}{4} d^2 \sqrt{2 \Delta p \varrho_1}}$$

Calibration of standard primary devices by means of incompressible fluids (liquids) shows that the discharge coefficient is dependent only on the Reynolds number for a given primary device in a given installation.

The numerical value of C is the same for different installations whenever such installations are geometrically similar and the flows are characterized by identical Reynolds numbers.

The equations for the numerical values of C given in this part of ISO 5167 are based on data determined experimentally.

NOTE 1 The quantity $1/\sqrt{1-\beta^4}$ is called the "velocity of approach factor" and the product

$$C \frac{1}{\sqrt{1-\beta^4}}$$

is called the "flow coefficient".

3.3.5 expansibility [expansion] factor, ε: Coefficient used to take into account the compressibility of the fluid. It is given by the formula

$$\varepsilon = \frac{q_m\sqrt{1-\beta^4}}{\frac{\pi}{4} d^2 C \sqrt{2\Delta p \varrho_1}}$$

Calibration of a given primary device by means of a compressible fluid (gas), shows that the ratio

$$\frac{q_m\sqrt{1-\beta^4}}{\frac{\pi}{4} d^2 \sqrt{2\Delta p \varrho_1}}$$

is dependent on the value of the Reynolds number as well as on the values of the pressure ratio and the isentropic exponent of the gas.

The method adopted for representing these variations consists of multiplying the discharge coefficient C of the primary device considered, as determined by direct calibration carried out with liquids for the same value of the Reynolds number, by the expansibility [expansion] factor ε.

ε is equal to unity when the fluid is incompressible and is less than unity when the fluid is compressible.

This method is possible because experiments show that ε is practically independent of the Reynolds number and, for a given diameter ratio of a given primary device, ε only depends on the differential pressure, static pressure and the isentropic exponent.

The numerical values of ε for orifice plates given in this part of ISO 5167 are based on data determined experimentally. For nozzles and Venturi tubes they are based on the thermodynamic general energy equation.

3.3.6 arithmetical mean deviation of the (roughness) profile, R_a: Arithmetic mean deviation from the mean line of the profile being measured. The mean line is such that the sum of the squares of the distances between the effective surface and the mean line is a minimum. In practice R_a can be measured with standard equipment for machined surfaces but can only be estimated for rougher surfaces of pipes. (See also ISO 468.)

For pipes, the uniform equivalent roughness k is used. This value can be determined experimentally (see 8.3.1) or taken from tables (see annex E).

4 Symbols and subscripts

4.1 Symbols

Symbol	Quantity	Dimension[1)]	SI unit
C	Coefficient of discharge	dimensionless	—
d	Diameter of orifice (or throat) of primary device at working conditions	L	m
D	Upstream internal pipe diameter (or upstream diameter of a classical Venturi tube) at working conditions	L	m
e	Relative uncertainty	dimensionless	—
k	Uniform equivalent roughness	L	m
l	Pressure tapping spacing	L	m
L	Relative pressure tapping spacing $L = \frac{l}{D}$	dimensionless	—
p	Absolute static pressure of the fluid	$ML^{-1} T^{-2}$	Pa
q_m	Mass rate of flow	MT^{-1}	kg/s
q_V	Volume rate of flow	$L^3 T^{-1}$	m^3/s
R	Radius	L	m
R_a	Arithmetical mean deviation of the (roughness) profile	L	m
Re	Reynolds number	dimensionless	—
Re_D	Reynolds number referred to D	dimensionless	—
Re_d	Reynolds number referred to d	dimensionless	—
t	Temperature of the fluid	Θ	°C
U	Mean axial velocity of the fluid in the pipe	LT^{-1}	m/s
β	Diameter ratio $\beta = \frac{d}{D}$	dimensionless	—
γ	Ratio of specific heat capacities[2)]	dimensionless	—
δ	Absolute uncertainty	[3)]	[3)]
Δp	Differential pressure	$ML^{-1} T^{-2}$	Pa
$\Delta \varpi$	Pressure loss	$ML^{-1} T^{-2}$	Pa
ε	Expansibility [expansion] factor	dimensionless	—
κ	Isentropic exponent[2)]	dimensionless	—
μ	Dynamic viscosity of the fluid	$ML^{-1} T^{-2}$	Pa·s
ν	Kinematic viscosity of the fluid $\nu = \frac{\mu}{\varrho}$	$L^2 T^{-1}$	m^2/s
ξ	Relative pressure loss	dimensionless	—
ϱ	Density of the fluid	ML^{-3}	kg/m^3
τ	Pressure ratio $\tau = \frac{p_2}{p_1}$	dimensionless	—
φ	Total angle of the divergent section	dimensionless	rad

1) M = mass, L = length, T = time, Θ = temperature.

2) γ is the ratio of the specific heat capacity at constant pressure to the specific heat capacity at constant volume. For ideal gases, the ratio of the specific heat capacities and the isentropic exponent have the same value (see 3.3.3). These values depend on the nature of the gas.

3) The dimensions and units are those of the corresponding quantity.

4.2 Subscripts

Subscript	Meaning
1	Upstream
2	Downstream

5 Principle of the method of measurement and computation

5.1 Principle of the method of measurement

The principle of the method of measurement is based on the installation of a primary device (such as an orifice plate, a nozzle or a Venturi tube) into a pipeline in which a fluid is running full. The installation of the primary device causes a static pressure difference between the upstream side and the throat or downstream side of the device. The rate of flow can be determined from the measured value of this pressure difference and from the knowledge of the characteristics of the flowing fluid as well as the circumstances under which the device is being used. It is assumed that the device is geometrically similar to one on which calibration has been carried out and that the conditions of use are the same, i.e. that it is in accordance with this part of ISO 5167.

The mass rate of flow can be determined, since it is related to the differential pressure within the uncertainty limits stated in this part of ISO 5167, by one of the following formulae:

$$q_m = \frac{C}{\sqrt{1-\beta^4}}\,\varepsilon_1\,\frac{\pi}{4}\,d^2\sqrt{2\Delta p \varrho_1} \qquad \ldots (1)$$

or

$$q_m = \frac{C}{\sqrt{1-\beta^4}}\,\varepsilon_2\,\frac{\pi}{4}\,d^2\sqrt{2\Delta p \varrho_2} \qquad \ldots (2)$$

where ϱ_2 and ε_2 are referred to the downstream conditions.

Note that

$$\varepsilon_2 = \varepsilon_1\sqrt{1+\frac{\Delta p}{p_2}}$$

Similarly, the value of the volume rate of flow can be calculated since

$$q_V = \frac{q_m}{\varrho} \qquad \ldots (3)$$

where ϱ is the fluid density at the temperature and pressure for which the volume is stated.

5.2 Method of determination of the diameter ratio of the selected standard primary device

In practice, when determining the diameter ratio of a primary element to be installed in a given pipeline, C and ε used in the basic formulae (1) and (2) are, in general, not known. Hence the following shall be selected a priori:

— the type of primary device to be used;

— a rate of flow and the corresponding value of the differential pressure.

The related values of q_m and Δp are then inserted in the basic formulae rewritten in the form

$$\frac{C\varepsilon\beta^2}{\sqrt{1-\beta^4}} = \frac{4q_m}{\pi D^2\sqrt{2\Delta p\varrho}}$$

in which ϱ and ε can be inserted for either upstream or downstream conditions (ϱ_1 and ε_1, or ϱ_2 and ε_2) and the diameter ratio of the selected primary device can be determined by iteration (see annex D).

5.3 Computation of rate of flow

Tables A.1 to A.16 are given for convenience: tables A.1 to A.13 give the values of C as a function of β, Re_D and D for orifice plates and nozzles, tables A.14 and A.15 give orifice, nozzle and Venturi tube expansibility factors ε_1, and table A.16 gives values of Venturi nozzle discharge coefficients. They are not intended for precise interpolation. Extrapolation is not permitted.

Computation of the rate of flow, which is a purely arithmetic process, is effected by replacing the different terms on the right-hand side of the basic formula (1) or (2) by their numerical values.

NOTES

2 Except for the case of Venturi tubes, C may be dependent on Re, which is itself dependent on q_m. In such cases the final value of C, and hence of q_m, has to be obtained by iteration. See annex D for guidance regarding the choice of the iteration procedure and initial estimates.

3 Δp represents the differential pressure, as defined in 3.1.3.

4 The diameters d and D mentioned in the formulae are the values of the diameters at the working conditions. Measurements taken at any other conditions should be corrected for any possible expansion or contraction of the primary device and the pipe due to the values of the temperature and pressure of the fluid during the measurement.

5 It is necessary to know the density and the viscosity of the fluid at the working conditions.

5.4 Determination of density

It is necessary to know the density of the fluid at the plane of the upstream or downstream pressure tapping; it can either be measured directly or be calculated from a knowledge of the static pressure, temperature and characteristics of the fluid at the appropriate plane. However, it is considered that the upstream pressure tapping will provide the most consistent results.

5.4.1 The static pressure of the fluid shall be measured in the plane of the upstream or downstream pressure tapping by means of an individual pipe-wall pressure tapping (as described in 8.2.1) or by means of carrier ring tappings (see figure 6).

5.4.1.1 The static pressure tapping shall preferably be separate from the tappings provided for measuring the components of the differential pressure, unless the intention is to measure upstream and downstream pressures separately.

It is, however, permissible to link simultaneously one pressure tapping with a differential pressure measuring device and a static pressure measuring device, provided that it is verified that this double connection does not lead to any distortion of the differential pressure measurement.

5.4.1.2 The static pressure value to be used in subsequent computations is that existing at the level of the centre of the measuring cross-section, which may differ from the pressure measured at the wall.

5.4.2 The temperature of the fluid shall preferably be measured downstream of the primary device. The thermometer well or pocket shall take up as little space as possible. The distance between it and the primary device shall be at least equal to $5D$ (and at most $15D$ when the fluid is a gas) if the pocket is located downstream, and in accordance with the values given in table 1, columns 10 and 11, if the pocket is located upstream.

Within the limits of application of this part of ISO 5167 it may generally be assumed that the downstream and upstream temperatures of the fluid are the same at the differential pressure tappings.

However, if the fluid is a gas, its upstream temperature may be calculated from the temperature measured downstream (at a distance of $5D$ to $15D$) of the primary device.

5.4.3 Any method of determining reliable values of the density, static pressure, temperature and viscosity of the fluid is acceptable if it does not interfere with the distribution of the flow in any way at the measuring cross-section.

5.4.4 The temperature of the primary device and that of the fluid upstream of the primary device are assumed to be the same (see 7.1.9).

6 General requirements for the measurements

In order to comply with this part of ISO 5167 the following requirements shall be met.

6.1 Primary device

6.1.1 The primary device shall be manufactured, installed and used in accordance with this part of ISO 5167.

When the manufacturing characteristics and conditions of use of the primary devices are outside the limits given in this part of ISO 5167, it is necessary to calibrate the primary device separately under the actual conditions of use.

6.1.2 The condition of the primary device shall be checked after each measurement or after each series of measurements, or at intervals close enough to each other so that conformity with this part of ISO 5167 is maintained.

It should be noted that even apparently neutral fluids may form deposits or encrustations on primary devices. Resulting changes in the discharge coefficient which can occur over a period of time can lead to values outside the uncertainties given in this part of ISO 5167.

6.1.3 The primary device shall be manufactured from material the coefficient of expansion of which is known, except if the user decides that the variations in the dimensions due to the temperature changes may be neglected.

6.2 Nature of the fluid

6.2.1 The fluid may be either compressible (gas) or considered as being incompressible (liquid).

6.2.2 The fluid shall be such that it can be considered as being physically and thermally homogeneous and single-phase. Colloidal solutions with a high degree of dispersion (such as milk), and only those solutions, are considered to behave as a single-phase fluid.

6.2.3 To carry out the measurement, it is necessary to know the density and viscosity of the fluid at the working conditions.

6.3 Flow conditions

6.3.1 The rate of flow shall be constant or, in practice, shall vary only slightly and slowly with time. This part of ISO 5167 does not provide for the measurement of pulsating flow, which is the subject of ISO/TR 3313[6].

6.3.2 The uncertainties specified in this part of ISO 5167 are valid only when there is no change of phase through the primary device. Increasing the bore or throat of the primary element will reduce the differential pressure, which may prevent a change of phase. To determine whether or not there is a change of phase, the flow computation shall be carried out on the assumption that the expansion is isothermal for liquids or isentropic for gases.

6.3.3 If the fluid is a gas, the pressure ratio as defined in 3.1.4 shall be greater than or equal to 0,75.

7 Installation requirements

7.1 General

7.1.1 The method of measurement applies only to fluids flowing through a pipeline of circular cross-section.

7.1.2 The pipe shall run full at the measuring section.

7.1.3 The primary device shall be installed in the pipeline at a position such that the flow conditions immediately upstream approach those of a fully developed profile and are free from swirl (see 7.4). Such conditions can be expected to exist if the installation conforms to requirements given in this clause.

7.1.4 The primary device shall be fitted between two sections of straight cylindrical pipe of constant cross-sectional area, in which there is no obstruction or branch connection (whether or not there is flow into or out of such connections during measurement) other than those specified in this part of ISO 5167.

The pipe is considered as straight when it appears so by visual inspection. The required minimum straight lengths of pipe, which conform to the description above, vary according to the nature of the fittings, the type of primary device and the diameter ratio. They are specified in tables 1 and 2.

7.1.5 The pipe bore shall be circular over the entire minimum length of straight pipe required. The cross-section is taken to be circular if it appears so by visual inspection. The circularity of the outside of the pipe can be taken as a guide, except in the immediate vicinity of the primary device where special requirements shall apply according to the type of primary device used (see 7.5.1 and 7.6.1).

Seamed pipe may be used provided that the internal weld bead is parallel to the pipe axis throughout the length of the pipe and satisfies the special requirements for the type of primary element. The seam shall not be situated in any sector of $\pm$ 30° centred on any pressure tapping.

7.1.6 The internal diameter D of the measuring pipe shall comply with the values given for each type of primary device.

7.1.7 The inside surface of the measuring pipe shall be clean and free from encrustations, pitting and deposits, and shall conform with the roughness criterion for at least a length of $10D$ upstream and $4D$ downstream of the primary device.

7.1.8 The pipe may be provided with drain holes and/or vent holes for the removal of solid deposits and fluids other than the measured fluid. However, there shall be no flow through the drain holes and vent holes during the measurement of the flow.

The drain holes and vent holes shall not be located near to the primary device, unless it is unavoidable to do so. In such a case, the diameter of these holes shall be smaller than $0{,}08D$ and their location shall be such that the distance, measured on a straight line from one of these holes to a pressure tapping of the primary device placed on the same side of this primary device, is always greater than $0{,}5D$. The axial planes of the pipe containing respectively the centre-line of a pressure tapping and the centre-line of a drain hole or vent hole shall be offset by at least 30°.

6) ISO/TR 3313:1974, *Measurement of pulsating fluid flow in a pipe by means of orifice plates, nozzles or Venturi tubes, in particular in the case of sinusoidal or square wave intermittent periodic-type fluctuations.*

7.1.9 The pipe and the pipe flanges shall be lagged. It is, however, unnecessary to lag the pipe when the temperature of the fluid, between the inlet of the minimum straight length of the upstream pipe and the outlet of the minimum straight length of the downstream pipe, does not exceed any limiting value for the accuracy of flow measurement required.

7.2 Minimum upstream and downstream straight lengths required for installation between various fittings and the primary device

7.2.1 The minimum straight lengths are given in tables 1 and 2.

The minimum straight lengths specified in table 2 for classical Venturi tubes are less than those specified in table 1 for orifice plates, nozzles and Venturi nozzles for the following reasons:

a) they are derived from different experimental results and different correlation approaches;

b) the convergent portion of the classical Venturi tube is designed to obtain a more uniform velocity profile at the throat of the device. Tests have shown that with identical diameter ratios, the minimum straight lengths upstream of the classical Venturi tube may be less than those required for orifice plates, nozzles and Venturi nozzles.

7.2.2 The straight lengths given in tables 1 and 2 are minimum values, and the use of straight lengths longer than those indicated is always recommended. For research work in particular, straight lengths of at least twice the upstream values given in tables 1 and 2 are recommended for "zero additional uncertainty"[7].

7.2.3 When the straight lengths are equal to or longer than the values given in tables 1 and 2 for "zero additional uncertainty"[7], there is no need to add any additional deviation to the discharge coefficient uncertainty to take account of the effect of such installation conditions.

7.2.4 When the upstream **or** downstream straight length is shorter than the "zero additional uncertainty"[7] values and equal to or greater than the "0,5 % additional uncertainty"[8] values, as given in tables 1 and 2, an additional uncertainty of 0,5 % shall be added arithmetically to the uncertainty on the discharge coefficient.

7.2.5 If the straight lengths are shorter than the "0,5 % additional uncertainty"[8] values given in tables 1 and 2, this part of ISO 5167 gives no information by which to predict the value of any additional uncertainty to be taken into account; this is also the case when the upstream **and** downstream straight lengths are both shorter than the "zero additional uncertainty"[7] values.

7.2.6 The valves mentioned in tables 1 and 2 shall be fully open. It is recommended that control of the flow-rate be effected by valves located downstream of the primary device. Isolating valves located upstream shall be fully open and shall be preferably of the "gate" type.

7.2.7 After a single change of direction (bend or tee), it is recommended that if pairs of single tappings are used they be installed so that their axes are perpendicular to the plane of the bend or tee.

7.2.8 The values given in tables 1 and 2 were obtained experimentally with a very long straight length upstream of the particular fitting in question and so it could be assumed that the flow upstream of the disturbance was virtually fully developed and swirl-free. Since in practice such conditions are difficult to achieve, the following information may be used as a guide for normal installation practice.

a) If the primary device is installed in a pipe leading from an upstream open space or large vessel, either directly or through any fitting, the total length of pipe between the open space and the primary device shall never be less than $30D$[9]. If any fitting is installed, then the straight lengths given in table 1 or 2 shall also apply between this fitting and the primary device.

b) If several fittings other than 90° bends[10] are placed in series upstream from the primary device, the following rule shall be applied: between the fitting (1) closest to the primary device and the primary device itself, there shall be a minimum straight length such as is indicated for the fitting (1) in question and for the actual values of β in table 1 or 2. But, in addition, between this fitting (1) and the preceding one (2) there shall be a straight length equal to one-half of the value

7) Values without parentheses in tables 1 and 2.

8) Values in parentheses in tables 1 and 2.

9) In the absence of experimental data, it seemed wise to adopt for classical Venturi tubes the conditions required for orifice plates and nozzles.

10) In the case of several 90° bends, refer to tables 1 and 2 which can be applied whatever the length between two consecutive bends.

Table 1 — Required straight lengths for orifice plates, nozzles and Venturi nozzles

Values expressed as multiples of D

Diameter ratio β	Upstream (inlet) side of the primary device										Downstream (outlet) side of the primary device
	Single 90° bend or tee (flow from one branch only)	Two or more 90° bends in the same plane	Two or more 90° bends in different planes	Reducer $2D$ to D over a length of $1,5D$ to $3D$	Expander $0,5D$ to D over a length of D to $2D$	Globe valve fully open	Full bore ball or gate valve fully open	Abrupt symmetrical reduction having a diameter ratio ⩾ 0,5	Thermometer pocket or well*) of diameter ⩽ $0,03D$	Thermometer pocket or well*) of diameter between $0,03D$ and $0,13D$	Fittings (columns 2 to 8)
1	2	3	4	5	6	7	8	9	10	11	12
0,20	10 (6)	14 (7)	34 (17)	5	16 (8)	18 (9)	12 (6)				4 (2)
0,25	10 (6)	14 (7)	34 (17)	5	16 (8)	18 (9)	12 (6)				4 (2)
0,30	10 (6)	16 (8)	34 (17)	5	16 (8)	18 (9)	12 (6)				5 (2,5)
0,35	12 (6)	16 (8)	36 (18)	5	16 (8)	18 (9)	12 (6)				5 (2,5)
0,40	14 (7)	18 (9)	36 (18)	5	16 (8)	20 (10)	12 (6)				6 (3)
0,45	14 (7)	18 (9)	38 (19)	5	17 (9)	20 (10)	12 (6)				6 (3)
0,50	14 (7)	20 (10)	40 (20)	6 (5)	18 (9)	22 (11)	12 (6)	30 (15)	5 (3)	20 (10)	6 (3)
0,55	16 (8)	22 (11)	44 (22)	8 (5)	20 (10)	24 (12)	14 (7)				6 (3)
0,60	18 (9)	26 (13)	48 (24)	9 (5)	22 (11)	26 (13)	14 (7)				7 (3,5)
0,65	22 (11)	32 (16)	54 (27)	11 (6)	25 (13)	28 (14)	16 (8)				7 (3,5)
0,70	28 (14)	36 (18)	62 (31)	14 (7)	30 (15)	32 (16)	20 (10)				7 (3,5)
0,75	36 (18)	42 (21)	70 (35)	22 (11)	38 (19)	36 (18)	24 (12)				8 (4)
0,80	46 (23)	50 (25)	80 (40)	30 (15)	54 (27)	44 (22)	30 (15)				8 (4)

*) The installation of thermometer pockets or wells will not alter the required minimum upstream straight lengths for the other fittings.

NOTES

1 The minimum straight lengths required are the lengths between various fittings located upstream or downstream of the primary device and the primary device itself. All straight lengths shall be measured from the upstream face of the primary device.

2 Values without parentheses are "zero additional uncertainty" values (see 7.2.3).

3 Values in parentheses are "0,5 % additional uncertainty" values (see 7.2.4).

Table 2 — Required straight lengths for classical Venturi tubes

Values expressed as multiples of D

Diameter ratio β	Single 90° bend*)	Two or more 90° bends in the same plane*)	Two or more 90° bends in different planes*) **)	Reducer $3D$ to D over a length of $3,5D$	Expander $0,75D$ to D over a length of D	Full bore ball or gate valve fully open
0,30	0,5***)	1,5 (0,5)	(0,5)	0,5***)	1,5 (0,5)	1,5 (0,5)
0,35	0,5***)	1,5 (0,5)	(0,5)	1,5 (0,5)	1,5 (0,5)	2,5 (0,5)
0,40	0,5***)	1,5 (0,5)	(0,5)	2,5 (0,5)	1,5 (0,5)	2,5 (1,5)
0,45	1,0 (0,5)	1,5 (0,5)	(0,5)	4,5 (0,5)	2,5 (1)	3,5 (1,5)
0,50	1,5 (0,5)	2,5 (1,5)	(8,5)	5,5 (0,5)	2,5 (1,5)	3,5 (1,5)
0,55	2,5 (0,5)	2,5 (1,5)	(12,5)	6,5 (0,5)	3,5 (1,5)	4,5 (2,5)
0,60	3,0 (1,0)	3,5 (2,5)	(17,5)	8,5 (0,5)	3,5 (1,5)	4,5 (2,5)
0,65	4,0 (1,5)	4,5 (2,5)	(23,5)	9,5 (1,5)	4,5 (2,5)	4,5 (2,5)
0,70	4,0 (2,0)	4,5 (2,5)	(27,5)	10,5 (2,5)	5,5 (3,5)	5,5 (3,5)
0,75	4,5 (3,0)	4,5 (3,5)	(29,5)	11,5 (3,5)	6,5 (4,5)	5,5 (3,5)

*) The radius of curvature of the bend shall be greater than or equal to the pipe diameter.
**) As the effect of these fittings may still be present after $40D$, no values without parentheses can be given.
***) Since no fitting can be placed closer than $0,5D$ to the upstream pressure tapping in the Venturi tube, the "zero additional uncertainty" values are the only ones applicable in this case.

NOTES

1 The minimum straight lengths required are the lengths between various fittings located upstream of the classical Venturi tube and the classical Venturi tube itself. All straight lengths shall be measured from the upstream pressure tapping plane of the classical Venturi tube. The pipe roughness, at least over the length indicated in this table, shall not exceed that of a smooth, commercially available pipe (approximately $k/D \leqslant 10^{-3}$).

2 Values without parentheses are "zero additional uncertainty" values (see 7.2.3).

3 Values in parentheses are "0,5 % additional uncertainty" values (see 7.2.4).

4 For downstream straight lengths, fittings or other disturbances (as indicated in this table) situated at least four throat diameters downstream of the throat pressure tapping plane do not affect the accuracy of the measurement.

given in table 1 or 2 for fitting (2) for a primary device of diameter ratio $\beta = 0,7$ whatever the actual value of β may be. This requirement does not apply when the fitting (2) is an abrupt symmetrical reduction, the case of which is covered by a) above.

If one of the minimum straight lengths so adopted appears in parentheses, a 0,5 % additional uncertainty shall be added arithmetically to the discharge coefficient uncertainty.

7.3 Flow conditioners

The use of flow conditioners of the types described in 7.3.2 and shown in figures 1 to 3 is recommended to permit the installation of primary devices downstream of fittings not included in table 1 or 2. When a large diameter ratio primary device is to be used, the inclusion of such devices sometimes permits the use of shorter installation lengths upstream of the primary device than are given in table 1.

When installed as described in 7.3.1, the use of a flow conditioner does not introduce any additional uncertainty in the discharge coefficient.

7.3.1 Installation

Any flow conditioner used shall be installed in the upstream straight length between the primary device and the disturbance or fitting closest to the primary device. Unless it can be verified that the flow conditions at the inlet of the primary device conform with the requirements of 7.1.3, the straight length between this fitting and the conditioner itself shall be equal to at least $20D$, and the straight length between the conditioner and the primary device shall be equal to at least $22D$. These lengths are measured from the upstream face and the downstream face respectively of the conditioner. Conditioners are only fully effective if their installation is such that the smallest possible gaps are left around the resistive elements of the device, therefore permitting no by-pass flows which would prevent their proper functioning.

When correctly built conditioners are used with the pipe length combinations described above, they can be used in conjunction with any entrance velocity profile.

7.3.2 Types of flow conditioners

The five standardized types of flow conditioners are shown in figures 1 to 3. The choice of a conditioner is dependent on the nature of the velocity distribution which has to be corrected and on the pressure loss which can be tolerated. The devices described below create a pressure loss of approximately