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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

Mesurage 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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

ISO 5167-4 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 2, *Pressure differential devices*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/SS F05, *Measuring instruments*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition of ISO 5167-4 cancels and replaces the first edition of ISO 5167-4:2003, which has been technically revised.

The main changes are as follows:

— The use of single pressure tappings on Venturi tubes is permitted.

— The discharge coefficient and uncertainty are given in Clause 5 for a Venturi tube with a machined convergent section for $Re_D > 10^6$.

— Flow calibration of Venturi tubes is included.

— There is improved wording of the rules for spacing of multiple fittings but no change in actual requirements.

A list of all parts in the ISO 5167 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

ISO 5167, consisting of six parts, covers the geometry and method of use (installation and operating conditions) of orifice plates, nozzles, Venturi tubes, cone meters and wedge meters 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.

ISO 5167 (all parts) 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 uncalibrated within specified limits of pipe size and Reynolds number, or alternatively they can be used across their calibrated range.

ISO 5167 (all parts) 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. ISO 5167 (all parts) also provides methodology for bespoke calibration of differential pressure meters.

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 to facilitate the instrument readings are known as secondary devices, and the flow computer that receives these readings and performs the algorithms is known as a tertiary device. ISO 5167 (all parts) covers primary devices; secondary devices (see ISO 2186) and tertiary devices will be mentioned only occasionally.

Aspects of safety are not dealt with in ISO 5167-1 to ISO 5167-6. It is the responsibility of the user to ensure that the system meets applicable safety regulations.

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 document specifies the geometry and method of use (installation and operating conditions) of Venturi tubes[1)] when they are inserted in a conduit running full to determine the flow rate of the fluid flowing in the conduit.

This document also provides background information for calculating the flow rate and is applicable in conjunction with the requirements given in ISO 5167-1.

This document 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, Venturi tubes can only be used uncalibrated in accordance with this standard within specified limits of pipe size, roughness, diameter ratio and Reynolds number, or alternatively they can be used across their calibrated range. This document is not applicable to the measurement of pulsating flow. It does not cover the use of uncalibrated 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 document deals with the three types of classical Venturi tubes:

a) “as cast”;

b) machined;

c) fabricated (also known as “rough-welded sheet-iron”).

A Venturi tube consists of a convergent inlet connected to a cylindrical throat which is in turn connected to a conical expanding section called the divergent section (or alternatively the diffuser). Venturi nozzles (and other nozzles) are dealt with in ISO 5167-3.

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

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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, *Measurement of fluid flow in closed conduits — Vocabulary and symbols*

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

ISO 5168, *Measurement of fluid flow — Procedures for the evaluation of uncertainties*

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

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

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. A static pressure difference exists between the upstream section and the throat section of the device. Venturi tube geometries and designs have been extensively tested across a wide range of flow conditions and shown to have a reproducible value of the discharge coefficient, C, within a given uncertainty. Uncalibrated Venturi tubes of one of these geometries and designs, within that same range of flow conditions, can be used to determine the flow rate from the measured value of this pressure difference and from a knowledge of the fluid conditions.

The mass flow rate can be determined by Formula (1):

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

The uncertainty limits can be calculated using the procedure given in ISO 5167-1:2022, Clause 8.

Similarly, the value of the volume flow rate 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 flow rate, which is an arithmetic process, is performed by replacing the different items on the right-hand side of Formula (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 Formula (1) (since D is required to calculate β) 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 document depends on the way in which they are manufactured.

Three types of standard classical Venturi tube are specified 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 (and hence roughness) are described in 5.1.2 to 5.1.4, and the resulting Venturi tubes have somewhat different characteristics.

There are limits given for the roughness of the internal surfaces and the Reynolds number for each type.

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 the convergent and divergent sections 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 the convergent and divergent sections may or may not be rounded.

These classical Venturi tubes can be used in pipes of diameter between 50 mm and 350 mm and with diameter ratios β between 0,4 and 0,75 inclusive.

5.1.4 Classical Venturi tube with a fabricated convergent section

This is a classical Venturi tube normally fabricated by rolling sheet iron (or an alternative sheet material) to form the sections of the Venturi tube, welding to complete the cylindrical, convergent and divergent sections, and then welding these together. 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 General

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.

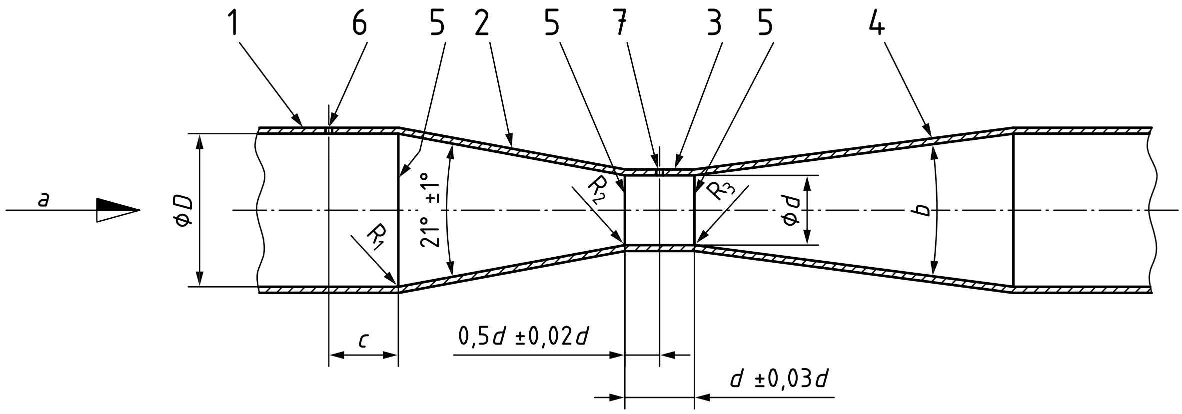
5.2.2 Entrance cylinder

The minimum cylinder length, measured from the plane containing the intersection of the convergent section 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 tapping(s). The number of measurements shall be at least four, of which one shall be measured near each pressure tapping. 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 tapping(s).

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 entrance cylinder A
2 conical convergent section B
3 cylindrical throat C
4 conical divergent section E
5 connecting planes
6 upstream pressure tapping(s)
7 throat pressure tapping(s)

a Direction of flow.
b 7° ≤ φ ≤ 15°.
c See 5.4.7.

Figure 1 — Geometric profile of the classical Venturi tube

5.2.3 Convergent section

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 section 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. The maximum deviation 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 Throat

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 tapping(s). The number of measurements shall be at least four, of which one shall be measured near each pressure tapping. 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 tapping(s).

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

5.2.5 Divergent section

The divergent section E shall be conical and may have an included angle, φ, of between 7° and 15°. For low pressure-loss applications, it is recommended that an angle between 7° and 8° be chosen. Its smallest diameter shall not be less than the throat diameter.

5.2.6 Truncated Venturi tube

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 Roughness

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 internal surface of the divergent section shall be clean and smooth. Other parts of the classical Venturi tube have specified roughness limits depending on the type considered.

5.2.8 Classical Venturi tube with an “as cast” convergent section

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 Classical Venturi tube with a machined convergent section

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 Classical Venturi tube with a fabricated convergent section

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

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

There shall be no joining curvature between the entrance cylinder A and the convergent section B other than that resulting from welding.

There shall be no joining curvature between the convergent section B and the throat C other than that resulting from welding.

There shall be no joining curvature between the throat C and the divergent section E other than that resulting from welding.

The internal surface of the entrance cylinder A and the convergent section B shall be clean and free from encrustation and welding deposits. It may be galvanized. Its roughness criterion, Ra, shall be about $5 \times 10^{-4}D$.

