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Measurement of clean water flow in closed conduits — Velocity-area method using current-meters in full conduits and under regular flow conditions

Mesurage de débit d'eau propre dans les conduites fermées — Méthode d'exploration du champ des vitesses dans les conduites en charge et dans le cas d'un écoulement régulier, au moyen de moulinets

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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.

This International Standard was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 5, *Velocity and mass methods*.

This third edition results from the reinstatement of ISO 3354:1988 which was withdrawn in 2003 and with which it is technically identical.

Measurement of clean water flow in closed conduits — Velocity-area method using current-meters in full conduits and under regular flow conditions

1 Scope

This International Standard specifies a method for the determination of the volume flow-rate in a closed conduit by means of the velocity-area method using propeller-type current-meters under the following conditions:

a) the velocity distribution is regular (see 6.1.2);

b) the fluid is water which is clean or considered to be clean [1)];

c) the conduit is full;

d) the flow is steady [2)].

It deals in particular with the technology and calibration of propeller-type current-meters, the measurement of local velocities and the calculation of the flow-rate by velocity integration.

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 3455, *Hydrometry — Calibration of current-meters in straight open tanks*

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

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

ISO 7194, *Measurement of fluid flow in closed conduits — Velocity-area methods of flow measurement in swirling or asymmetric flow conditions in circular ducts by means of current-meters or Pitot static tubes*

1) This method may be applied to other single-phase fluids but special precautions should be taken in this case.

2) The steady flows observed in conduits are in practice flows in which quantities such as velocity, pressure, density and temperature vary in time about mean values independent of time; these are actually "mean steady flows".

3 Terms, definitions and symbols

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

3.1 Terms

3.1.1
current-meter
device provided with a rotor the rotational frequency of which is a function of the local velocity of the fluid in which the device is immersed

NOTE 1 This International Standard is concerned only with propeller-type current-meters, i.e. current-meters the rotor of which is a propeller rotating around an axis approximately parallel to the direction of flow.

NOTE 2 Obviously this definition does not prohibit the use of self-compensating propellers (see 6.1.5), the merit of which is, in particular, that they can be used at a rather high angle relative to the local direction of the flow. However, the use of cup-type current-meters is not allowed for the purposes of this International Standard.

3.1.2
stationary array
set of current-meters mounted on one or more fixed supports which sample simultaneously the whole measuring cross-section

3.1.3
peripheral flow-rate
the volume flow-rate in the area located between the pipe wall and the contour defined by the velocity measuring points which are closest to the wall

3.1.4
mean axial fluid velocity
ratio of the volume flow-rate (the integral over a cross-section of the conduit of the axial components of the local fluid velocity) to the area of the measuring cross-section

3.1.5
relative velocity
ratio of the flow velocity at the considered point to a reference velocity measured at the same time, which is either the velocity at a particular point (e.g. at the centre of a circular conduit) or the mean axial fluid velocity in the measuring section

3.1.6
straight length
portion of a conduit whose axis is straight, and in which the cross-sectional area and cross-sectional shape are constant; the cross-sectional shape is usually circular or rectangular, but could be annular or any other regular shape

3.1.7
irregularity
any pipe fitting or configuration of a conduit which renders the conduit different from a straight length or which produces a considerable difference in wall roughness

NOTE In the case of the method of measurement specified in this International Standard, those irregularities which create the most serious disturbances are generally bends, valves, gates and sudden widening of the cross-section.

3.1.8
hydraulic diameter
diameter equal to four times the hydraulic radius, i.e. four times the ratio of the wetted cross-sectional area to the wetted perimeter

EXAMPLE In a conduit of circular cross-section running full, the hydraulic diameter is equal to the geometric diameter.

3.1.9
index of asymmetry
⟨for circular ducts⟩ ratio of the standard deviation of the mean velocities calculated along each radius (i.e. along each radial line from the pipe centre to the wall along which velocity measuring positions are located) to the mean axial fluid velocity calculated for the pipe, i.e.

$$Y = \frac{\sigma_{U_i}}{U} = \frac{1}{U}\left[\frac{\sum_{i=1}^{n}\left(U_i - U\right)^2}{n-1}\right]^{1/2}$$

where

U_i is the mean velocity, calculated, in accordance with the integration method agreed, from the individual point velocity measurements on the ith radius (see 8.2 and 9.2);

U is the mean axial fluid velocity calculated from all the individual point velocity measurements throughout the cross-section;

n is the number of radii along which measurements are made

3.1.10
regular velocity distribution
distribution of velocities which sufficiently approaches a fully developed velocity distribution to permit an accurate measurement of the flow-rate to be made

3.2 Symbols

Symbol	Quantity	Dimension	SI unit
A	area of the measuring cross-section	L^2	m^2
a, a'	distance along a measuring line in a rectangular cross-section from the extreme measuring point to the nearest wall	L	m
D	pipe diameter	L	m
d	propeller diameter	L	m
e	uncertainty (absolute value)	—[a]	—[a]
e_r	random uncertainty	—[a]	—[a]
e_s	systematic uncertainty	—[a]	—[a]
E	relative uncertainty	—	—
E_r	relative random uncertainty	—	—
E_s	relative systematic uncertainty	—	—
H	length of the smaller side of the cross-section of a rectangular conduit	L	m
h	distance from a given measuring point to the reference wall, in the direction parallel with the smaller side of the cross-section	L	m
k	equivalent uniform roughness	L	m
L	length of the larger side of the cross-section of a rectangular conduit	L	m

Symbol	Quantity	Dimension	SI unit
l	distance from a given measuring point to the reference wall, in the direction parallel with the larger side of the cross-section	L	m
m	boundary layer coefficient	—	—
n	frequency of rotation of a propeller	T^{-1}	r/s
p	number of measuring points along a radius (circular cross-section) or a straight line (rectangular cross-section)	—	—
q_V	volume flow-rate	L^3T^{-1}	m^3/s
R	pipe radius	L	m
r	measuring circle radius	L	m
r^*	measuring circle relative radius, $r^* = r/R$	—	—
Re	Reynolds number	—	—
U	mean axial fluid velocity	LT^{-1}	m/s
u	mean velocity along a measurement circumference or line	LT^{-1}	m/s
v	local velocity of the fluid	LT^{-1}	m/s
v_0	local velocity of the fluid at the centre-line of the pipe	LT^{-1}	m/s
Y	index of asymmetry of the flow	—	—
y	distance from a measuring point to the nearest wall	L	m
y^*	relative interval between two measuring points, $y^* = (l_i - l_{i-1})/L$	—	—
α	polar angle of a measuring point (in a circular cross-section)	—	rad
λ	universal coefficient for pipe head loss	—	—

[a] The dimensions and units are those of the quantity to which the symbol refers.

4 Principle

4.1 General

The principle of the method consists of

a) measuring the dimensions of the measuring section, which shall be chosen to be normal to the conduit axis; this measurement is for defining the area of the cross-section (see 4.2);

b) defining the position of the measuring points in this cross-section, where the number of measuring points shall be sufficient to permit adequate determination of the velocity distribution (see 4.3);

c) measuring the axial component of the velocity at these measuring points;

d) determining the mean axial fluid velocity from the preceding measurements;

e) calculating the volume flow-rate, which is equal to the product of the cross-sectional area and the mean axial fluid velocity.

However, for certain cross-sections of particular shape, the treatment of the measurement leads directly to the flow-rate determination without a preliminary calculation of the cross-sectional area and mean axial fluid velocity (see Annex A).

The error resulting from the use of the velocity-area method is dependent, among other factors, on the shape of the velocity profile and on the number and position of the measuring points.

The method of measurement and the requirements defined in this International Standard aim at achieving (at the 95 % confidence level) an uncertainty in flow-rate not greater than ± 2 % provided that the correction for blockage effect (see 6.4.3 and Annex B) has been applied.

However, this method is valid only if the flow is not affected by excessive swirl or asymmetry; criteria are given in 6.1.2 so that an estimate can be made of whether or not the flow is regular enough for this International Standard to be applicable and whether the uncertainty lies within the required range. If not, reference should be made to ISO 7194.

In general, if any of the requirements of this International Standard are not fulfilled, this method may still be applied but the uncertainty in the flow-rate measurement will be larger.

Moreover, only circular and rectangular cross-sections are specifically dealt with in this International Standard, to cover the large majority of practical cases. Nevertheless, directions on how to proceed for certain other cross-sections of particular shape are given in Annex A.

This International Standard presents three methods for determining the mean axial fluid velocity as follows.

4.1.1 Graphical integration of the velocity area (see Clause 8)

This method consists of plotting the velocity profile on a graph and evaluating the area under the curve which is bounded by the measuring points closest to the wall. To the value thus obtained is added a term representing the peripheral flow-rate (see 3.1.3) which is calculated on the assumption that the velocity profile in this zone satisfies a power law.

For this method, the measuring points may be located at whichever positions are required in order to obtain a satisfactory knowledge of the velocity profile.

4.1.2 Numerical integration of the velocity area (see Clause 9)

The only difference between this method and the previous method (4.1.1) lies in the fact that the graphical velocity profile is replaced by an algebraic curve and the integration is carried out mathematically.

4.1.3 Arithmetical methods (see Clause 10)

The arithmetical methods assume that the velocity distribution follows a particular law; the mean velocity in the conduit is then given by a linear combination of the individual velocities measured at the locations specified by the method.

For the arithmetical methods described in Clause 10, the assumption is made that in the peripheral zone the velocity distribution follows a logarithmic law as a function of the distance from the wall.

4.2 Measurement of the measuring cross-section

4.2.1 Circular cross-sections

The mean diameter of the conduit is taken as equal to the arithmetic mean of measurements carried out on at least four diameters which are at approximately equal angles to one another in the measuring section. If the difference between the lengths of two consecutive diameters is greater than 0,5 %, the number of measured diameters shall be doubled.

4.2.2 Rectangular cross-sections

The smaller side and larger side of the conduit shall both be measured at least on each straight line passing through the measuring points. If the difference between the widths (or heights) corresponding to two successive measuring lines is greater than 1 %, the number of measured widths (or heights) shall be doubled.

4.3 Measurement of local velocities

4.3.1 General

The flow velocity at a point of the measuring section is determined by measuring the rotational frequency of a current-meter placed at that point and by entering this value in the calibration equation of the current-meter.

The current-meter rotational frequency may be obtained:

— either by counting the number of propeller rotations which occur within a predetermined period; or

— by measuring the time required by the propeller to perform a specified number of rotations.

Another method that may be used is that whereby the velocity is determined by direct measurement of the signal frequency.

For both methods, various measuring points in the cross-section may be explored simultaneously or successively (see 4.3.2 and 4.3.3).

4.3.2 Simultaneous measurements

When several current-meters are used simultaneously, the method by measuring the time requires more sophisticated counting equipment than the method by counting the number of revolutions, but it is more accurate. The latter method may actually lead to an error since if a time interval is chosen, it may not correspond to a whole number of rotations.

As local velocities are generally subject to long-term fluctuations, it is necessary to provide a sufficient period of measurement for determining the mean velocity correctly. This period of time may be determined by measuring the same flow-rate during gradually increasing intervals of time. The time of measurement, t, to be adopted shall be such that the values of the mean velocity in the cross-section, obtained for measuring times equal to t and $t + \Delta t$, shall not vary by more than x %. For example, Δt could be about 30 s and x chosen to be 0,1 %. Time, t, may vary according to the mean fluid velocity.

4.3.3 Non-simultaneous measurements

In cases where all velocity measurements points are not sampled simultaneously, it is essential that the shape of the velocity profile in the measuring cross-section remain stable and be unaffected by possible variations in the flow-rate during the measuring period. The steadiness of flow-rate shall then be checked and point velocities possibly corrected by means of a continuous measurement, during the whole duration of gauging, of the velocity at a reference point.

If only one measuring device is available, the steadiness of the flow-rate shall be checked by frequently repeating measurements at the reference point.

However, note that velocity profile fluctuations do not necessarily create flow-rate fluctuations. In such a case the use of a reference point velocity may lead to errors and it is preferable to check that the flow-rate is steady by means of any pressure-difference device (e.g. standardized or non-standardized pressure-difference flow-meter, a piezometric control on a convergence, a device on a bend, a spiral casing, a device for indicating a peculiar pressure loss) even if it is not calibrated, provided that its reliability and adequate sensitivity have been ascertained.

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