International Standard ISO 5221

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Air distribution and air diffusion — Rules to methods of measuring air flow rate in an air handling duct

Distribution et diffusion de l'air — Règles pour la technique de mesure du débit d'air dans un conduit aéraulique

First edition — 1984-01-15

UDC 697.922 : 533.6.08 **Ref. No. ISO 5221-1984 (E)**

Descriptors : air distribution, air diffusion, air flow, flow rate, flow measurement, aeraulic pipes, flowmeters, Venturi tubes, Reynolds number, dimensions, dimensional tolerances, characteristics.

ISO 5221-1984 (E)

Price based on 33 pages

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of developing International Standards is carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been authorized 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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 5221 was developed by Technical Committee ISO/TC 144, *Air distribution and air diffusion*, and was circulated to the member bodies in July 1980.

It has been approved by the member bodies of the following countries :

Australia	Ireland	South Africa, Rep. of
Austria	Italy	Sweden
Belgium	Korea, Rep. of	United Kingdom
Czechoslovakia	Norway	USA
Finland	Poland	
France	Romania	

No member body expressed disapproval of the document.

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Air distribution and air diffusion — Rules to methods of measuring air flow rate in an air handling duct

0 Introduction

These rules result from several special considerations, which should be kept in mind :

a) The fluid is air, its temperature and pressure being almost those at ambient conditions.

b) Since the flow rates are sometimes relatively small, the Reynolds numbers to be considered may sometimes correspond to relatively small values (for instance some thousands).

c) The widest possible freedom of choice is provided in order to have methods which can be applied either to laboratory testing or to site testing.

d) The methods of measuring air flow rates in a duct have reached a higher degree in the matter of accuracy than is sometimes necessary for the requirements of air distribution and air diffusion.

This International Standard, partially derived from International Standards already published (see clause 2), has been prepared taking into account these considerations but without keeping all the specifications because of the reduced requirements concerning uncertainty on flow quality which are limited to a value of ± 2 % or even more for some devices (see clauses 7.8 and 7.9).

The values indicated for the uncertainty of the coefficients given must be increased for the uncertainty of the air flow rate itself when inappropriate manometers are used.

Finally it should not be forgotten that the values which are mentioned throughout this International Standard would be seriously in error if the flow approaching the measuring device is not free from swirl and that some of the measuring devices herein described do not offer any guarantee on this point without the addition of a suitable accessory.

In cases where low Reynolds numbers occur and where reduced requirements concerning accuracy are acceptable, such as measurement of leakage flow rates, special information has been given in an annex to this International Standard.

1 Scope and field of application

This International Standard gives different methods of measuring air flow rate in an air handling duct which, without the need of calibration, meet various specific requirements in the field of air distribution and air diffusion.

For the purpose of this International Standard an "air handling duct" is defined as a tight section of straight ductwork such that the general conditions for device installation can be met. The cross-section of the duct may be circular or, excluding for device 14, rectangular.

2 References

ISO 3966, *Measurement of fluid flow in closed conduits — Velocity area method using Pitot static tubes.*

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

3 Proposed measuring devices

This International Standard proposes the use of one of the following devices :

1) Orifice plate with corner taps (see 7.0 and 7.1)

2) Orifice plate with flange taps (see 7.0 and 7.2)

3) Orifice plate with D and $D/2$ tappings (see 7.0 and 7.3)

4) ISA 1932 nozzle (see 7.4)

5) "Long-radius" nozzle (see 7.5)

6) Classical Venturi tube (see 7.6)

7) Venturi nozzle (see 7.7)

8) Orifice plate with conical entrance (see 7.8)

9) "Quarter circle" orifice plate (see 7.9)

10) Orifice plate located at the inlet end of the system (see 7.10)

11) "Quarter circle" nozzle located at the inlet end of the system (see 7.11)

12) Inlet cone (see 7.12)

13) Venturi nozzle with sonic throat (see 7.13)

14) Pitot-static tube (see 7.14)

4 General formulae of calculation

These devices depend on three different principles :

a) for the first twelve devices mentioned, the flow rate measurement requires the measurement of the differential pressure Δp between the upstream and the downstream (or throat) sides of the device,

b) for the thirteenth device, the air reaches a velocity equal to the speed of sound at the throat and the flow rate measurement thus requires only knowledge of the state of the fluid upstream of the device,

c) for the fourteenth device, used in the velocity area method, the differential pressure measured at a number of points permits the discharge velocity to be determined through the corresponding local velocities and hence, the flow rate.

For the devices 1 to 12 the formulae giving the flow rate is :

$$q_m = \alpha \, \varepsilon \, \frac{\pi}{4} \, d^2 \sqrt{2 \varrho_1 \, \Delta p}$$

where

q_m is the mass rate of flow;

α is the flow coefficient;

ε is the expansibility (expansion) factor;

d is the diameter of orifice or throat;

ϱ_1 is the mass density of the fluid upstream of the device (section of the upstream pressure tap);

Δp is the differential pressure between the upstream and downstream pressure taps.

For device 13 (see 7.13), the basic formula used is :

$$q_m = K \, C \, \frac{\pi}{4} \, d^2 \, \frac{p_{am}}{\sqrt{\Theta_{am}}}$$

where

K is a critical flow function of air;

C is the coefficient of discharge;

p_{am} is the absolute stagnation pressure in the free space upstream of the device;

Θ_{am} is the absolute stagnation temperature in this free space.

For device 14 (see 7.14), the basic formula used for the calculation of local velocity, is :

$$u = \alpha \, \varepsilon \sqrt{\frac{2 \Delta p}{\varrho}}$$

where ε is the correction factor for compressibility which can be determined by the relation :

$$\varepsilon = \left[1 - \frac{1}{2\gamma} \frac{\Delta p}{p} + \frac{\gamma - 1}{6\gamma^2} \left(\frac{\Delta p}{p} \right)^2 \right]^{1/2}$$

in which

Δp is the differential pressure indicated by the Pitot-static tube;

ϱ is the density of air;

p is the local pressure (absolute pressure);

γ is the heat capacities ratio;

α is the calibration factor of Pitot-static tube.

In the case of ambient air, the following formula can be given :

$$\varepsilon = 1 - 0{,}18 \frac{\Delta p}{p}$$

Coefficient α can generally be taken equal to 1, a value from which it differs, if ever, only by some thousandths at a maximum under the conditions mentioned in 7.14.

The discharge velocity, i.e. the volume flow rate through the considered cross-section divided by its area, can then be determined from the local velocity values, either by graphical integration, or numerical integration, or by an arithmetic method. The volume rate of flow is deduced at the same time by obtaining the product of the discharge velocity and the area of the section.

5 Symbols and units

See table 1.

6 General conditions for the installation of the various devices

6.1 Subsonic pressure-difference devices (devices 1 to 12)

Certain devices are disposed between two straight lengths of duct, whereas other devices such as 10, 11 and 12 are located at the upstream end of a duct. This latter location has the advantage of substantially reducing cumbersomeness of the test system to be used for the flow rate measurement.

It should be noted that one of the possible serious errors with such devices is a swirling flow at the approach to the device and that it is essential to obtain protection against such effects by means of proper anti-swirl devices (crosspiece straightener within a circular duct, with a length of $2D$ and eight radial blades; honeycombs; AMCA straightener, etc.) which are located at a distance from the flow rate measuring device in order that the flow pattern at the approach to the measuring device is close to the pattern of a fully developed flow.

Table 1

Symbol	Represented quantity	Dimensions[1]	Corresponding SI unit	Symbol	Represented quantity	Dimensions[1]	Corresponding SI unit
C	Coefficient of discharge	—		Re_D	Reynolds number of the flow referred to D $Re_D = \frac{4q_m}{\pi \varrho_1 D \nu}$	—	
c_p	Heat capacity at constant pressure	$L^2 T^{-2} \Theta^{-1}$	$J \cdot kg^{-1} K^{-1}$	Re_d	Reynolds number of the flow referred to d $Re_d = \frac{4q_m}{\pi \varrho_1 d \nu}$	—	
c_V	Heat capacity at constant volume	$L^2 T^{-2} \Theta^{-1}$	$J \cdot kg^{-1} K^{-1}$	U	Discharge velocity	$L T^{-1}$	$m \cdot s^{-1}$
d	Diameter of orifice or throat of primary device at operating conditions, or diameter of Pitot tube stem	L	m	u	Local flow velocity (see 7.14)	$L T^{-1}$	$m \cdot s^{-1}$
D	Upstream duct diameter of primary device (or upstream diameter of a classical Venturi tube), or diameter of the circular section of a duct, at operating conditions	L	m	α	Flow coefficient for devices 1 to 12 or calibration factor for device 14	—	
g	Acceleration due to gravity	$L T^{-2}$	$m \cdot s^{-2}$	β	Diameter ratio $\beta = \frac{d}{D}$	—	
k	Absolute roughness	L	m	γ	Specific heat capacities ratio $\frac{c_p}{c_V}$	—	
l	Length	L	m	ε	Expansibility (expansion) factor	—	
Ma	Local Mach number $Ma = \frac{\mu}{\sqrt{\frac{\kappa p}{\varrho}}}$	—		Θ	Absolute temperature of the fluid	Θ	K
p	Pressure of the fluid	$ML^{-1} T^{-2}$	Pa	κ	Isentropic exponent	—	
Δp	Differential pressure ($\Delta p = p_1 - p_2$)	$ML^{-1} T^{-2}$	Pa	μ	Dynamic viscosity of the fluid	$ML^{-1} T^{-1}$	Pa·s
q_m	Mass rate of flow	$M T^{-1}$	$kg \cdot s^{-1}$	ν	Kinematic viscosity of the fluid	$L^2 T^{-1}$	$m^2 \cdot s^{-1}$
q_V	Volume rate of flow	$L^3 T^{-1}$	$m^3 \cdot s^{-1}$	ϱ	Mass density of the fluid	ML^{-3}	$kg \cdot m^{-3}$
R	Radius	L	m	φ	Total angle of the divergent (for a Venturi-nozzle)	—	°

Indices 1 and 2 refer to the fluid conditions at the upstream and downstream tappings for devices 1 to 12 respectively.

6.1.1 Inserted subsonic pressure-difference devices (devices 1 to 7)[2]

The devices inserted in the duct require, in fact, recourse to the use of long straight lengths on both sides of the device, these lengths being greater when an adjacent fitting causes the swirl in the flow (for example, successive bends in different planes).

It should be noted furthermore that the minimum lengths required increase with the diameter ratio β of the device.

Tables 2 and 3 indicate the minimum straight lengths required between various fittings located upstream or downstream of the subsonic devices mentioned above, expressed as multiples of the diameter D.

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

2) See ISO 5167, subclause 6.2.

Table 2 — Case of orifice plates, nozzles or Venturi nozzles

Minimum straight lengths required between various fittings located upstream or downstream of the primary element and the primary element itself.

β	On upstream side of the primary device					On downstream side
	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 $1,5\,D$ to $3D$)	Expander ($0,5\,D$ to D over a length of $1D$ to $2D$)	All fittings included in this table
$\leqslant$ 0,20	10 (6)	14 (7)	34 (17)	5 *	16 (8)	4 (2)
0,25	10 (6)	14 (7)	34 (17)	5 *	16 (8)	4 (2)
0,30	10 (6)	16 (8)	34 (17)	5 *	16 (8)	5 (2,5)
0,35	12 (6)	16 (8)	36 (18)	5 *	16 (8)	5 (2,5)
0,40	14 (7)	18 (9)	36 (18)	5 *	16 (8)	6 (3)
0,45	14 (7)	18 (9)	38 (19)	5 *	17 (9)	6 (3)
0,50	14 (7)	20 (10)	40 (20)	6 (5)	18 (9)	6 (3)
0,55	16 (8)	22 (11)	44 (22)	8 (5)	20 (10)	6 (3)
0,60	18 (9)	26 (13)	48 (24)	9 (5)	22 (11)	7 (3,5)
0,65	22 (11)	32 (16)	54 (27)	11 (6)	25 (13)	7 (3,5)
0,70	28 (14)	36 (18)	62 (31)	14 (7)	30 (15)	7 (3,5)
0,75	36 (18)	42 (21)	70 (35)	22 (11)	38 (19)	8 (4)
0,80	46 (23)	50 (25)	80 (40)	30 (15)	54 (27)	8 (4)

Fittings	Minimum upstream straight length required
Abrupt symmetrical reduction having a diameter ratio $\geqslant$ 0,5	30 (15)
Thermometer pocket of diameter $\leqslant 0,03\,D$	5 (3)
Thermometer pocket of diameter between $0,03\,D$ and $0,13\,D$	20 (10)

* As no fitting can be located within $5D$ of the upstream pressure taps the value for "nil additional limit error" is applicable.

NOTES

1 The values without brackets are values for "nil additional limit error". The values in brackets are values for "additional limit error of ± 0,5 %".

2 All straight lengths are expressed in multiples of diameter D. They must be measured from the upstream face of the primary element.

6.1.1.1 If the primary element is situated in an air handling duct connecting it to an open enclosure or to a large container situated upstream, either directly or by means of accessories, the total length of duct between the open enclosure and the primary element should in no case be less than $30\,D$.[1)]

If there is an accessory, the straight lengths have furthermore to correspond to the requirements for straight lengths between this accessory and the primary element given in the tables above.

6.1.1.2 If several accessories other than 90° elbows follow one another upstream from the primary element, the following rule must be applied : between the accessory (1) which is closest to the primary element and the primary element itself, maintain a minimum straight length, such as indicated for the accessory (1) in question and the real value of β in tables 2 and 3. Also maintain between this accessory (1) and the preceding accessory (2), a straight length equal to half the value indicated in the tables 2 and 3 for the accessory (2) applicable to a primary element with a diameter ratio $\beta = 0,7$, whichever the real value of β. This rule does not apply when accessory (2) is a sudden symmetrical reduction, which case is treated in the above paragraph.[2)]

If one of the minimum retained straight lengths corresponds to a value between brackets, one has to add the supplementary limit error of ± 0,5 % to the error on the flow coefficient.

6.1.1.3 Each pressure measuring section includes at least one pressure tap. The drilling axis of the latter shall be perpendicular to the axis of the duct and the edge of the hole shall present a sharp deburred edge. The dimension of the taps other than corner taps shall be such that their diameter remains in any case less than 0,08 times the pipe diameter D and preferably smaller than 12 mm. For corner taps, either individual taps whose diameter lies between 1 and 10 mm, and simultaneously between $0,005\,D$ and $0,03\,D$ if $\beta \leqslant 0,65$ and between $0,01\,D$ and $0,02\,D$ if $\beta > 0,65$, or annular slots can be used.

1) In the absence of experimental data, it seemed advisable to adopt for classical Venturi tubes the same prescriptions required for orifice plates and for nozzles.

2) In the case of several 90° elbows, refer to tables 2 and 3 which can apply, whatever the length between two consecutive elbows may be.

Table 3 — Case of classical Venturi tubes

Minimum straight lengths required between various fittings located upstream of the classical Venturi tube and the classical Venturi tube itself.

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

1) The radius of curvature of the bend should be equal to or greater than the duct diameter.

2) As the effect of these fittings may still be present after 40 D, no unbracketed values can be given in the table.

3) Since no fitting can be placed closer than 0,5 D to the upstream pressure taps of the Venturi tube, the ''zero additional tolerance'' value is applicable in this instance.

NOTES

1 The values without brackets are values for ''nil additional limit error''. The values in brackets are values for ''additional limit error of ± 0,5 %''.

2 All straight lengths are expressed in multiples of diameter D. They must be measured from the plane of the upstream pressure taps of the classical Venturi tube. The roughness of the duct, at least for the length indicated in the previous table should not exceed that of commercially available ducts (approximately $\frac{k}{D} \leqslant 10^{-3}$).

3 Downstream straight lengths : the accessories or obstacles (indicated in table 3) situated downstream at least four times the throat diameter from the plane of the pressure taps at the throat do not affect the accuracy of measurements.

6.1.1.4 The annular slots are usually flush on their entire perimeter without discontinuity. If this is not the case, each annular chamber shall communicate with the interior of the pipe by openings whose axes form equal angles with respect to one another, the number of which is at least four, and whose individual opening surface is at least equal to 12 mm^2.

6.1.1.5 The pressure tappings shall be cylindrical over a length at least 2,5 times the diameter of the tapping, measured from the inner wall of the duct.

6.2 Venturi-nozzles with sonic throat (devices 13)

For these devices it is enough to measure the absolute pressure and temperature in the chamber of diameter D at least equal to three times the throat diameter d and to check that the ratio of the absolute pressures downstream and upstream of the device does not exceed a critical value (see 7.13). If substantial pressure fluctuations prevail downstream of the device, the measurement and the value of the flow rate are not affected by them and the knowledge of the nature and the upstream state of the fluid allows the measured value of the flow rate to be obtained when the throat size is known.

The device shall be installed in the duct at a position such that the flow conditions immediately upstream are free from swirl.

6.3 Pitot-static tube (devices 14)

The section chosen to carry out the measurements shall be situated in a straight length and be perpendicular to the duct axis . It shall be of a simple form, either circular or rectangular for example.

It shall be situated in an area where the measured velocities are within the normal range of the employed device.

In the proximity of the measuring section, the flow shall be noticeably parallel to the duct axis (angle generally less than 5°) and shall present neither excessive turbulence nor swirl. The measuring section has consequently to be chosen at a sufficient distance from any fitting which could create dissymmetry, swirl or turbulence and might therefore seriously alter the data obtained from the tube which is parallel to the duct axis within 5°.

The straight length which may be necessary to satisfy these conditions varies according to flow velocity, upstream fittings, turbulence level and degree of swirl, if any.

7 Characteristics and employment limitations of the different devices

7.0 Common characteristics of devices under clauses 7.1, 7.2 and 7.3

The orifice plate shall conform with the drawing in figure 1.

The principal specifications relating to the plate are :

— Plane upstream face, its roughness (total height) being inferior to 0,000 3 d within a circle of diameter 1,5 d, which is concentric to the orifice.

— Plane downstream face parallel to the upstream face.

— $e \leqslant E \leqslant 0,05\ D$

$(0,005\ D \leqslant e \leqslant 0,02\ D)$

— $30° \leqslant F \leqslant 45°$

— If $E \leqslant 0,02\ D$, bevelling not compulsory.

— Sharp upstream edge G.

— Determination of d as the mean of the measurements of four diameters at least angularly distributed (none of the four measurements differing from the average by more than $5 \times 10^{-4}\ d$).

The orifice plate which is described above can be associated to one of the three pressure tap types mentioned under 7.1, 7.2 and 7.3.

Reference shall be made to ISO 5167 for specifications related to pressure taps.

The conditions for use of the three types of orifice plates are :

$0,012\ 5\ m \leqslant d$

$0,050\ m \leqslant D$

$0,20 \leqslant \beta \leqslant 0,75$

$\frac{k}{D} \leqslant 10^{-3}$

$\frac{\Delta p}{p_1} \leqslant 0,25$

The Reynolds number Re_D shall be greater than or equal to a minimum value of $1,26 \times 10^6\ \beta^2\ D$.

The flow coefficient α is given by the Stolz formula :

$$\alpha = \alpha_\infty + 0,002\ 9\ (1 - \beta^4)^{-0,5}\ \beta^{2,5} \left(\frac{10^6}{Re_D}\right)^{0,75}$$

where

$$\alpha_\infty = (1 - \beta^4)^{-0,5}\ [0,595\ 9 + 0,031\ 2\ \beta^{2,1} - 0,184\ 0\ \beta^8 + 0,090\ 0\ l_1\ D^{-1}\ \beta^4 (1 - \beta^4)^{-1} - 0,033\ 7\ l'_2\ D^{-1}\ \beta^3]$$

in which

l_1 is the distance of the upstream pressure tap to the upstream face of the orifice plate;

l'_2 is the distance of the downstream pressure tap to the downstream face of the orifice plate.

NOTE — When

$$0,050\ m \leqslant D \leqslant \frac{2,286}{39}\ m (\approx 0,059\ m)$$

the term

$$(1 - \beta^4)^{-0,5}\ [0,090\ 0\ l_1\ D^{-1}\ \beta^4\ (1 - \beta^4)^{-1}]$$

is to be replaced by

$$(1 - \beta^4)^{-0,5}\ [0,039\ 0\ \beta^4\ (1 - \beta^4)^{-1}]$$

Table 4 gives values of coefficient α_∞ and of $2,9\ (1 - \beta^4)^{-0,5}\ \beta^{2,5}$ for a series of values of β and D.

Because of the rounding off to within 10^{-3} of the values of α_∞, linear interpolation is permitted between two successive values of β.

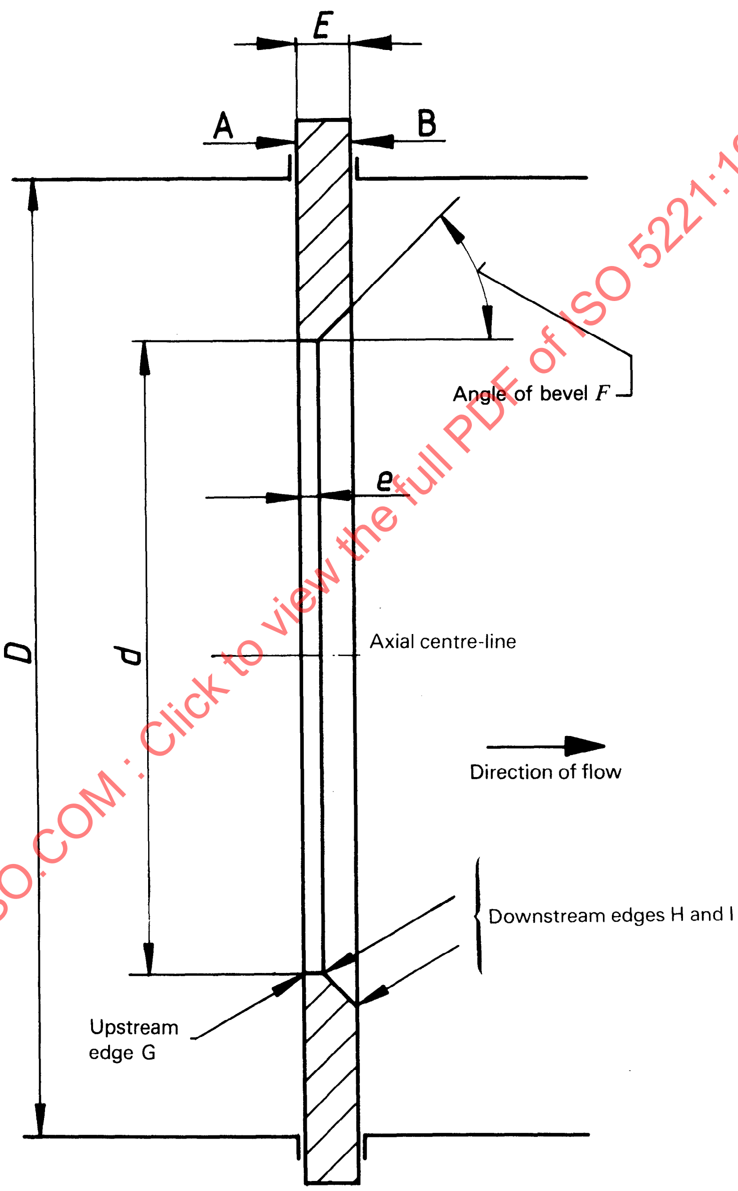


Figure 1 — Standard orifice plate

Table 4 — Values of coefficient α_∞ and of $2{,}9\,(1 - \beta^4)^{-0{,}5}\,\beta^{2{,}5}$ for orifice plates as a function of β and D

β	Corner taps	Flange taps							D and $\frac{D}{2}$ taps	$2{,}9\,(1 - \beta^4)^{-0{,}5}\,\beta^{2{,}5}$
	$D = \infty$	D = 0,600	D = 0,400	D = 0,200	D = 0,150	D = 0,100	D = 0,060	D = 0,050		
0,20	0,597	0,597	0,597	0,597	0,597	0,597	0,597	0,597	0,597	0,052
0,25	0,599	0,599	0,599	0,599	0,599	0,599	0,599	0,599	0,599	0,091
0,30	0,601	0,601	0,601	0,601	0,601	0,601	0,601	0,601	0,601	0,144
0,32	0,602	0,602	0,602	0,602	0,602	0,602	0,602	0,602	0,602	0,169
0,34	0,603	0,603	0,603	0,603	0,603	0,603	0,603	0,603	0,603	0,197
0,36	0,605	0,605	0,605	0,605	0,605	0,605	0,605	0,604	0,605	0,227
0,38	0,606	0,606	0,606	0,606	0,606	0,606	0,606	0,606	0,606	0,261
0,40	0,608	0,608	0,608	0,608	0,608	0,608	0,608	0,608	0,608	0,297
0,41	0,609	0,609	0,609	0,609	0,609	0,609	0,609	0,609	0,609	0,317
0,42	0,610	0,610	0,610	0,610	0,610	0,610	0,611	0,610	0,610	0,337
0,43	0,612	0,612	0,612	0,612	0,612	0,612	0,612	0,612	0,612	0,358
0,44	0,613	0,613	0,613	0,613	0,613	0,613	0,613	0,613	0,613	0,380
0,45	0,614	0,614	0,614	0,614	0,614	0,614	0,614	0,614	0,614	0,402
0,46	0,616	0,616	0,616	0,616	0,616	0,616	0,616	0,616	0,616	0,426
0,47	0,617	0,617	0,617	0,617	0,617	0,617	0,618	0,617	0,617	0,450
0,48	0,619	0,619	0,619	0,619	0,619	0,619	0,619	0,619	0,619	0,476
0,49	0,620	0,620	0,621	0,621	0,621	0,621	0,621	0,621	0,621	0,502
0,50	0,622	0,622	0,622	0,622	0,623	0,623	0,623	0,623	0,623	0,530
0,51	0,624	0,624	0,624	0,624	0,624	0,625	0,625	0,625	0,625	0,558
0,52	0,626	0,626	0,626	0,626	0,626	0,627	0,627	0,627	0,627	0,587
0,53	0,628	0,628	0,628	0,629	0,629	0,629	0,629	0,629	0,629	0,618
0,54	0,631	0,631	0,631	0,631	0,631	0,631	0,632	0,631	0,632	0,650
0,55	0,633	0,633	0,633	0,633	0,634	0,634	0,634	0,634	0,634	0,683
0,56	0,635	0,636	0,636	0,636	0,636	0,636	0,637	0,637	0,637	0,717
0,57	0,638	0,638	0,638	0,639	0,639	0,639	0,640	0,640	0,640	0,752
0,58	0,641	0,641	0,641	0,641	0,642	0,642	0,643	0,643	0,643	0,789
0,59	0,644	0,644	0,644	0,645	0,645	0,645	0,646	0,646	0,646	0,827
0,60	0,647	0,647	0,647	0,648	0,649	0,649	0,650	0,649	0,649	0,867
0,61	0,650	0,650	0,651	0,651	0,651	0,652	0,653	0,653	0,653	0,908
0,62	0,654	0,654	0,654	0,655	0,655	0,656	0,657	0,656	0,657	0,951
0,63	0,657	0,658	0,658	0,658	0,659	0,659	0,661	0,660	0,661	0,995
0,64	0,661	0,661	0,662	0,662	0,663	0,664	0,665	0,665	0,665	1,042
0,65	0,665	0,665	0,666	0,666	0,667	0,668	0,670	0,669	0,669	1,090
0,66	0,669	0,670	0,670	0,671	0,671	0,672	0,674	0,674	0,674	1,140
0,67	0,674	0,674	0,674	0,675	0,676	0,677	0,680	0,679	0,679	1,193
0,68	0,678	0,679	0,679	0,680	0,681	0,682	0,685	0,684	0,685	1,247
0,69	0,683	0,684	0,684	0,685	0,686	0,688	0,691	0,690	0,690	1,304
0,70	0,688	0,689	0,690	0,691	0,692	0,693	0,697	0,696	0,696	1,337
0,71	0,694	0,695	0,695	0,697	0,697	0,699	0,703	0,702	0,703	1,426
0,72	0,700	0,701	0,701	0,703	0,704	0,706	0,710	0,709	0,709	1,492
0,73	0,706	0,707	0,707	0,709	0,710	0,713	0,717	0,716	0,717	1,560
0,74	0,712	0,713	0,714	0,716	0,717	0,720	0,725	0,724	0,725	1,633
0,75	0,719	0,720	0,721	0,723	0,725	0,728	0,733	0,732	0,733	1,709

The expansibility factor ε is calculated using the empirical formula

$$\varepsilon = 1 - (0{,}41 + 0{,}35\,\beta^4)\,\frac{\Delta p}{\kappa p_1}$$

Figure 2 gives the expansifility factor ε for $\kappa = 1{,}4$.

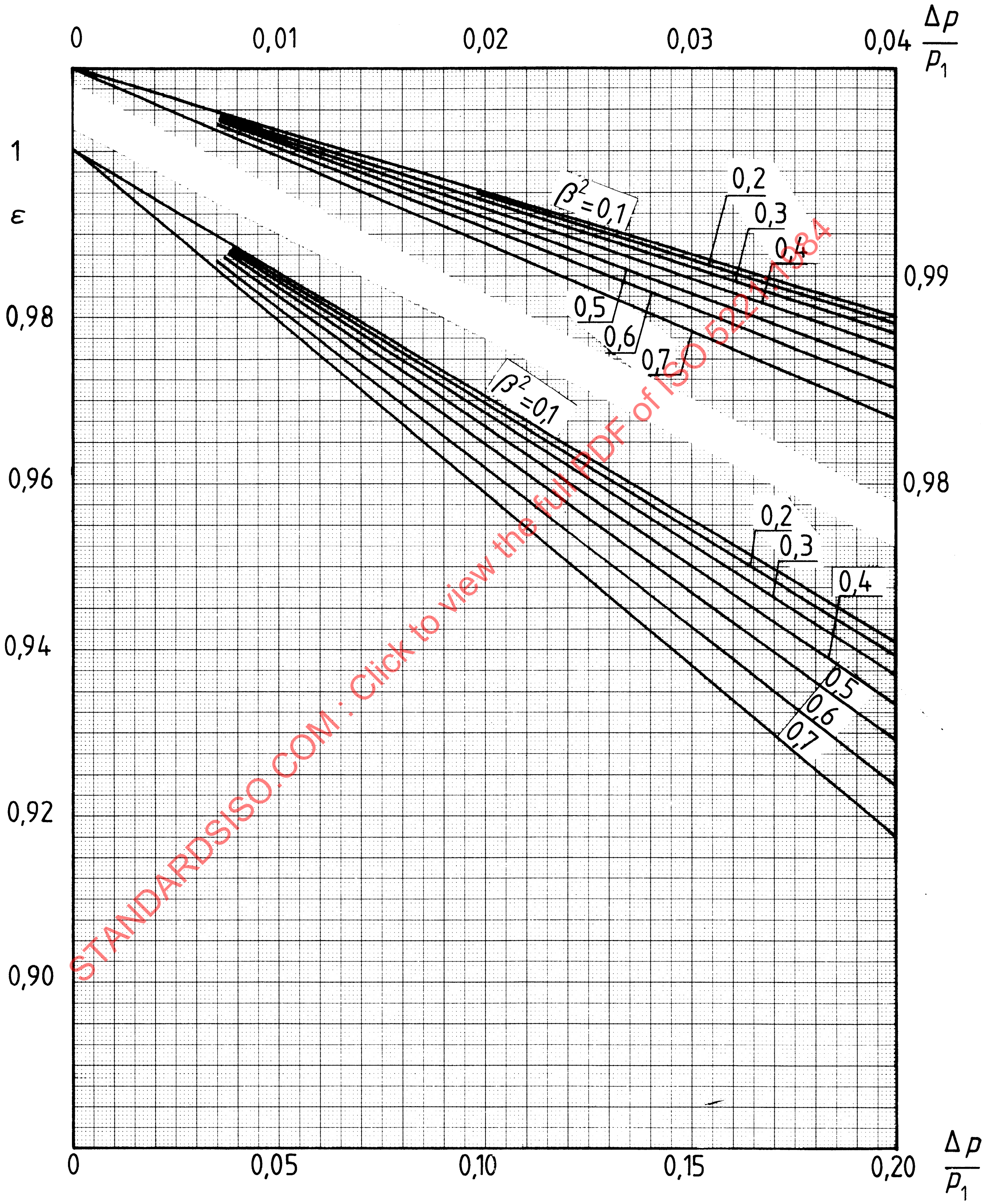


Figure 2 — Orifice plates with corner taps or flange taps, or D and $D/2$ taps : Expansibility factor ε for κ = 1,4

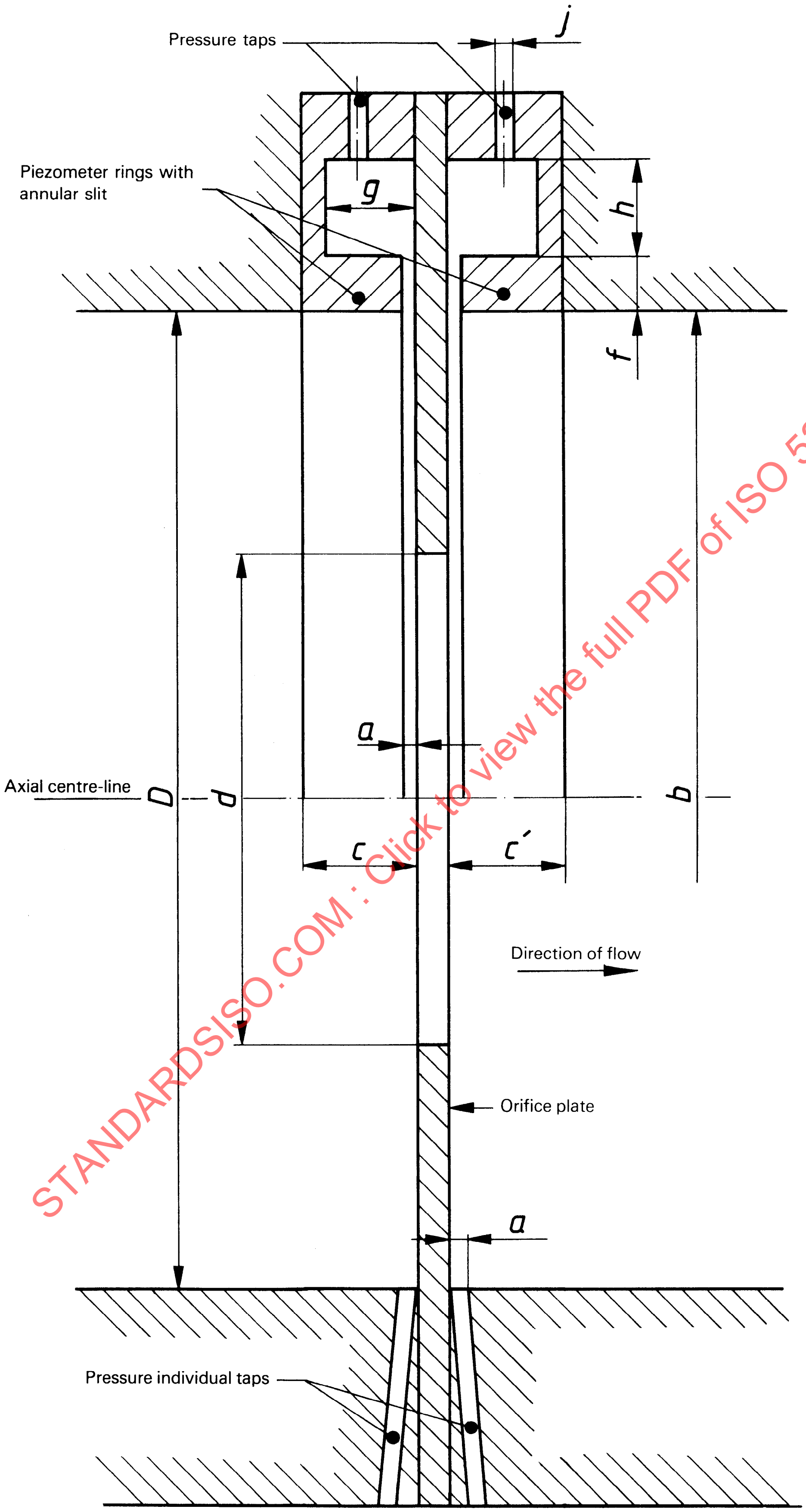


Figure 3 — Corner taps

7.1 Orifice plates with corner taps

The primary element is represented in figure 3. The orifice plate shall conform with figure 1 and with the specifications of 7.0.

The pressure taps may be either individual taps (lower part of figure 3) or annular slits opening into the annular chambers of piezometer rings (upper part of figure 3). The conditions for use are as defined in 7.0.

The flow coefficient α is calculated using the Stolz formula given in 7.0. In the expression for α_∞, the two terms with D^{-1} shall be zero, and hence α_∞ is only dependent on β and becomes

$$\alpha_\infty = (1 - \beta^4)^{-0,5} [0,595\,9 + 0,031\,2\, \beta^{2,1} - 0,184\,0\, \beta^8]$$

The corresponding value of β is given in the first column of table 4.

7.2 Orifice plate with flange taps

The primary element is represented in figure 4. The orifice plate shall conform with the drawing of figure 1 and with the specifications mentioned in 7.0.

The conditions of use of this device are as defined in 7.0.

The flow coefficient α is calculated from the Stolz formula given in 7.0 taking into account the value, in metres, of the duct diameter D.

Table 4 can be used and linear interpolation carried out between two successive values of β, and of D for values of D less than 0,600 m or D^{-1} for values of D greater than 0,600 m.

7.3 Orifice plates with D and $D/2$ tappings

The primary element is represented in figure 5. The orifice plate conforms to figure 1 and to specifications mentioned in 7.0.

The conditions for use of this device are as defined in clause 7.0.

The flow coefficient α is calculated from the Stolz formula given in 7.0 and applied to the particular conditions of these tappings. In this case the flow coefficient α is given by

$$\alpha = \alpha_\infty + 0,002\,9\, (1 - \beta^4)^{-0,5}\, \beta^{2,5} \left(\frac{10^6}{Re_D}\right)^{0,75}$$

where

$$\alpha_\infty = (1 - \beta^4)^{-0,5} [0,595\,9 + 0,031\,2\, \beta^{2,1} - 0,184\,0\, \beta^8 + 0,039\, \beta^4 (1 - \beta^4)^{-1} - 0,015\,839\, \beta^3]$$

As for device 7.1 and contrary to device 7.2, the value of α_∞ is only dependent on β and it is given in the penultimate column of table 4.

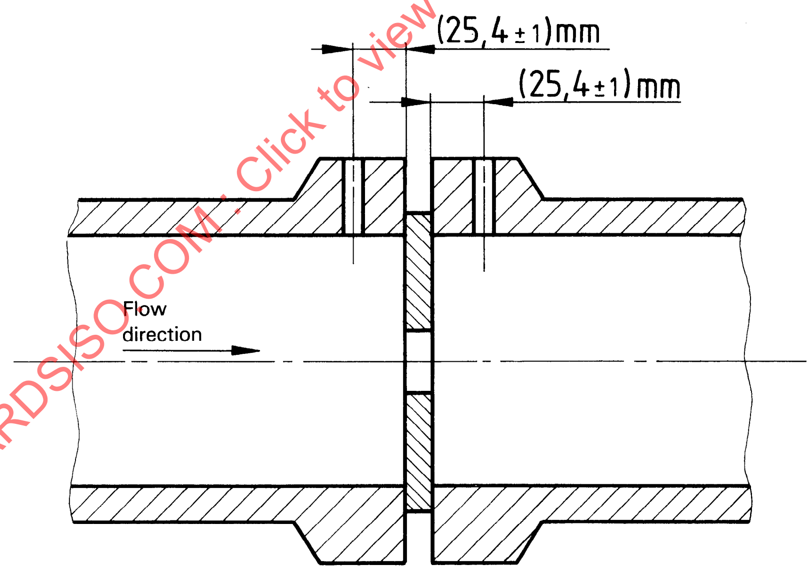


Figure 4 — Orifice plate with flange taps

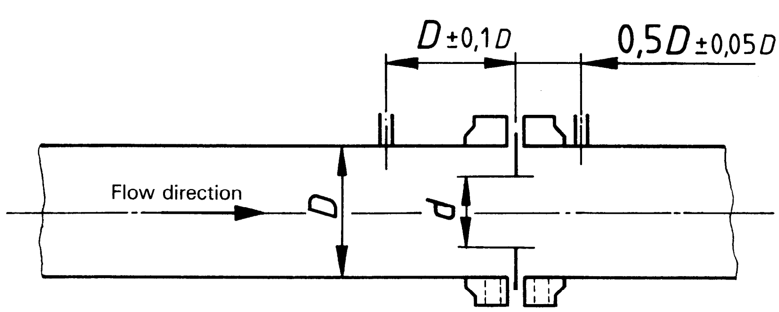


Figure 5 Orifice plate with D and $D/2$ tappings

7.4 ISA 1932 nozzle

The primary element is represented in figure 6. The pressure taps are corner taps similar to those used for orifice plate with corner taps. ISO 5167 gives the specifications related to these corner taps and to the nozzle shape.

The conditions for use of this device are as follows :

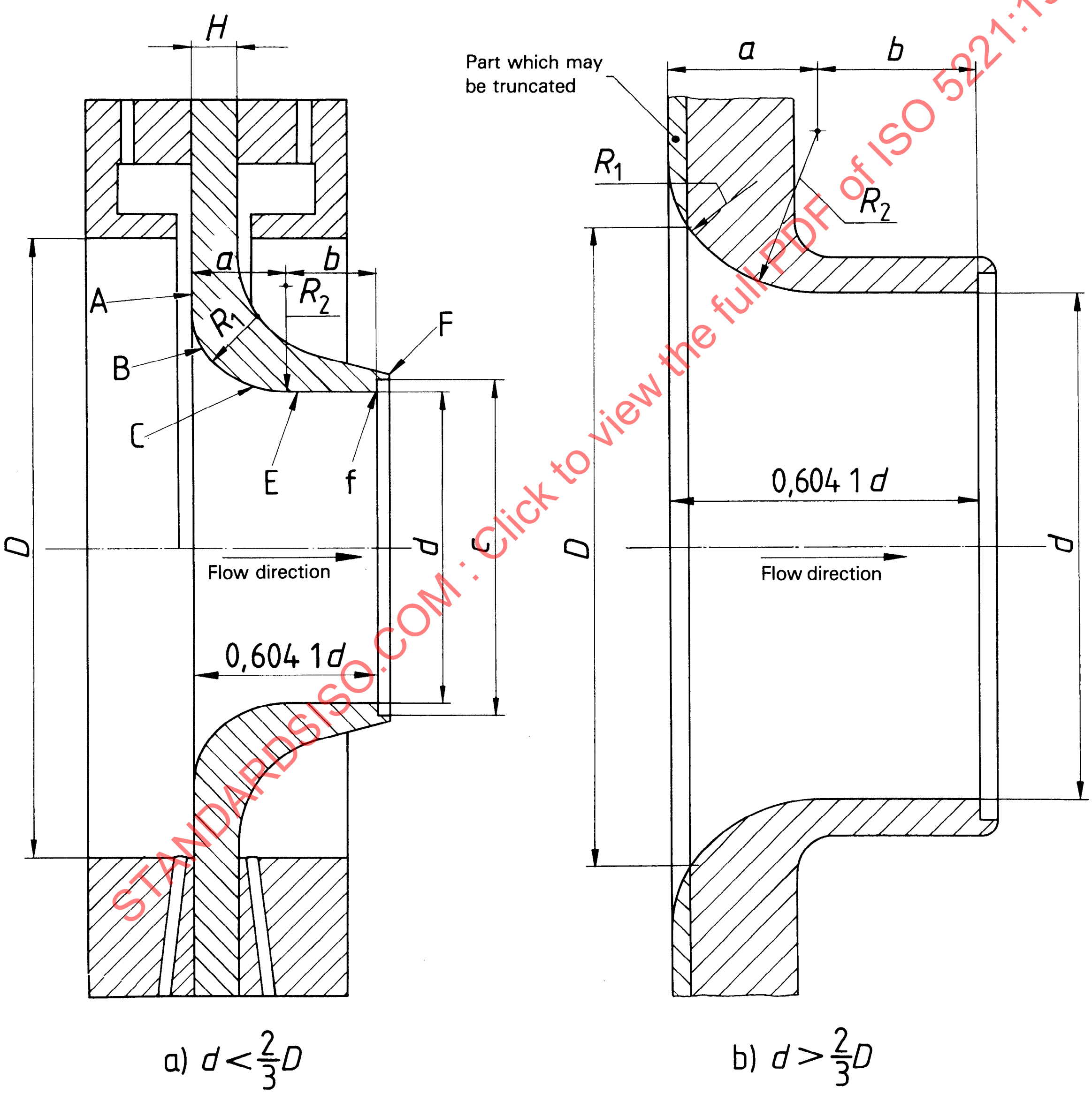
$0{,}050 \text{ m} \leqslant D \leqslant 0{,}500 \text{ m}$

$0{,}30 \leqslant \beta \leqslant 0{,}80$

$7.10^4 \leqslant Re_D \leqslant 10^7$ if $0{,}30 \leqslant \beta < 0{,}44$

$2.10^4 \leqslant Re_D \leqslant 10^7$ if $0{,}44 \leqslant \beta < 0{,}80$

$\frac{\Delta p}{p_1} \leqslant 0{,}25$



a) $d < \frac{2}{3}D$

b) $d > \frac{2}{3}D$

$R_1 = 0{,}200d \pm 0{,}020d$ if $\beta < 0{,}5$

$R_1 = 0{,}200d \pm 0{,}006d$ if $\beta \geqslant 0{,}5$

$R_2 = 0{,}333d \pm 0{,}033d$ if $\beta < 0{,}5$

$R_2 = 0{,}333d \pm 0{,}010d$ if $\beta \geqslant 0{,}5$

Figure 6 — ISA 1932 nozzle

Table 5 gives many corresponding numerical values.

Table 5 — Flow coefficient α for ISA 1932 nozzles

β \ Re_D	2×10^4	3×10^4	5×10^4	7×10^4	10^5	3×10^5	10^6	2×10^6
0,30	***	***	***	0,990 0	0,990 8	0,991 9	0,992 3	0,992 4
0,32	***	***	***	0,990 3	0,991 2	0,992 6	0,993 0	0,993 0
0,34	***	***	***	0,990 7	0,991 8	0,993 3	0,993 8	0,993 9
0,36	***	***	***	0,991 3	0,992 5	0,994 3	0,994 8	0,994 9
0,38	***	***	***	0,992 2	0,993 5	0,995 4	0,996 0	0,996 1
0,40	***	***	***	0,993 2	0,994 7	0,996 8	0,997 4	0,997 5
0,42	***	***	***	0,994 6	0,996 1	0,998 3	0,999 0	0,999 1
0,44	0,980 3	0,988 1	0,993 9	0,996 2	0,997 9	1,000 2	1,000 9	1,001 0
0,46	0,981 5	0,989 6	0,995 7	0,998 2	0,999 9	1,002 4	1,003 1	1,003 2
0,48	0,983 2	0,991 7	0,998 0	1,000 5	1,002 3	1,004 9	1,005 7	1,005 8
0,50	0,985 5	0,994 2	1,000 7	1,003 3	1,005 2	1,007 8	1,008 6	1,008 7
0,52	0,988 4	0,997 3	1,003 9	1,006 6	1,008 5	1,011 2	1,012 0	1,012 1
0,54	0,992 1	1,001 0	1,007 7	1,010 4	1,012 3	1,015 0	1,015 8	1,016 0
0,56	0,996 6	1,005 5	1,012 2	1,014 8	1,016 7	1,019 4	1,020 2	1,020 4
0,58	1,002 1	1,010 9	1,017 4	1,020 0	1,021 9	1,024 5	1,025 3	1,025 4
0,60	1,008 7	1,017 1	1,023 4	1,025 9	1,027 7	1,030 3	1,031 0	1,031 2
0,62	1,016 5	1,024 5	1,030 4	1,032 8	1,034 5	1,036 9	1,037 6	1,037 8
0,64	1,025 8	1,033 1	1,038 6	1,040 8	1,042 3	1,044 6	1,045 2	1,045 3
0,66	1,036 7	1,043 2	1,048 0	1,050 0	1,051 4	1,053 3	1,053 9	1,054 0
0,68	1,049 5	1,054 9	1,059 0	1,060 6	1,061 8	1,063 4	1,063 9	1,064 0
0,70	1,064 6	1,068 7	1,071 7	1,073 0	1,073 8	1,075 1	1,075 4	1,075 5
0,72	1,082 3	1,084 7	1,086 6	1,087 3	1,087 9	1,088 6	1,088 8	1,088 9
0,74	1,103 1	1,103 6	1,104 0	1,104 2	1,104 3	1,104 4	1,104 5	1,104 5
0,76	1,127 8	1,126 0	1,124 6	1,124 0	1,123 6	1,123 0	1,122 9	1,122 8
0,78	1,157 2	1,152 5	1,148 9	1,147 5	1,146 5	1,145 1	1,144 7	1,144 6
0,80	1,192 4	1,184 3	1,178 2	1,175 7	1,174 0	1,171 5	1,170 8	1,170 6

The flow coefficient α is given by the following formula :

$$\alpha = (1 - \beta^4)^{-0,5} \left[0,990\,0 - 0,226\,2\,\beta^{4,1} + (0,000\,215 - 0,001\,125\,\beta + 0,002\,490\,\beta^{4,7}) \left(\frac{10^6}{Re_D} \right)^{1,15} \right]$$

The expansibility factor ε is calculated using a theoretical formula. Table 6 gives the expansibility factor ε for $\kappa = 1,40$. Indications related to the effect of κ upon value ε will be found in ISO 5167 : the relative change in ε when κ is varied is less than 0,001 for a relative change of 0,01 in κ.

Table 6 — Expansion factor ε of nozzles and Venturis for $\kappa = 1,40$

$\Delta p/p_1$		0	0,02	0,04	0,06	0,08	0,10	0,15	0,20	0,25
β^2	β^4									
0	0	1,000	0,989	0,978	0,967	0,956	0,945	0,916	0,886	0,856
0,316	0,100	1,000	0,988	0,975	0,962	0,950	0,938	0,906	0,873	0,840
0,447	0,200	1,000	0,986	0,971	0,957	0,943	0,929	0,893	0,858	0,821
0,548	0,300	1,000	0,983	0,967	0,950	0,934	0,918	0,878	0,839	0,800
0,632	0,400	1,000	0,980	0,960	0,941	0,922	0,904	0,859	0,815	0,773
0,640	0,410	1,000	0,980	0,960	0,940	0,920	0,902	0,857	0,813	0,770

7.5 "Long-radius" nozzles

The primary element is represented in figure 7. Specifications related to the primary element which require pressure taps with D and $\frac{D}{2}$ are mentioned in ISO 5167.

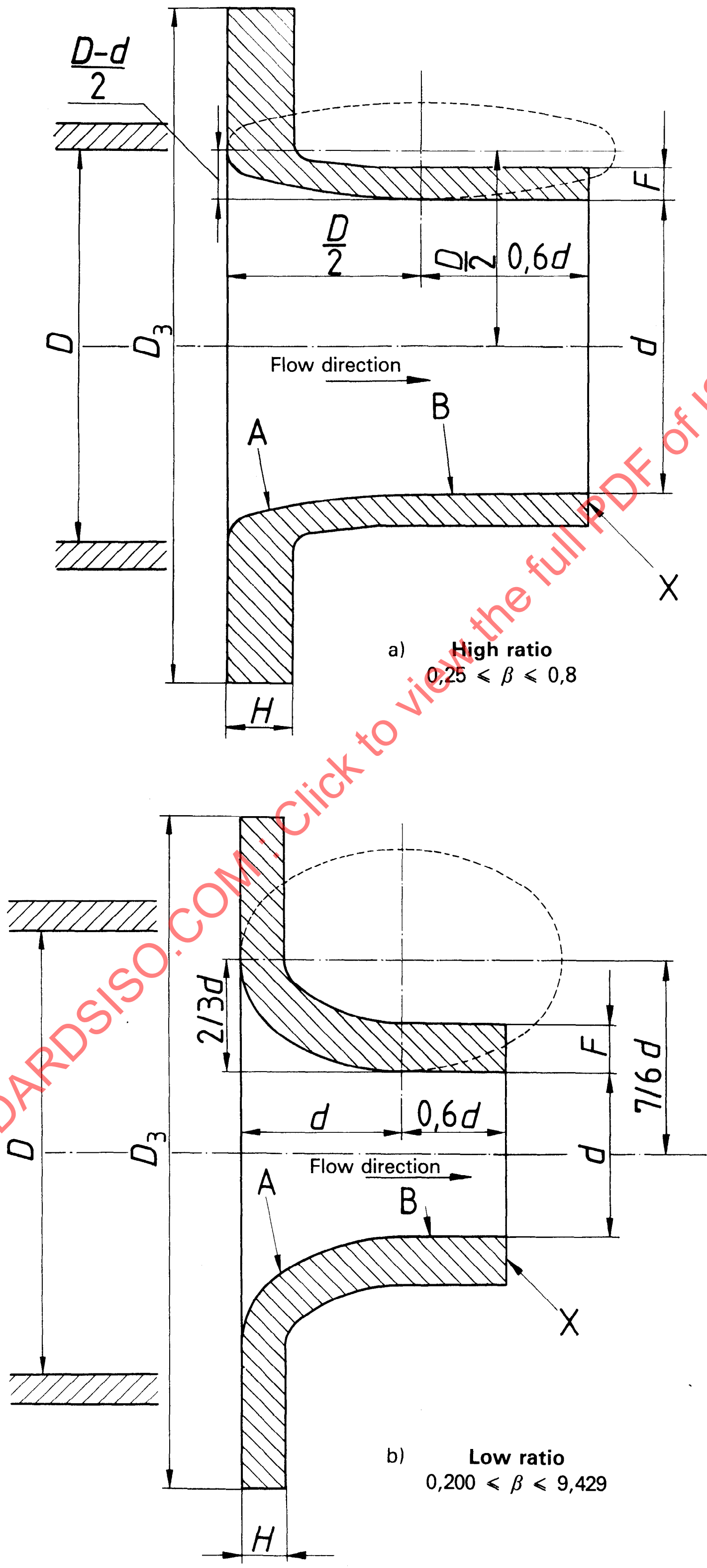


Figure 7 — Long radius nozzle

The conditions for use of this device are as follows :

$0{,}050 \text{ m} \leqslant D \leqslant 0{,}630 \text{ m}$

$0{,}20 \leqslant \beta \leqslant 0{,}80$

$\frac{k}{D} \leqslant 10^{-3}$

$\frac{\Delta p}{p_1} \leqslant 0{,}25$

The Reynolds number Re_D should not be less than 10^4.

The flow coefficient α is given by the formula :

$$\alpha = (1 - \beta^4)^{-0{,}5} (0{,}996\,5 - 6{,}53\, Re_D^{-0{,}5}\, \beta^{0{,}5})$$

or

$$\alpha = (1 - \beta^4)^{-0{,}5} (0{,}996\,5 - 6{,}53\, Re_d^{-0{,}5})$$

Table 7 gives many corresponding numerical values.

The expansibility factor ε is calculated using the same theoretical formula as for ISA 1932 nozzles. Table 6 gives the value of ε for $\kappa = 1{,}40$.

Table 7 — Flow coefficient α for "long radius" nozzles

β \ Re_D	10^4	2×10^4	5×10^4	10^5	2×10^5	5×10^5	10^6	5×10^6	10^7	10^8
0,20	0,968	0,977	0,984	0,988	0,991	0,993	0,994	0,996	0,996	0,997
0,22	0,967	0,976	0,984	0,988	0,991	0,993	0,995	0,996	0,997	0,997
0,24	0,966	0,975	0,984	0,988	0,991	0,994	0,995	0,997	0,997	0,998
0,26	0,965	0,975	0,984	0,988	0,991	0,994	0,995	0,997	0,998	0,998
0,28	0,965	0,975	0,984	0,989	0,992	0,995	0,996	0,998	0,998	0,999
0,30	0,965	0,975	0,985	0,989	0,993	0,995	0,997	0,999	0,999	1,000
0,32	0,965	0,976	0,985	0,990	0,993	0, 997	0,998	1,000	1,001	1,001
0,34	0,965	0,976	0,986	0,991	0,995	0,998	0,999	1,002	1,002	1,003
0,36	0,965	0,977	0,987	0,992	0,996	0,999	1,001	1,003	1,004	1,005
0,38	0,966	0,978	0,989	0,994	0,998	1,001	1,003	1,005	1,006	1,007
0,40	0,968	0,980	0,991	0,996	1,000	1,004	1,005	1,008	1,008	1,009
0,42	0,969	0,982	0,993	0,999	1,003	1,006	1,008	1,011	1,010	1,012
0,44	0,972	0,984	0,996	1,002	1,006	1,009	1,011	1,014	1,014	1,015
0,46	0,974	0,988	0,999	1,005	1,009	1,013	1,015	1,018	1,018	1,019
0,48	0,978	0,991	1,003	1,009	1,014	1,017	1,019	1,023	1,022	1,024
0,50	0,981	0,995	1,008	1,014	1,019	1,022	1.024	1,027	1,028	1,029
0,52	0,986	1,000	1,013	1,020	1,024	1,028	1,030	1,033	1,034	1,035
0,54	0,992	1,006	1,019	1,026	1,031	1,035	1,037	1,040	1,040	1,041
0,56	0,998	1,013	1,026	1,033	1,038	1,042	1,044	1,047	1,048	1,049
0,58	1,005	1,021	1,035	1,041	1,046	1,051	1,053	1,056	1,057	1,058
0,60	1,014	1,030	1,044	1,051	1,056	1,060	1,063	1,066	1,066	1,068
0,62	1,024	1,040	1,055	1,062	1,067	1,072	1,074	1,077	1,078	1,079
0,64	1,035	1,052	1,067	1,074	1,080	1,084	1,087	1,090	1,091	1,092
0,66	1,048	1,065	1,081	1,088	1,094	1,099	1,101	1,104	1,105	1,106
0,68	1,063	1,081	1,097	1,105	1,110	1,115	1,118	1,121	1,122	1,123
0,70	1,080	1,099	1,115	1,123	1,129	1,134	1,137	1,140	1,141	1,143
0,72	1,101	1,119	1,136	1,145	1,151	1,156	1,159	1,162	1,163	1,165
0,74	1,124	1,143	1,161	1,170	1,176	1,181	1,184	1,188	1,189	1,190
0,76	1,151	1,171	1,190	1,199	1,205	1,211	1,214	1,218	1,219	1,220
0,78	1,183	1,204	1,223	1,233	1,239	1,245	1,248	1,252	1,253	1,255
0,80	1,221	1,243	1,263	1,273	1,280	1,286	1,289	1,293	1,294	1,296

7.6 Classical Venturi tube

The primary element is represented in figure 8.

There are three varieties of classical standardized Venturi tubes which are characterized by the method of manufacture of the inside surface of the convergent part and the amount of rounding at the intersection of the convergent part and the throat.

Specifications related to the primary element are detailed in ISO 5167.

The conditions of use and the value of the flow coefficient α are as follows :

a) Venturi tube with a rough cast convergent
[R_1 = 1,375 D ± 20 %, R_2 = (3,625 ± 0,125) d, R_3 = (5 to 15) d]

$0,100 \text{ m} \leqslant D \leqslant 0,800 \text{ m}$

$0,30 \leqslant \beta \leqslant 0,75$

$2.10^5 \leqslant Re_D \leqslant 2.10^6$

$\alpha = 0,984\ (1 - \beta^4)^{-0,5}$

b) Venturi tube with a machined convergent
(R_1 < 0,25 D, R_2 < 0,25 d, R_3 < 0,25 d)

$0,050 \text{ m} \leqslant D \leqslant 0,250 \text{ m}$

$0,40 \leqslant \beta \leqslant 0,75$

$2.10^5 \leqslant Re_D \leqslant 10^6$

$\alpha = 0,995\ (1 - \beta^4)^{-0,5}$

c) Venturi tube with a rough welded sheet-iron convergent (R_1 = R_2 = R_3 = 0)

$0,200 \text{ m} \leqslant D \leqslant 1,200 \text{ m}$

$0,40 \leqslant \beta \leqslant 0,70$

$2.10^5 \leqslant Re_D \leqslant 2.10^6$

$\alpha = 0,985\ (1 - \beta^4)^{-0,5}$

The expansibility factor ε is given by the same theoretical formula as for the nozzles. The values of ε for κ = 1,40 are indicated in table 6.

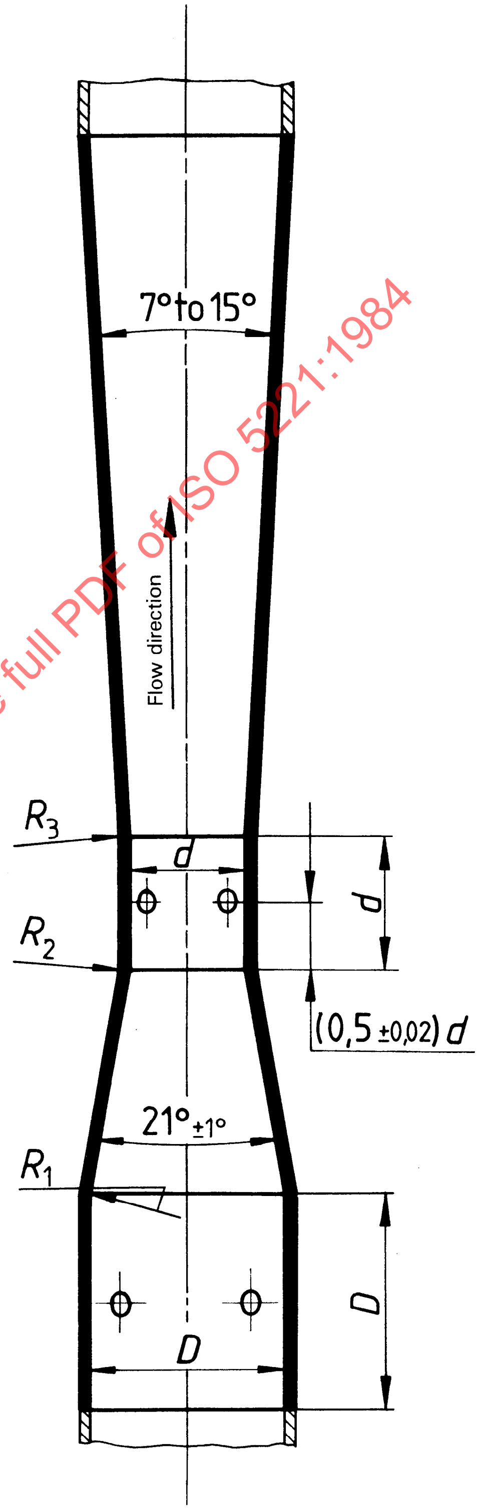


Figure 8 — Classical Venturi tube

7.7 Venturi nozzle

The primary element is represented in figure 9. Specifications related to the primary element are mentioned in ISO 5167. Outlet diameter of Venturi-nozzle may be less than inlet diameter D (truncated divergent). In both cases, the angle ϕ shall not exceed 30°.

The conditions for use of these devices are as follows :

$0{,}065 \text{ m} \leqslant D \leqslant 0{,}500 \text{ m}$

$0{,}316 \leqslant \beta \leqslant 0{,}775$

$0{,}050 \text{ m} \leqslant d$

$1{,}5.10^5 \leqslant Re_D \leqslant 2.10^6$

$\frac{k}{D} \leqslant 10^{-3}$

a) **Truncated divergent**

$d < \frac{2}{3} D$

$L_1 > 0{,}65\ L$

L being the length which the divergent would have if not truncated

$R_1 = 0{,}2\ d$

$R_2 = 0{,}333\ d$

b) **Non-truncated divergent**

$d > \frac{2}{3} D$

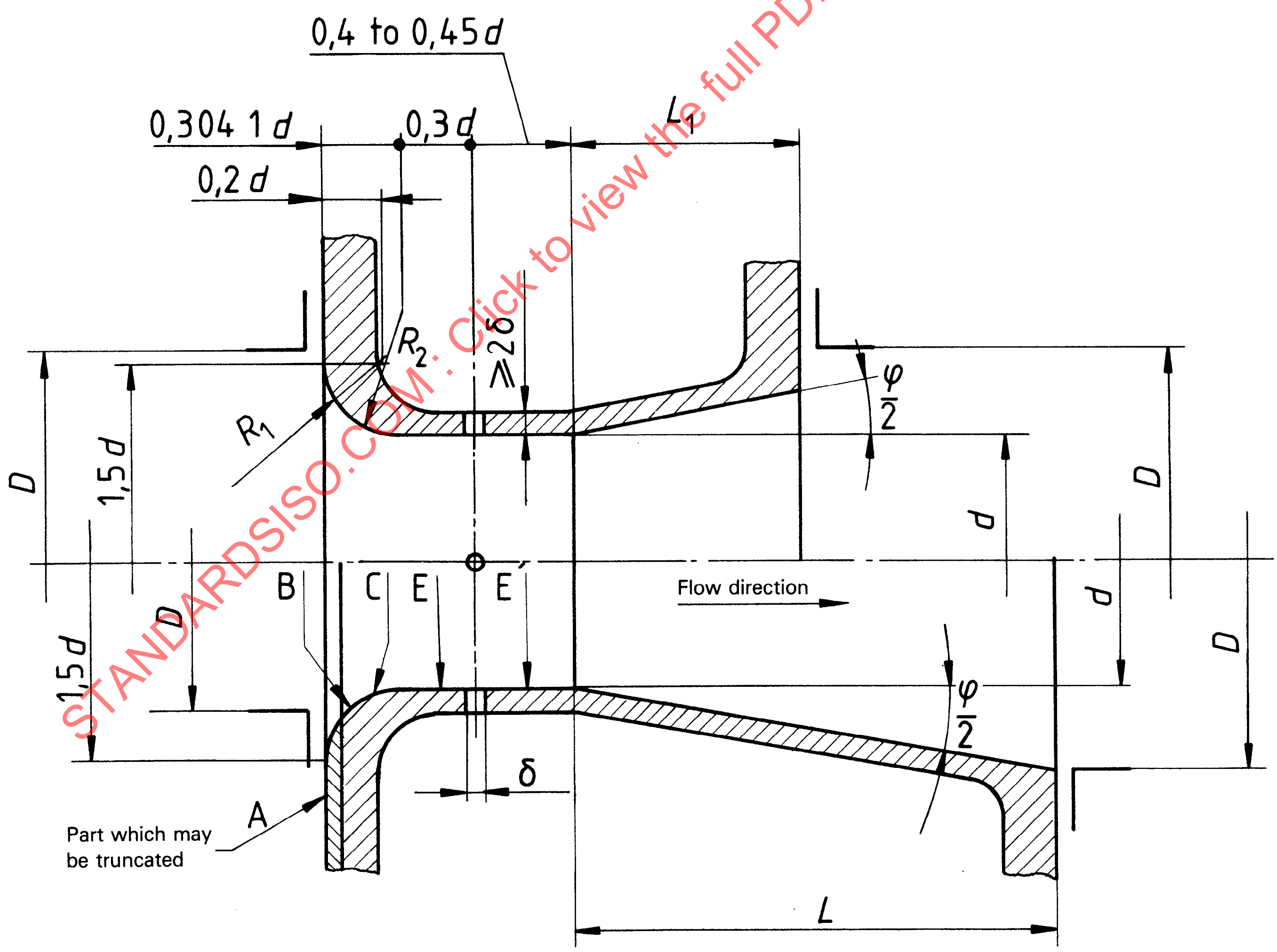


Figure 9 — Venturi nozzle

The flow coefficient is given by the Stolz formula :

$$\alpha = (1 - \beta^4)^{-0,5}\,(0{,}985\,8 - 0{,}196\,\beta^{4,5})$$

Table 8 gives many corresponding numerical values.

Table 8 — Flow coefficient α of Venturi nozzles

β	α
0,316	0,990
0,32	0,990
0,34	0,991
0,36	0,992
0,38	0,994
0,40	0,995
0,42	0,997
0,44	1,000
0,46	1,003
0,48	1,006
0,50	1,009
0,52	1,013
0,54	1,018
0,56	1,023
0,58	1,029
0,60	1,036
0,62	1,043
0,64	1,052
0,66	1,062
0,68	1,073
0,70	1,086
0,72	1,101
0,74	1,118
0,76	1,138
0,775	1,155

For small values of the Reynolds number and a reduced range of values of β the flow coefficient α is given in table 9.

Table 9 — Flow coefficient α of Venturi nozzles at small Reynolds numbers

β \ Re_D	30 000	50 000	70 000	100 000
0,55	1,003	1,011	1,015	1,018
0,56	1,006	1,014	1,018	1,021
0,57	1,009	1,017	1,021	1,024
0,58	1,012	1,020	1,024	1,027
0,59	1,016	1,024	1,027	1,030
0,60	1,020	1,028	1,031	1,034
0,61	1,024	1,031	1,035	1,037
0,62	1,028	1,036	1,039	1,041
0,63	1,033	1,040	1,043	1,046
0,64		1,045	1,048	1,050
0,65		1,050	1,053	1,055
0,66		1,055	1,058	1,060
0,67		1,061	1,064	1,066
0,68		1,067	1,070	1,072
0,69		1,074	1,076	1,078
0,70		1,081	1,083	1,085
0,71		1,088	1,090	1,092

The expansibility factor ε is given by the same theoretical formula as for classical Venturis and nozzles. The values of ε for κ = 1,40 are indicated in table 6.

7.8 Conical entrance orifice plate

The device is of particular interest for measuring small flow rates (for example leakage from a piece of air handling ducting) which need not be known with great precision. As the device described under 7.9, it has been especially designed for use at low Reynolds numbers without too substantial a variation of the flow rate coefficient with the Reynolds number.

The primary element is represented in figure 10. Each of the two types of pressure tappings which may be used is represented.[1)]

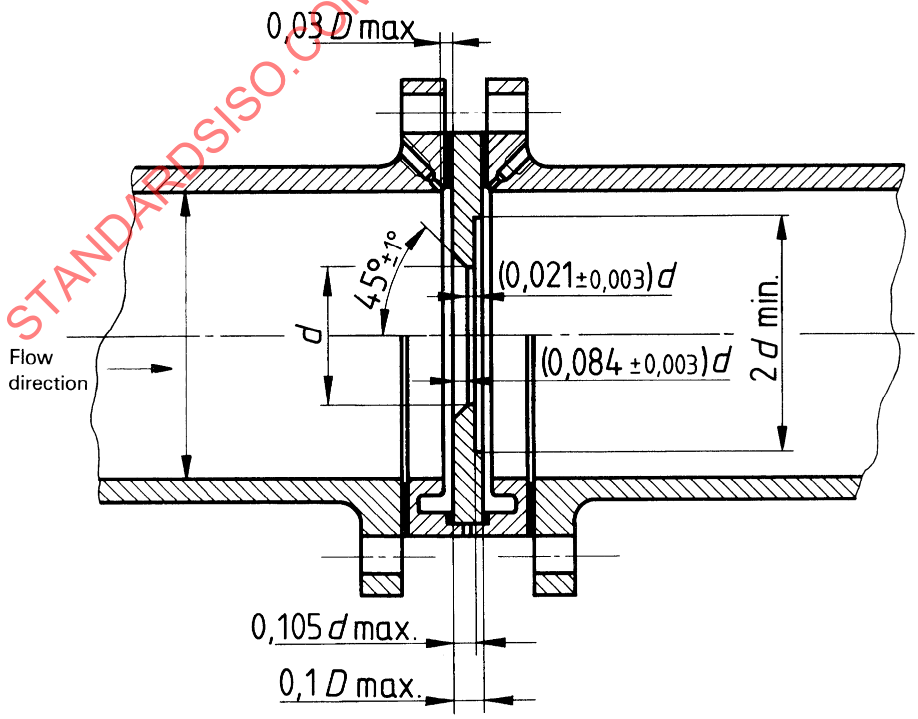


Figure 10 — Conical entrance orifice plate

1) See British Standard BS 1042.

The conditions for use of this device are as follows :

$D \geqslant 0{,}050$ m

$d \geqslant 0{,}006$ m

$\beta \leqslant 0{,}316$

$250 \leqslant Re_d \leqslant 2.10^5$

Upstream straight length > 25 D

The flow coefficient α is given by the formula :

$$\alpha = C(1 - \beta^4)^{-0{,}5}$$

where

C is the discharge coefficient whose value is dependent on the Reynolds number Re_d only at a low rate.

The discharge coefficient shall be taken, with an uncertainty of ± 2,5 %

$C = 0{,}735$ for $\beta < 0{,}25$
$C = 0{,}740$ for $\beta > 0{,}25$

The expansibility factor ε shall be taken as being equal to

$$\varepsilon = 1 - 0{,}58 \frac{\Delta p}{\kappa p_1}$$

NOTE — The main difficulty in using this device is essentially due to the observation of the specifications of the two dimensions of nominal thickness, i.e. 0,084 d and 0,021 d respectively with a tolerance of ± 0,003 d. In order to take into account the fact that they are often difficult to observe, the uncertainty indicated in the British Standard BS 1042 is herein increased as suggested after the experimentation made since then by Stoll and Lientara in the United States, by Vasy, Kastner and Mc Veigh in the United Kingdom.

7.9 "Quarter-circle" orifice plate

Like the previous one, this device is intended for measurements of low values of flow rate which are not required to be known with the best accuracy. The primary element is represented in figure 11. The two types of pressure tappings which may be used are indicated.

The radius of the upstream profile r shall satisfy the following conditions :

$r \geqslant 0{,}003$ m

$0{,}101 \leqslant r/d \leqslant 0{,}208$

The radius r shall be accurate within 5 % at a maximum of the value inferred from figure 12.

The conditions for use of this device are as follows :

$d \geqslant 0{,}015$ m

$0{,}245 \leqslant \beta \leqslant 0{,}60$

Upstream straight length : see 6.1 if $Re_D > 4 \times 10^3$; if not make allowance for an upstream straight length of 10 D to 20 D between a plenum and the "quarter-circle orifice plate".

The Reynolds number Re_d shall be between a maximum value equal to 10^5 and a minimum value, function of β (see figure 13).

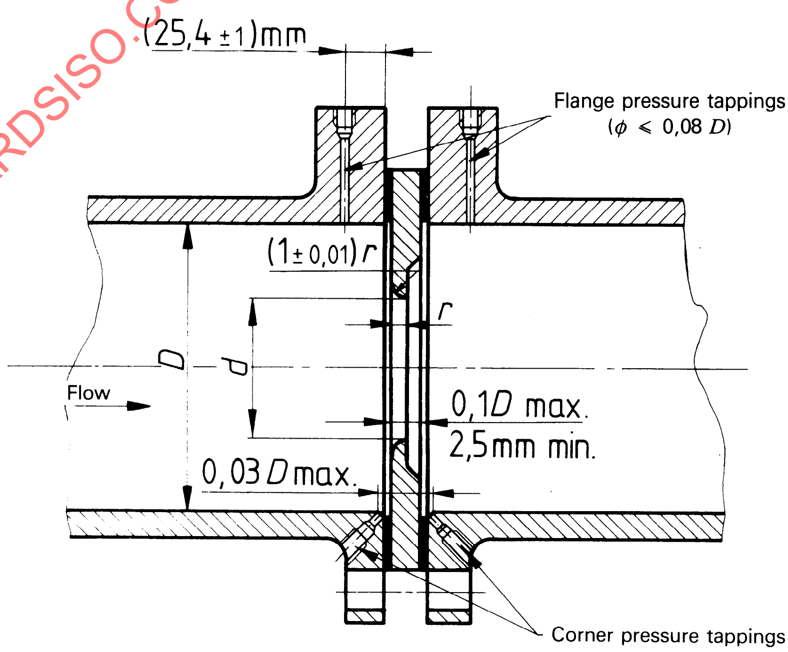


Figure 11 — "Quarter-circle" orifice plate

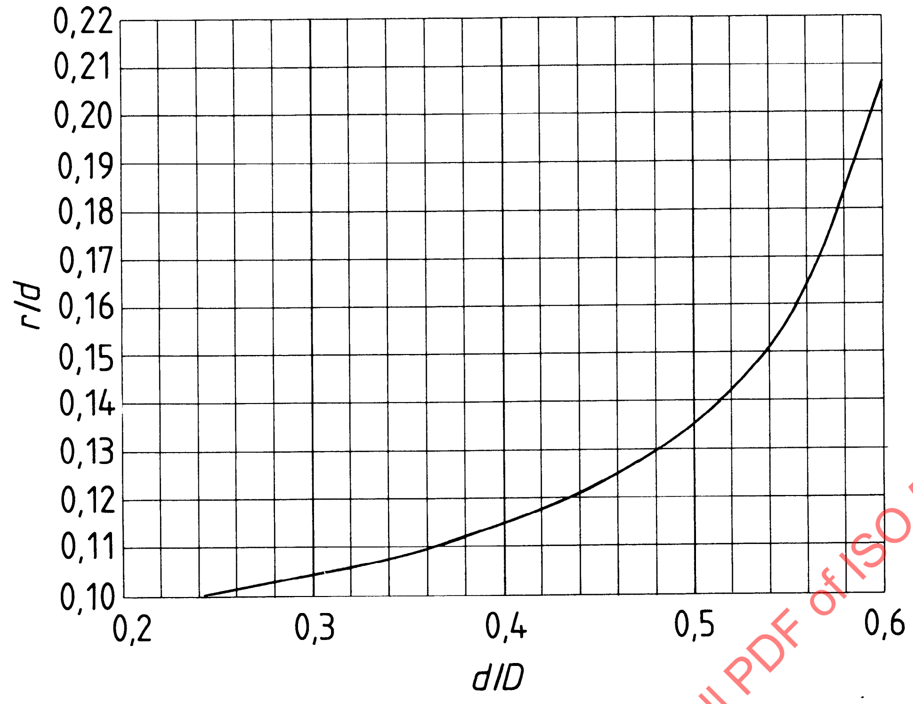


Figure 12 — Values of r/d for the "quarter-circle" orifice plates

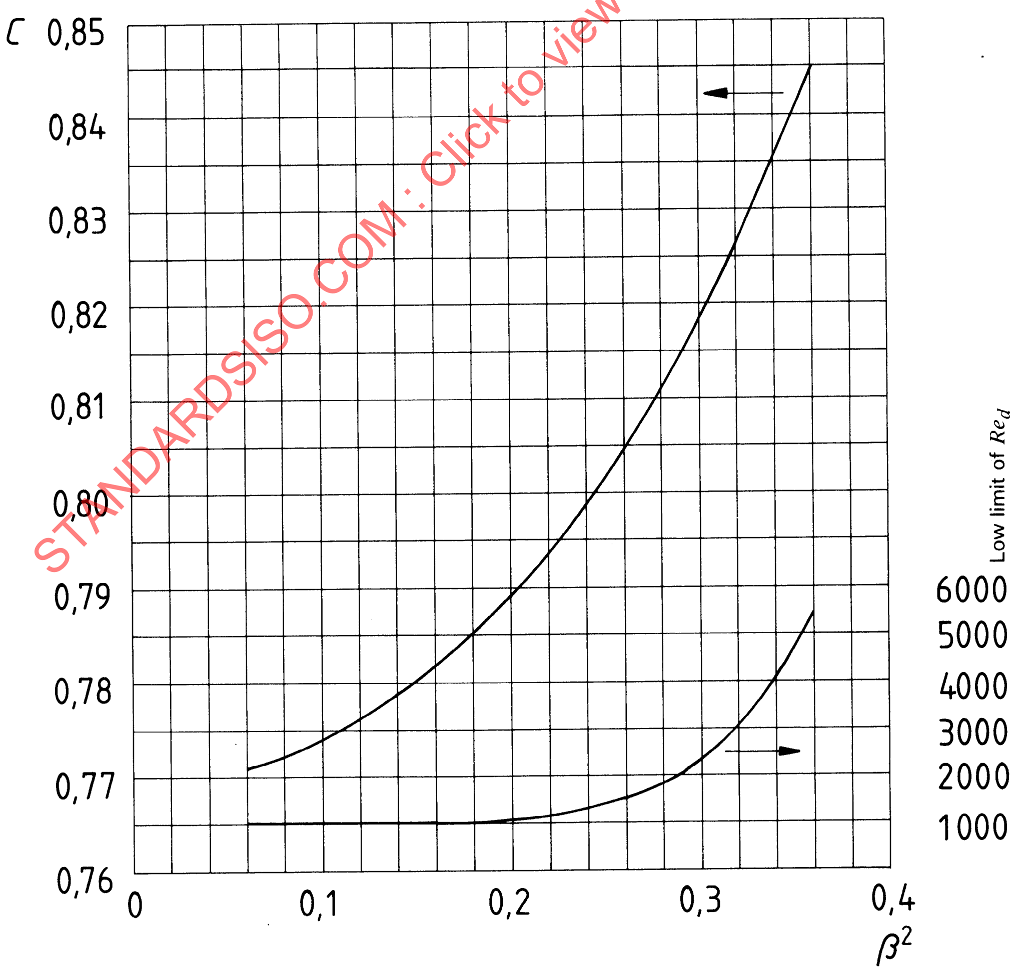


Figure 13 — Discharge coefficient C for the "quarter-circle" orifice plates

The flow coefficient α is given by the formula

$$\alpha = C(1 - \beta^4)^{-0,5}$$

where C is the discharge coefficient, whose values are shown in figure 13. The uncertainty on C value is ± 2 % if $\beta^4 > 0,1$ and ± 2,5 % if $\beta^4 < 0,1$.

The expansibility factor ε for $\frac{\Delta p}{\kappa p_1} < 0,09$ can be considered equal to the expansibility factor for the orifice plates with flange taps (see figure 4). For $0,09 < \frac{\Delta p}{\kappa p_1} < 0,20$ experiments have shown a difference between the values of ε for these two devices of less than 0,5 %.

7.10 Inlet orifice plate

The orifice plate conforms to the design of figure 14.

The main specifications are :

— Plane upstream face roughness (total height) less than 0,000 3 d in a circle of diameter 1,5 d.

— Plane upstream face parallel to the upstream face.

— $0,003\,D < E < 0,10\,D$

— $25° < F < 45°$

— If $E < 0,01\,d$, chamfering is not necessary.

— Sharp upstream edge G.

— Determination of d as measurement average of four diameters angularly distributed (none of the four measures differ from the average by more than $5 \times 10^{-4}\,d$).

— Wall pressure tapping on the duct a distance of the downstream face of the plate equal to $(0,10 \pm 0,05)\,D$.

— Upstream space free from any obstacle over a distance of at least 1 d within a coaxial cylinder of diameter 1,5 D for $\frac{d}{D} > 0,60$ and of 1,1 D for $\frac{d}{D} < 0,60$.

— Downstream straight length > 4 D if it is followed by a sudden variation in section. This straight length 4 D may be reduced to 0,75 D if it is followed by a gradual and symmetrical variation in duct section (for example of a conical convergent of total angle 7°). If there is any risk of flow rotation in the downstream duct, the straight length shall be followed by an anti-swirl device.

The conditions for use of this device are as follows :

$$\frac{d}{D} < 0,75$$

$$Re_d > 5.10^4$$

The corresponding flow coefficient α is equal to 0,598.

The expansibility factor is given by the formula :

$$\varepsilon = 1 - 0,27\,\frac{\Delta p}{p_1}$$

for $\kappa = 1,40$.

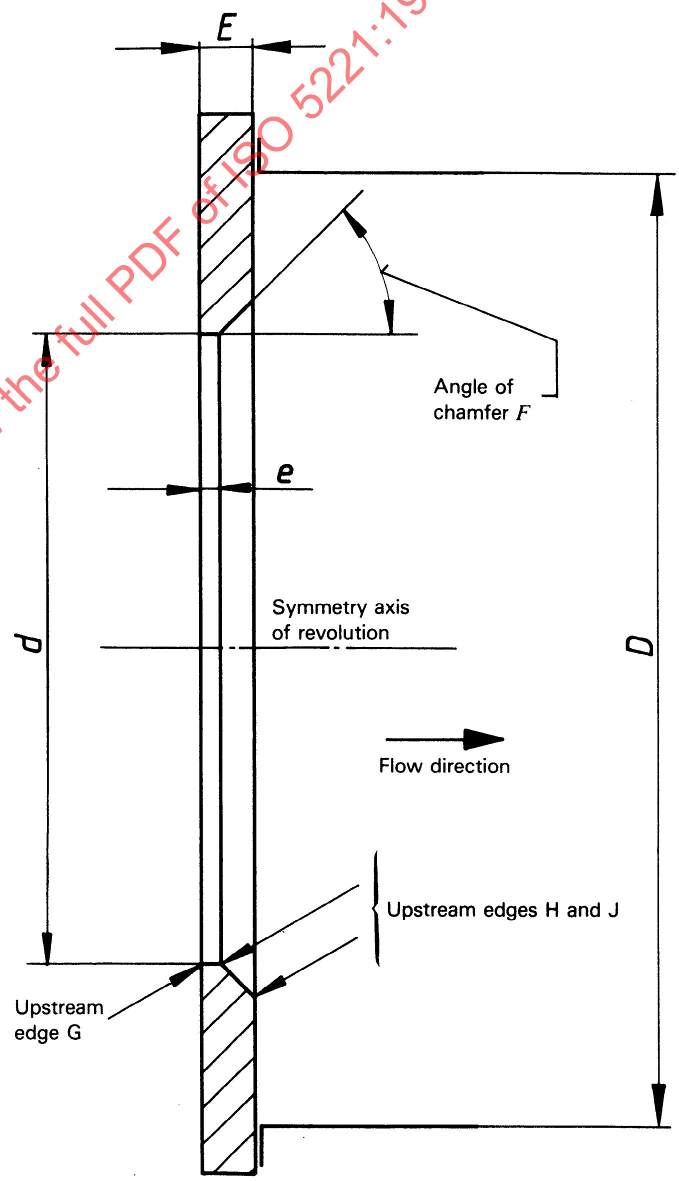


Figure 14 — Orifice plate located at the inlet end of the system

7.11 Inlet "quarter-circle" nozzle

The primary element is represented in figure 15.

The profile of the convergent section has the shape of a quarter-circle with a radius equal to 0,675 times the throat diameter the cylindrical length of which is 0,75 times this diameter.

The (or the four) pressure tapping(s) in the duct wall shall be arranged at a distance between 0,75 and 0,95 times the throat diameter : if d/D does not exceed 1/3, a single wall tapping will do; if d/D exceeds 1/3, it should be checked that four pressure tapping holes in the ductwall bored at the distance 4 D from the shaped inlet, all having the same diameter and 90° apart, indicate individual negative pressures the maximum relative deviation of which does not exceed 1 %.

The upstream face of the convergent of the primary element will be extended by a flat disc, the external diameter of which will be equal to as less than $3d$ on the one hand or D on the other. Moreover, the convergent and the flat disc will be free from any protrusion (bolts, etc.) within a circle of diameter 2,55 d.

It is advisable to install the nozzle at the upstream end of a cylindrical duct at least four diameters long, and, if there is any risk of flow rotation in this duct, to have the nozzle followed by an anti-swirl device.

Upstream from the shaped inlet an inlet space free from any obstacle shall be provided over a face distance of at least $3d$ inside a coaxial cylinder of radius 0,75 D.

The conditions for use of this device are as follows :

$$\frac{1}{6} \leqslant \frac{d}{D} \leqslant 0,4$$

$$2 \times 10^4 \leqslant Re_d \leqslant 7 \times 10^5$$

It may be considered, with an uncertainty less than 1 %, that the value of the flow coefficient corresponds to the values indicated in table 10.[1)]

Table 10 — Flow coefficient of the nozzle located at the inlet end of the system for a cylindrical length of the throat equal to 0,75 d

Re_d	20 000	30 000	40 000	60 000	80 000	100 000	200 000 to 700 000
α	0,952	0,960	0,964	0,969	0,973	0,975	0,982

The expansibility factor, which is calculated from a theoretical formula, is indicated in table 6.

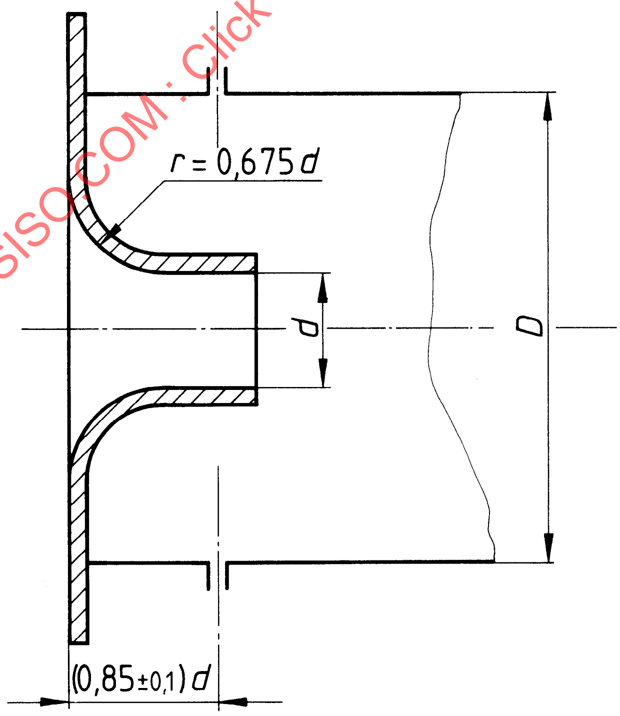


Figure 15 — "Quarter-circle" nozzle located at the inlet end of the system

1) For cylindrical lengths of throat equal to 0,60 d, slightly higher values of the flow coefficient have been observed.

7.12 Inlet cone

The primary element is represented in figure 16.

The specifications related to its manufacture and installation are as follows :

a) The cylindrical part (with a circular cross-section of diameter D) should be smooth (the equivalent relative roughness should not exceed 2×10^{-5}) and parallel with a circular cross-section (both parallel and circular within 0,005 D) along a length equal to D; it should be continued keeping the same nominal diameter for a further length of at least 3 D.

b) The included angle at the cone top should be equal to 60° ± 1°; the junctions of the cone 1 and 2 should be with sharp edges and the edges shall be considered as being sharp when the corresponding radii do not exceed 0,005 D and are free from burrs and projections that may be seen with the eye.

c) The wall pressure tappings should be located through a same plane perpendicular to the duct axis which is at a distance from junction 2 of between 0,48 D and 0,52 D; they should be carefully made and have a sharp edge of the hole with neither irregularity nor burr that might be detected by eye or finger at the points where the tappings are opened into the D diameter duct; the diameter of these tappings shall be between 1,5 and 4 mm and the cylindrical bore will have a length of at least twice its diameter.

d) Within the region bounded as indicated by dashed lines on figure 17 there must be neither partition nor obstruction, nor extraneous air current (which would correspond at a velocity exceeding 5 % of the discharge velocity within the D diameter duct when the inlet cone is not used).

e) The inlet cone will be used only for Reynolds number Re_D exceeding 2×10^5 and for differential pressures Δp less than 4 000 Pa.

$$Re_D = \frac{4\, q_m}{\pi\, \varrho_1\, D\, \nu} = (\alpha\, \varepsilon)\, \frac{D}{\nu} \sqrt{\frac{2 \Delta p}{\varrho_1}}$$

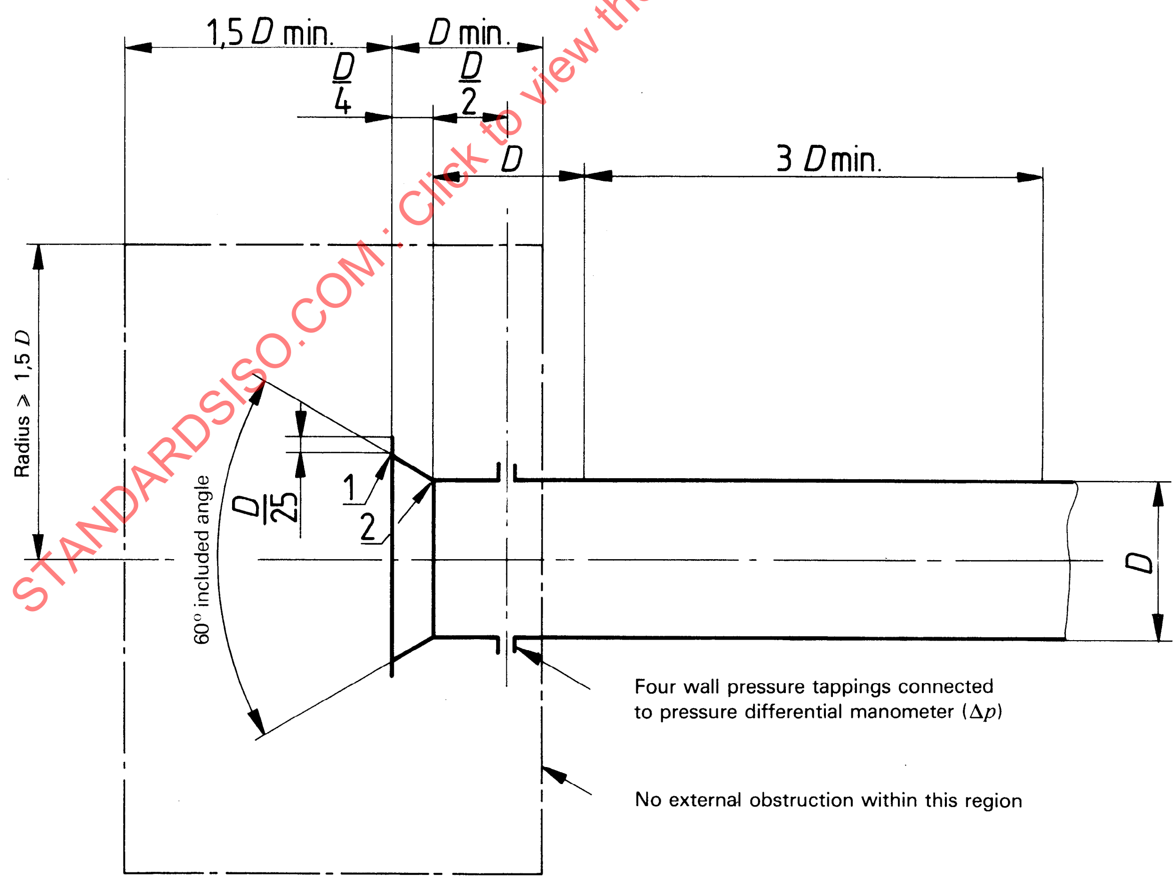


Figure 16 — Inlet cone

The mass flow rate is derived from the formula :

$$q_m = (\alpha\ \varepsilon)\ \frac{\pi}{4}\ D^2 \sqrt{2\varrho_1 \cdot \Delta p}$$

taking $(\alpha\ \varepsilon)$ as equal to :

(0,955 ± 0,020) if Re_D is between 2×10^5 and 3×10^5

(0,960 ± 0,015) if Re_D exceeds 3×10^5

7.13 Venturi-nozzles with sonic throat

Two alternatives are recommended for the primary element : the so-called Smith and Matz device and the so-called LMEF device. The first alternative is represented in figure 17.

The discharge coefficient C for this first alternative is given by the formula :

$$C = 0{,}993\,54 - 1{,}525\ Re_d^{-0{,}5}$$

for $10^5 \leqslant Re_d \leqslant 10^7$.

Table 11 gives many numerical values of C for various values of Re_d.

Table 11 — Discharge coefficient, C, of the Venturi-nozzle with sonic throat type Smith and Matz

Re_d	10^5	2.10^5	5.10^5	7.10^5	10^6	5.10^6	10^7
C	0,989	0,990	0,991	0,992	0,992	0,993	0,993

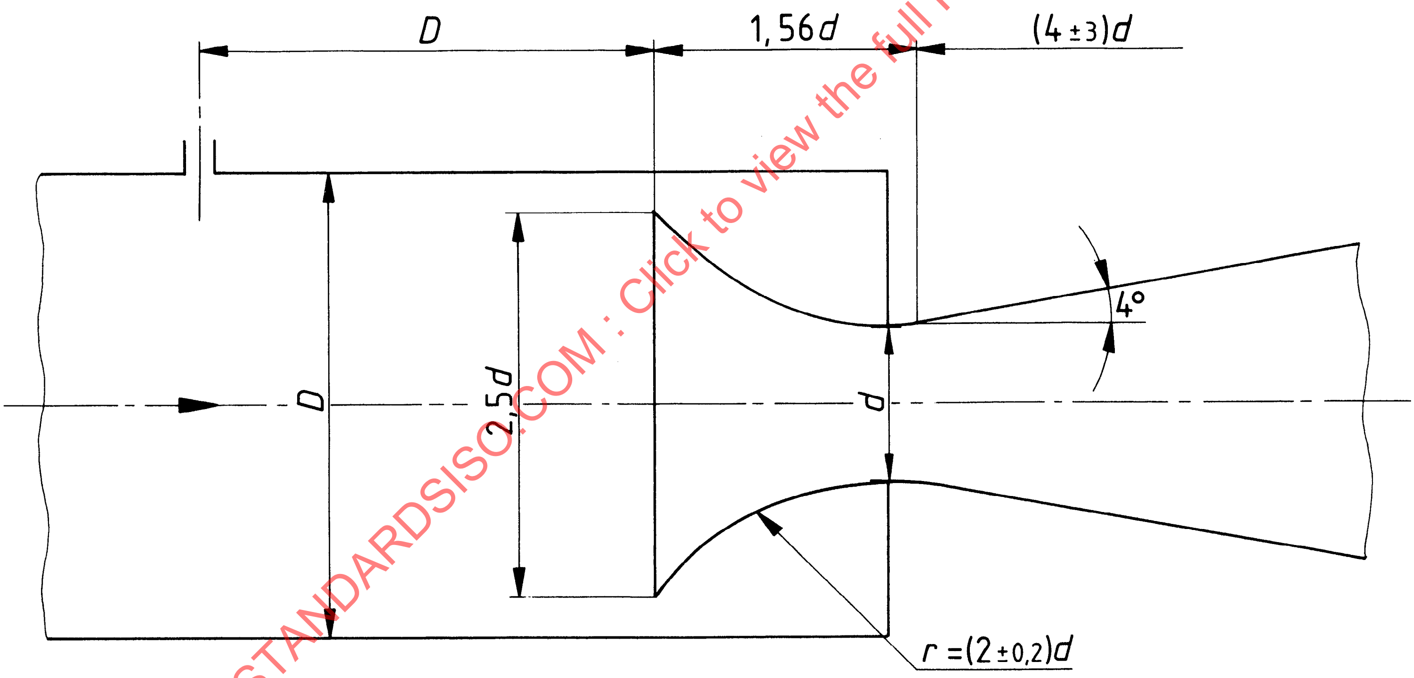


Figure 17 — Venturi-nozzle with sonic throat type Smith and Matz

The second alternative is represented in figure 18.

The discharge coefficient C for this second alternative is given by the formulae :

$$C = 1 - 7{,}24\ Re_d^{-0{,}5} \quad (10^4 \leqslant Re_d \leqslant 4 \times 10^5)$$

$$C = 0{,}988\ 6 \quad (4 \times 10^5 \leqslant Re_d \leqslant 2{,}8 \times 10^6)$$

$$C = 1 - 0{,}221\ 5\ Re_d^{-0{,}2} \quad (2{,}8 \times 10^6 \leqslant Re_d \leqslant 2 \times 10^7)$$

Table 12 gives many numerical values of C for various values of Re_d.

Table 12 — Discharge coefficient C of the Venturi-nozzle with sonic throat type LMEF ($Re_d > 10^4$)

Re_d	10^4	2.10^4	5.10^4	10^5	2.10^5	5.10^5	10^6	2.10^6	5.10^6	10^7	2.10^7
C	0,928	0,949	0,968	0,980	0,986	0,989	0,989	0,989	0,990	0,991	0,992

The uncertainty related to these numerical values does not exceed 1 % if $Re_d < 10^5$ and 0,5 % if $Re_d > 10^5$.

For both alternatives it may be considered that the critical expansibility ratio exceeds about 0,90 as soon as the opening ratio of the expander (ratio of the outlet section area to the inlet section area) is about 2. For an area ratio of the expander of at least 4, the critical expansibility ratio exceeds about 0,93. The ratio between the (absolute) static pressures downstream on the one hand and upstream on the other hand, of the Venturi-nozzle must not exceed the value of the critical expansibility ratio to be sure that the flow is actually critical. This value of the ratio of the downstream and upstream absolute static pressures shall be checked to be sure that this device can be used under these conditions of use for the critical flow method.

For air approaching the usual ambient conditions upstream of the device the critical flow function K shall be taken equal to 0,040 4.

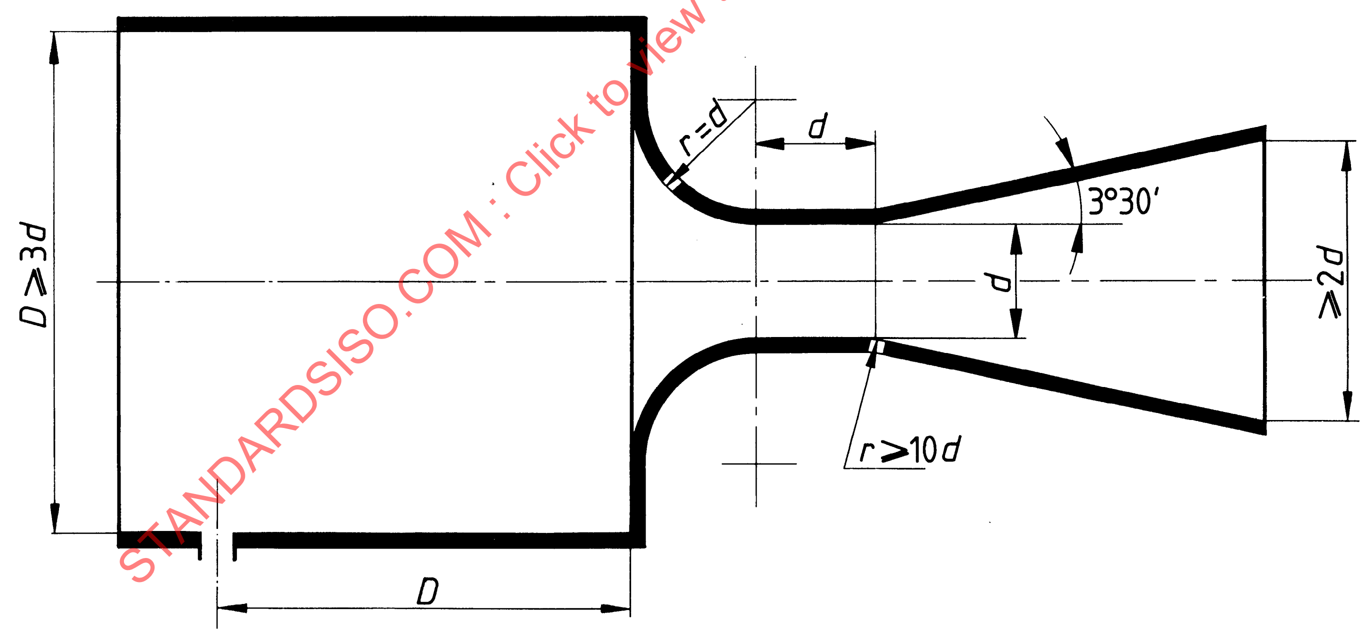


Figure 18 — Venturi-nozzle with sonic throat type "LMEF"

7.14 Pitot-static tubes

Three types of Pitot-static tubes are being selected as examples and are drawn below.

— Type A[1)]

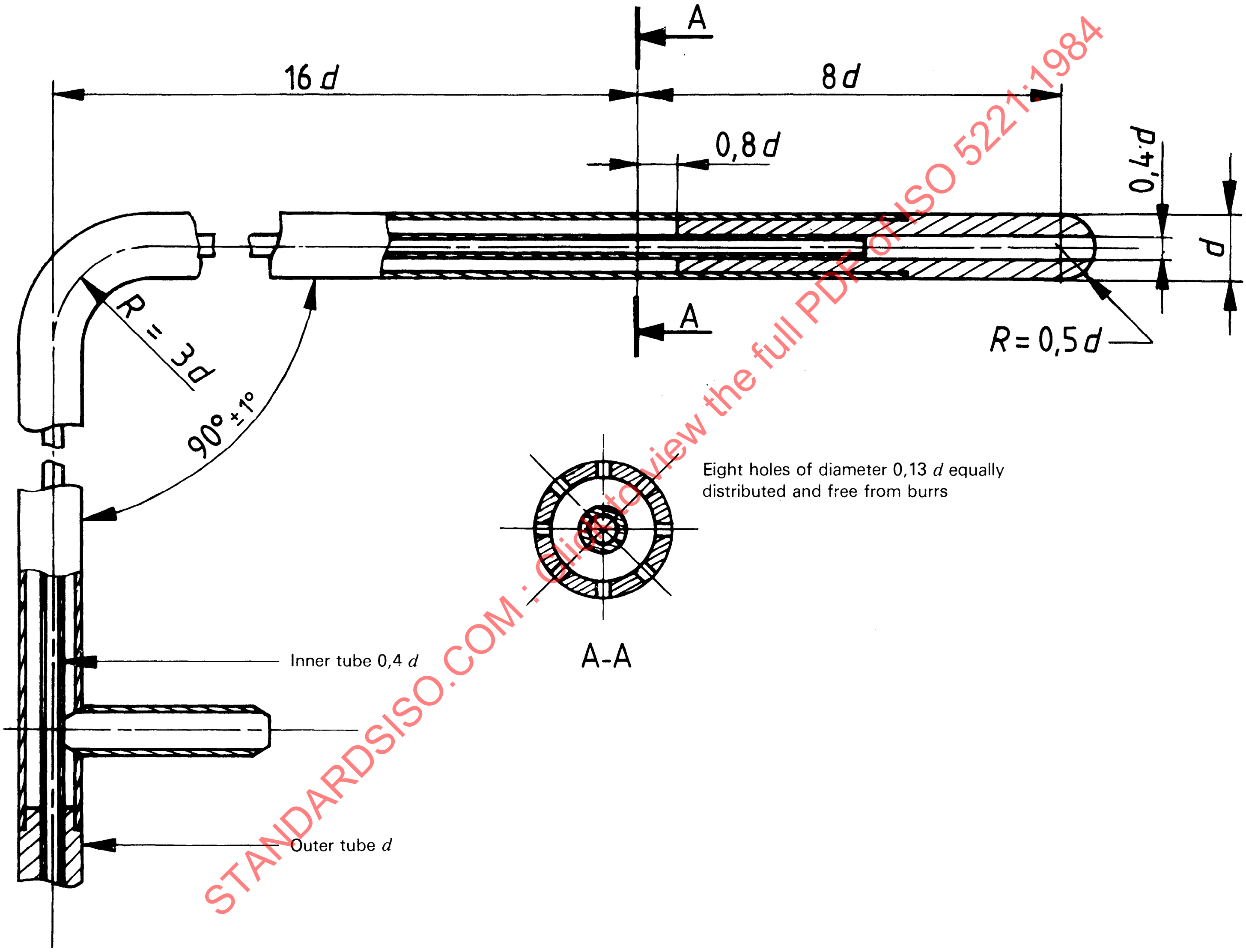


Figure 19 — Pitot-static tube, type AMCA

1) This type is described in document "AMCA Standard test Code for air moving devices". Bulletin No. 210 of January 1967 — page 21.