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Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full —

Part 4: **Venturi tubes**

Mesure de débit des fluides au moyen d'appareils déprimogènes insérés dans des conduites en charge de section circulaire —

Partie 4: Tubes de Venturi

Reference number
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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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

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

ISO 5167-4 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 2, *Pressure differential devices*.

This first edition of ISO 5167-4, together with the second edition of ISO 5167-1 and the first editions of ISO 5167-2 and ISO 5167-3, cancels and replaces the first edition of ISO 5167-1:1991, which has been technically revised, and ISO 5167-1:1991/Amd.1:1998.

ISO 5167 consists of the following parts, under the general title *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full*:

— *Part 1: General principles and requirements*

— *Part 2: Orifice plates*

— *Part 3: Nozzles and Venturi nozzles*

— *Part 4: Venturi tubes*

Introduction

ISO 5167, divided into four parts, covers 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 flowrate of the fluid flowing in the conduit. It also gives necessary information for calculating the flowrate and its associated uncertainty.

ISO 5167 is applicable only to pressure differential devices in which the flow remains subsonic throughout the measuring section and where the fluid can be considered as single-phase, but is not applicable to the measurement of pulsating flow. Furthermore, each of these devices can only be used within specified limits of pipe size and Reynolds number.

ISO 5167 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”. ISO 5167 covers primary devices; secondary devices[1)] will be mentioned only occasionally.

ISO 5167 is divided into the following four parts.

a) Part 1 of ISO 5167 gives general terms and definitions, symbols, principles and requirements as well as methods of measurement and uncertainty that are to be used in conjunction with Parts 2 to 4 of ISO 5167.

b) Part 2 of ISO 5167 specifies orifice plates, which can be used with corner pressure tappings, D and $D/2$ pressure tappings[2)], and flange pressure tappings.

c) Part 3 of ISO 5167 specifies ISA 1932 nozzles[3)], long radius nozzles and Venturi nozzles, which differ in shape and in the position of the pressure tappings.

d) This part of ISO 5167 specifies classical Venturi tubes[4)].

Aspects of safety are not dealt with in Parts 1 to 4 of ISO 5167. It is the responsibility of the user to ensure that the system meets applicable safety regulations.

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

2) Orifice plates with “vena contracta” pressure tappings are not considered in 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.

Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full —

Part 4: Venturi tubes

1 Scope

This part of ISO 5167 specifies the geometry and method of use (installation and operating conditions) of Venturi tubes when they are inserted in a conduit running full to determine the flowrate of the fluid flowing in the conduit.

This part of ISO 5167 also provides background information for calculating the flowrate and is applicable in conjunction with the requirements given in ISO 5167-1.

This part of ISO 5167 is applicable only to Venturi tubes in which the flow remains subsonic throughout the measuring section 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, roughness, diameter ratio and Reynolds number. This part of ISO 5167 is not applicable to the measurement of pulsating flow. It does not cover the use of Venturi tubes in pipes sized less than 50 mm or more than 1 200 mm, or where the pipe Reynolds numbers are below 2×10^5.

This part of ISO 5167 deals with the three types of classical Venturi tubes:

a) cast;

b) machined;

c) rough welded sheet-iron.

A Venturi tube is a device which consists of a convergent inlet connected to a cylindrical throat which is in turn connected to a conical expanding section called the “divergent”. The differences between the values of the uncertainty of the discharge coefficient for the three types of classical Venturi tube show, on the one hand, the number of results available for each type of classical Venturi tube and, on the other hand, the more or less precise definition of the geometric profile. The values are based on data collected many years ago. Venturi nozzles (and other nozzles) are dealt with in ISO 5167-3.

NOTE 1 Research into the use of Venturi tubes in high-pressure gas [$\geqslant$ 1 MPa ($\geqslant$ 10 bar)] is being carried out at present (see References [1], [2], [3] in the Bibliography). In many cases for Venturi tubes with machined convergent sections discharge coefficients which lie outside the range predicted by this part of ISO 5167 by 2 % or more have been found. For optimum accuracy Venturi tubes for use in gas should be calibrated over the required flowrate range. In high-pressure gas the use of single tappings (or at most two tappings in each plane) is not uncommon.

NOTE 2 In the USA the classical Venturi tube is sometimes called the Herschel Venturi tube.

2 Normative references

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

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

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4006 and ISO 5167-1 apply.

4 Principles of the method of measurement and computation

The principle of the method of measurement is based on the installation of a Venturi tube into a pipeline in which a fluid is running full. In a Venturi tube a static pressure difference exists between the upstream section and the throat section of the device. Whenever the device is geometrically similar to one on which direct calibration has been made, the conditions of use being the same, the flowrate can be determined from the measured value of this pressure difference and from a knowledge of the fluid conditions.

The mass flowrate can be determined by the following formula:

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

The uncertainty limits can be calculated using the procedure given in Clause 8 of ISO 5167-1:2003.

Similarly, the value of the volume flowrate can be calculated since

$$q_V = \frac{q_m}{\rho}$$

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

Computation of the flowrate, which is a purely arithmetic process, is performed by replacing the different items on the right-hand side of Equation (1) by their numerical values. Table A.1 gives Venturi tube expansibility factors (ε). They are not intended for precise interpolation. Extrapolation is not permitted.

The diameters d and D mentioned in Equation (1) are the values of the diameters at 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.

It is necessary to know the density and the viscosity of the fluid at working conditions. In the case of a compressible fluid, it is also necessary to know the isentropic exponent of the fluid at working conditions.

5 Classical Venturi tubes

5.1 Field of application

5.1.1 General

The field of application of the classical Venturi tubes dealt with in this part of ISO 5167 depends on the way in which they are manufactured.

Three types of standard classical Venturi tube are defined according to the method of manufacture of the internal surface of the entrance cone and the profile at the intersection of the entrance cone and the throat. These three methods of manufacture are described in 5.1.2 to 5.1.4 and have somewhat different characteristics.

There are limits to the roughness and Reynolds number for each type which shall be addressed.

5.1.2 Classical Venturi tube with an "as cast" convergent section

This is a classical Venturi tube made by casting in a sand mould, or by other methods which leave a finish on the surface of the convergent section similar to that produced by sand casting. The throat is machined and the junctions between the cylinders and cones are rounded.

These classical Venturi tubes can be used in pipes of diameter between 100 mm and 800 mm and with diameter ratios β between 0,3 and 0,75 inclusive.

5.1.3 Classical Venturi tube with a machined convergent section

This is a classical Venturi tube cast or fabricated as in 5.1.2 but in which the convergent section is machined as are the throat and the entrance cylinder. The junctions between the cylinders and cones may or may not be rounded.

These classical Venturi tubes can be used in pipes of diameter between 50 mm and 250 mm and with diameter ratios β between 0,4 and 0,75 inclusive.

5.1.4 Classical Venturi tube with a rough-welded sheet-iron convergent section

This is a classical Venturi tube normally fabricated by welding. For larger sizes it may not be machined if the tolerance required in 5.2.4 can be achieved, but in the smaller sizes the throat is machined.

These classical Venturi tubes can be used in pipes of diameter between 200 mm and 1 200 mm and with diameter ratios β between 0,4 and 0,7 inclusive.

5.2 General shape

5.2.1 Figure 1 shows a section through the centreline of the throat of a classical Venturi tube. The letters used in the text refer to those shown on Figure 1.

The classical Venturi tube is made up of an entrance cylinder A connected to a conical convergent section B, a cylindrical throat C and a conical divergent section E. The internal surface of the device is cylindrical and concentric with the pipe centreline. The coaxiality of the convergent section and the cylindrical throat is assessed by visual inspection.

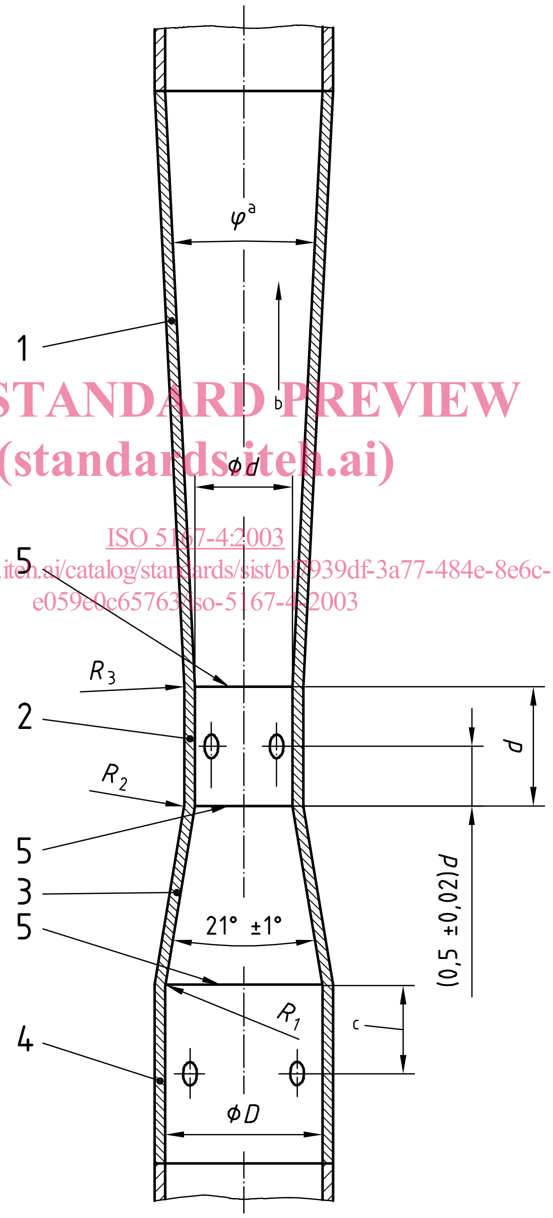
5.2.2 The minimum cylinder length, measured from the plane containing the intersection of the cone frustum B with the cylinder A, may vary as a result of the manufacturing process (see 5.2.8 to 5.2.10). It is, however, recommended that it be chosen to be equal to D.

The entrance cylinder diameter D shall be measured in the plane of the upstream pressure tappings. The number of measurements shall be at least equal to the number of pressure tappings (with a minimum of four).

The diameters shall be measured near each pair of pressure tappings, and also between these pairs. The arithmetic mean value of these measurements shall be taken as the value of D in the calculations.

Diameters shall also be measured in planes other than the plane of the pressure tappings.

No diameter along the entrance cylinder shall differ by more than 0,4 % from the value of the mean diameter. This requirement is satisfied when the difference in the length of any of the measured diameters complies with the said requirement with respect to the mean of the measured diameters.



Key

1 conical convergent E
2 cylindrical throat, C
3 conical convergent B
4 entrance cylinder A
5 connecting planes

a $7° \leqslant \varphi \leqslant 15°$
b Flow direction
c See 5.4.7

Figure 1 — Geometric profile of the classical Venturi tube

5.2.3 The convergent section B shall be conical and shall have an included angle of 21°± 1° for all types of classical Venturi tube. It is limited upstream by the plane containing the intersection of the cone frustum B with the entrance to cylinder A (or their prolongations) and downstream by the plane containing the intersection of the cone frustum B with the throat C (or their prolongations).

The overall length of the convergent B measured parallel to the centreline of the Venturi tube is therefore approximately equal to $2{,}7(D - d)$.

The convergent section B is blended to the entrance cylinder A by a curvature of radius R_1, the value of which depends on the type of classical Venturi tube.

The profile of the convergent section shall be checked by means of a template. The deviation between the template and the conical section of the convergent section shall not exceed, in any place, $0{,}004D$.

The internal surface of the conical section of the convergent section is taken as being a surface of revolution if two diameters situated in the same plane perpendicular to the axis of revolution do not differ from the value of the mean diameter by more than 0,4 %.

It shall be checked in the same way that the joining curvature with a radius R_1 is a surface of revolution.

5.2.4 The throat C shall be cylindrical with a diameter d. It is limited upstream by the plane containing the intersection of the cone frustum B with the throat C (or their prolongations) and downstream by the plane containing the intersection of the throat C with the cone frustum E (or their prolongations). The length of the throat C, i.e the distance between those two planes, shall be equal to $d \pm 0{,}03d$ whatever the type of classical Venturi tube.

The throat C is connected to the convergent section B by a curvature of radius R_2 and to the divergent section E by a curvature of radius R_3. The values of R_2 and R_3 depend on the type of classical Venturi tube.

The diameter d shall be measured very carefully in the plane of the throat pressure tappings. The number of measurements shall be at least equal to the number of pressure tappings (with a minimum of four). The diameters shall be measured near each pair of pressure tappings and also between these pairs. The arithmetic mean value of all these measurements shall be taken as the value of d in the calculations.

Diameters shall also be measured in planes other than the plane of the pressure tappings.

No diameter along the throat shall differ by more than 0,1 % of the value of the mean diameter. This requirement is satisfied when the difference in the length of any of the measured diameters complies with the said requirement in respect of the mean of the measured diameters.

The throat of the classical Venturi tube shall be machined or be of equivalent smoothness over the whole of its length to the surface roughness specified in 5.2.7.

It shall be checked that the joining curvatures into the throat with radii R_2 and R_3 are surfaces of revolution as described in 5.2.3. This requirement is satisfied when two diameters, situated in the same plane perpendicular to the axis of revolution, do not differ from the value of the mean diameter by more than 0,1 %.

The values of the radii of curvature R_2 and R_3 shall be checked by means of a template.

The deviation between the template and the classical Venturi tube shall evolve in a regular way for each curvature so that the single maximum deviation that is measured occurs at approximately midway along the template profile. The value of this maximum deviation shall not exceed $0{,}02d$.

5.2.5 The divergent section E shall be conical and may have an included angle, φ, of between 7° and 15°. It is, however, recommended that an angle between 7° and 8° be chosen. Its smallest diameter shall not be less than the throat diameter.

5.2.6 A classical Venturi tube is called “truncated” when the outlet diameter of the divergent section is less than the diameter D and “not truncated” when the outlet diameter is equal to diameter D. The divergent portion may be truncated by about 35 % of its length without significantly modifying the pressure loss of the device or its discharge coefficient.

5.2.7 The roughness criterion Ra, of the throat and that of the adjacent curvature shall be as small as possible and shall always be less than $10^{-4}d$. The divergent section is rough cast. Its internal surface shall be clean and smooth. Other parts of the classical Venturi tube have specified roughness limits depending on the type considered.

5.2.8 The profile of the classical Venturi tube with an "as cast" convergent section has the following characteristics.

The internal surface of the convergent section B is sand cast. It shall be free from cracks, fissures, depressions, irregularities and impurities. The roughness criterion Ra for the surface shall be less than $10^{-4}D$.

The minimum length of the entrance cylinder A shall be equal to the smaller of the following two values:

— D, or

— $0{,}25D + 250$ mm (see 5.2.2).

The internal surface of the entrance cylinder A may be left "as cast" provided that it has the same surface finish as the convergent section B.

The radius of curvature R_1 shall be equal to $1{,}375D \pm 0{,}275D$.

The radius of curvature R_2 shall be equal to $3{,}625d \pm 0{,}125d$.

The length of the cylindrical part of the throat shall be no less than $d/3$. In addition, the length of the cylindrical part between the end of the joining curvature R_2 and the plane of the pressure tappings, as well as the length of the cylindrical part between the plane of the throat pressure tappings and the beginning of the joining curvature R_3, shall be no less than $d/6$ (see also 5.2.4 for the throat length).

The radius of curvature R_3 shall lie between $5d$ and $15d$. Its value shall increase as the divergent angle decreases. A value close to $10d$ is recommended.

5.2.9 The profile of the classical Venturi tube with a machined convergent section has the following characteristics.

The minimum length of the entrance cylinder A shall be equal to D.

The radius of curvature R_1 shall be less than $0{,}25D$ and preferably equal to zero.

The radius of curvature R_2 shall be less than $0{,}25d$ and preferably equal to zero.

The length of the throat cylindrical part between the end of the curvature R_2 and the plane of the throat pressure tappings shall be no less than $0{,}25d$.

The length of the throat cylindrical part between the plane of the throat pressure tappings and the beginning of the joining curvature R_3 shall be no less than $0{,}3d$.

The radius of curvature R_3 shall be less than $0{,}25d$ and preferably equal to zero.

The entrance cylinder and the convergent section shall have a surface finish equal to that of the throat (see 5.2.7).

5.2.10 The profile of the classical Venturi tube with a rough-welded sheet-iron convergent section has the following characteristics.

