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This third edition results from the reinstatement of ISO 3354:1988 which was withdrawn in 2003 and with which it is technically identical.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

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.

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

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.

When the curve of the reference velocity, v_r, has been plotted against time, this curve is used to relate all velocity measurements to the same reference flow-rate, q_0 (preferably that which corresponds to the mean of the reference velocity measurements). For comparatively small changes in the reference velocity, the velocity, $v_{i,t}$, measured at any point at time, t, can be corrected by multiplying by the ratio of the reference velocity, $v_{r,0}$, corresponding to the flow-rate, q_0, to reference velocity, $v_{r,t}$, at time, t:

$$v_{i,0} = v_{i,t} \left(\frac{v_{r,0}}{v_{r,t}} \right)$$

where $v_{i,0}$ is the velocity at point i to be used for the integration.

4.3.4 Checking the velocity distribution

Even when the mean axial fluid velocity is calculated by a method which does not require plotting of the velocity profile, it is recommended, in order to be confident that the velocity distribution is regular, that this plotting be carried out, or at least that its regularity be checked by some other means.

In the same way, when several measurements are made on the same cross-section at different flow-rates, it is recommended that the velocity profiles be plotted in a non-dimensional manner [i.e. by using the relative velocities (see 3.1.5)] to check their consistency with one another and hence to ensure that there are no abnormal features at particular flow-rates (thus, the profiles shall not change erratically as the flow-rate varies over a wide range of Reynolds numbers).

It may also be useful to plot the velocity distribution curves as indicated above in order to detect any error in the measurement of a local velocity. The doubtful measurement shall be repeated whenever possible; when this cannot be done, it shall be rejected and the velocity profile drawn on the basis of the remaining data, provided that there are independent reasons for believing that the doubtful measurement is false.

4.4 Location and number of measuring points in the cross-section

4.4.1 General

The location of the measuring points depends on the method chosen to calculate the flow-rate. The rules relating to the methods specified in this International Standard are given in Clauses 8, 9 and 10.

Whatever the method, the following dimensional rules shall be complied with:

— the minimum distance between the current-meter axis and the wall shall be 0,75d;

— the minimum distance between the axes of two current-meters shall be $(d_1 + d_2)/2 + 0{,}03$ m, where d_1 and d_2 are the outside diameters of the propellers of the current-meters.

NOTE Usually, d_1 and d_2 are equal, but it can be useful to set current-meters having propellers smaller in diameter than those used at other locations in the cross-section in the vicinity of the wall to explore best the flow pattern in this area (see Clause 8).

The location of any current-meter shall be measured to the smaller of the following two uncertainties:

$\pm$ 0,01 L, where L is the dimension of the conduit parallel to the direction of measurement of the current-meter position;

$\pm$ 0,02 y, where y is the distance of the current-meter from the nearest wall.

The minimum number of measuring points, applying in particular to small-dimension conduits, is specified in 4.4.2 and 4.4.3. As it is necessary that the velocity profile be known as accurately as possible, it may be advantageous to increase the number of measuring points provided that this is allowed by the requirements given above and that it does not cause notable blockage effects (see 6.4.3).

When a single current-meter is traversed across a conduit, it is first necessary to determine the distance between a reference point (from which each position is measured) and the wall of the duct. This may introduce a relatively large systematic error in all position measurements. In such circumstances it is recommended, in the case of a circular cross-section conduit, that complete diameters be traversed (rather than opposite radii on each diameter) since the systematic error will then tend to cancel out on the two halves of the traverse. However, blockage and vibration problems may be more severe when a complete diameter is traversed.

4.4.2 Circular cross-sections

The measuring points on circular cross-sections shall be located at every point of intersection between a given number of circles concentric with the pipe axis and a given number of diameters at equal angular spacing.

The mimimum numbers recommended in the scope of this International Standard are three circles and two mutually perpendicular diameters (see last paragraph) so that the minimum number of measuring points in the cross-section is 12. An additional measuring point at the centre of the conduit is desirable to check the shape of the velocity profile.

However, this minimum number is acceptable only if one of the following conditions is fulfilled:

— if it is known that the velocity distribution is very nearly axisymmetrical, which is checked either by examining the layout of the pipe or by measurements previously carried out in the same cross-section, or

— if the use of a higher number of diameters results in a prohibitive blockage of the measuring section (see 6.4.3).

If neither of these conditions is fulfilled, the velocity distribution shall be scanned more closely, e.g. by increasing to three the number of diameters. It should be noted that in general the uncertainty in flow measurement is reduced more by increasing the number of radii along which measurements are made than by increasing the number of points per radius; nevertheless, there is little advantage in exceeding four diameters.

When the measurements are carried out by means of a stationary array, reference should be made to 6.4.4 for the minimum diameter of conduits in which this method can be applied; however, in any case the general requirements given in 4.4.1 on the minimum distance between two current-meters prohibit the use of a stationary array in conduits the diameter of which is less than 7,5 $d + 0{,}18$ m.

If a high accuracy is not required, measurements may be made along a single diameter provided that there is a straight length of at least 60 D upstream of the measurement section and provided that the Reynolds number is in excess of the values given in Table 1 for the corresponding values of the universal coefficient for pipe head loss λ. (For the estimation of λ, see Annex E.)

Table 1 — The minimum Reynolds number as a function of the universal coefficient for pipe head loss, λ

λ	Re_D
$\geqslant 0{,}03$	10^4
0,025	3×10^4
0,02	10^5
0,01	10^6

4.4.3 Rectangular cross-sections

The minimum number of measuring points shall be 25. Unless a special layout of measuring points is adopted for the use of an arithmetical method, their position shall be defined by the intersections of at least five straight lines running parallel to each of the boundaries of the cross-section.

When the measurements are carried out by means of a stationary array, reference should be made to 6.4.4 for the minimum dimensions of conduits in which this method can be applied; however, in any case the general requirements given in 4.4.1 on the minimum distance between two current-meters prohibit the use of a stationary array in conduits the smaller dimension of which is less than 5,5 $d + 0{,}12$ m.

5 Description of the current-meter

A propeller-type current-meter consists of a propeller, an axis of rotation, bearings and the current-meter body with the counting device.

Each current-meter may be fitted with different types of propeller (e.g. of different pitch, diameter). Propellers may have two or more blades and may be manufactured out of metal or plastics material.

Current-meters for site measurements shall be manufactured out of non-corrosive material only or shall be effectively protected against corrosion. They shall be of sufficiently sturdy construction for their calibration to remain valid under normal field operating conditions.

Components shall be interchangeable to allow easy replacement of worn or damaged parts, but this replacement shall not increase the uncertainty in the measurement.

Output signals may be generated by mechanical contact or by any magnetic, electrical or optical device. They are totalized or recorded on an appropriate receiver or indicated by an acoustic or optical device.

Counting shall be accurate and reliable for any given velocity within the operational range specified by the manufacturer. The number of signals delivered per propeller revolution shall be consistent with the velocities to be measured, the design of the receiver and an acceptable measuring period. In some cases, it will therefore be necessary to be able to choose the number of signals per propeller revolution.

Provision shall be made for fixing the current-meter on a support in a well-defined position.

6 Requirements for the use of current-meters

6.1 Selection of the measuring cross-section

6.1.1 The cross-section selected for the measurements shall be located in a straight length; it shall be perpendicular to the direction of flow and of simple shape, e.g. circular, rectangular. The measuring cross-section shall be located in an area where the individual local velocities fall within the normal working range of the current-meters used (see 6.4.2).

6.1.2 Close to the measuring cross-section, the flow shall be such that it may be considered to be “regular”, i.e. it shall be substantially parallel to and symmetric about the conduit axis and shall present neither excessive turbulence nor swirl. (For further information, see ISO 7194.)

The flow may be assumed to be sufficiently regular to permit the use of this International Standard if the two following conditions are fulfilled:

a) at any point of the cross-section, the swirl angle shall be less than or equal to 5°;

b) the index of asymmetry, Y (as defined in 3.1.9), shall be less than or equal to 0,05.