International Standard ISO 6416

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Liquid flow measurement in open channels — Measurement of discharge by the ultrasonic (acoustic) method

Mesure de débit des liquides dans les canaux découverts — Mesure de débit à l'aide de la méthode ultrasonique (acoustique)

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Foreword

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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. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

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Annexes

Liquid flow measurement in open channels — Measurement of discharge by the ultrasonic (acoustic) method

1 Scope and field of application

This International Standard describes the establishment and operation of an ultrasonic (acoustic) gauging station on a river or open channel for the measurement of discharge. For the operation and performance of instrumentation, reference should be made to ISO 6418.

2 References

ISO 748, *Liquid flow measurement in open channels — Velocity-area methods.*

ISO 772, *Liquid flow measurement in open channels — Vocabulary and symbols.*

ISO 1100/2, *Liquid flow measurement in open channels — Part 2: Determination of the stage discharge relation.*

ISO 4373, *Measurement of liquid flow in open channels — Water level measuring devices.*

ISO 5168, *Measurement of fluid flow — Estimation of uncertainty of a flow-rate measurement.*

ISO 6418, *Liquid flow measurement in open channels — Ultrasonic (acoustic) velocity meters.*

3 Definitions

For the purpose of this International Standard, the definitions given in ISO 772 apply.

4 Units of measurement

The units of measurement used in this International Standard are those of the International System of Units (SI).

5 Principles of the measurement method

5.1 The principle of the ultrasonic (acoustic) method is measurement of the velocity of flow at a certain elevation, or elevations, in the channel by transmitting acoustic pulses in both directions through the water from transducers located in the banks on both sides of the river. The transducers may be designed to transmit and receive pulses; they are not located directly opposite each other but are staggered so that there is a time difference between pulses travelling downstream and those travelling upstream. The angle between the transmission path and the direction of flow should normally be between 30 and 60° (see figures 2 and 3).

5.2 The difference between the time of travel of the acoustic pulses crossing the river in an upstream direction and those travelling downstream is directly related to the average velocity of the water at the elevation of the transducers. This velocity can then be related to the average velocity of flow of the whole cross-section and, if desirable, by incorporating an area factor in the electronic processor, the system can give an output of discharge.

6 Site selection

6.1 The site selected should be such that it is feasible to measure the whole range and all types of flow which may be encountered or of which measurement is required. The following factors should be considered:

a) a reliable source of electrical energy should be available;

b) there should be good all-weather access to the site;

c) the measuring reach should be straight and uniform; abrupt bends and irregularities in the channel should be avoided if possible but these may be acceptable provided that condition d) is satisfied or where changes can be effectively monitored by a crossed acoustic path. Sections in which appreciable cross-currents or large eddies form should be avoided;

d) at cross-sections taken in the reach between the upstream and downstream transducer mountings, the velocity distribution should be similar;

e) if the bed profile should change significantly with stage, regular bed surveys should be carried out at different stages of flow to determine the change in area in order to compute the discharge;

f) the section should be free of weed growth since this will attenuate the acoustic signal;

g) the installation should take into consideration reflection and timing error problems caused by multipath interferences. The minimum depth for transducer placement increases as path length increases. Timing errors inhibit the use of low frequencies (see annex A);

h) refraction of the acoustic signal can be caused by temperature gradients and the signal may be lost due to this cause alone. A water temperature survey should therefore be made at the proposed site particularly during extremes of temperature; refraction of the acoustic signal can also be caused by density gradients;

j) attenuation of the acoustic signal can be caused by the absorption, reflection and scatter of the propagated pressure wave. Attenuation losses inhibit the use of high frequencies over an extremely long path;

k) suspended solids may have a significant effect on signal attenuation and entrained air bubbles can have considerably more effect. Due regard should therefore be given to the operating frequency and path length. Suspended particle size and concentration and/or bubble population should be assessed to define attenuation;

m) for sites which do not meet one or more of the above requirements, a preliminary test should be carried out using portable acoustic equipment.

7 Design and construction

7.1 The gauging station should consist of

a) transducers, arranged as follows:

1) one or more transducers installed on both sides of the river and fixed permanently in position, or

2) one or more transducers installed on both sides of the river having the facility of movement in the vertical plane or on an incline;

b) a console containing an electronic data processor and facilities for recording and/or transmitting data;

c) a water level recorder interfaced with the electronic data processor where a hard copy record of stage or discharge or both is required;

d) a reference gauge and a permanent bench mark.

All interconnecting cabling to and from transducers shall be armoured and/or protected from damage during installation and operation.

7.2 For the method of fixed transducers [see 7.1 a) 1)], a path or index velocity is obtained which is related to stage and area to obtain discharge. Calibration shall be performed using a current-meter, transducer traverse or by extension of the velocity profile theory.

7.2.1 For the method whereby the transducers are designed to move on a vertical or inclined assembly [see 7.1 a) 2)], the transducers may be used to calibrate the station. This is performed by establishing vertical distributions of line velocity curves by moving the transducers to the various paths and obtaining a series of path velocities in the vertical. This should be performed at different values of stage and the resulting curves analysed to determine the optimum location to fix the transducers. If possible, an independent check should be made by current-meter or another suitable method.

7.3 In the multipath system, where several pairs of transducers are employed, the optimum positions of these should be determined from a preliminary examination of vertical velocity curves obtained by current-meter. Unless unusual vertical velocity profiles are expected, the classic parabolic (or logarithmic) distribution can be assumed. The transducers should then be either fixed, as in 7.1 a) 1), or installed on an assembly, as in 7.1 a) 2). Generally the former is preferable.

7.4 The decision to use a single-path or multipath system will depend on the intended accuracy of the desired system, the range in stage to be expected, the vertical velocity distribution at these stages and the attenuation and reflection limitations. If a satisfactory rating can be achieved from a velocity index at all stages, then a single-path system may be considered in preference to a multipath system.

7.5 Where the transducers are to be permanently fixed in position [see 7.1 a) 1)], they should be mounted rigidly. Where they are designated to slide on an assembly [see 7.1 a) 2)], the construction of the mountings and guides should be such as to withstand damage from debris and from any accumulation of silt, etc. The guides should be securely fastened to the bed or banks and set in concrete so as to be free from sinking, tilting or washing away. The anchorages should extend below ground to a level free from disturbance by frost.

In both these methods the construction should be sufficiently rigid so as to be capable of withstanding the effects of floods.

7.6 In order to increase the reliability and accuracy of the system, a detailed level survey should be made of the bed and banks extending from one channel width upstream of the proposed upstream transducer mounting to at least one channel width below the downstream transducer mounting. Depending on the result of this survey, consideration should be given to the improvement of the bed and banks by cleaning or dredging, after which the survey should be repeated.

7.7 When the positions of the transducer mountings have been decided, the angle and path length between the mountings should be carefully surveyed for subsequent programming into the electronic processor. A survey of the bed level between the transducer mountings along the path length should be made and the average bed level should then be calculated for input into the electronic processor where discharge is being determined on site. This survey should be repeated periodically as an operational requirement.

7.8 The output from an ultrasonic station may be recorded in any one of the following modes:

a) path (or line) velocity (or an index which is numerically proportional to the path or line velocity);

b) path velocity and stage;

c) discharge and stage;

d) velocity and discharge;

e) velocity, discharge and stage.

If stage is not included in the mode, it should be recorded separately by water level recorder for subsequent off-site processing.

7.9 When operating in the discharge mode, a manual facility should be provided in the electronic processor to make any adjustment necessary for a change in bed level (see 7.7).

7.10 Reference gauge

The reference gauge shall comply with the requirements of ISO 4373.

7.11 Station bench mark

A station bench mark shall be established to comply with the requirements of ISO 4373.

7.12 Stilling well

The design and construction of the stilling well, if used, shall comply with the requirements of ISO 4373.

7.13 Water level recorder

The water level recorder shall comply with the requirements of ISO 4373.

8 Calibration

8.1 General

The calibration of an ultrasonic gauging station may be achieved independently using current-meters or using the ultrasonic meter itself. In either case, if channel conditions change with time, it will be necessary to re-evaluate the calibration.

8.1.1 The line (index) velocity method of calibration is used when a single pair of transducers is fixed in position (see figure 2) and the system requires independent calibration by current-meter or another suitable method. (Figure 4 shows an example of such calibration.)

8.1.2 It should be noted that the measurement of the path angle, θ, cannot be determined accurately since this would require measurement of θ at several points along the ultrasonic (acoustic) path and weighting the results with respect to velocity. In any case, θ would generally change as the discharge changes. However the coefficient K compensates for inaccuracies in both θ and L, where K is the coefficient relating line velocity, V_L, to the average velocity, $\overline{V}$, and L is the path length (see figure 3).

8.2 Movable transducers in a single-path system

8.2.1 The following methods assume the theoretical relation of the ultrasonic meter to be reliable. It is therefore recommended that independent checks of this reliability are carried out either by a series of electronic tests to establish that the meter is operating as designed or by a separate portable ultrasonic system. If possible, current-meter checks should also be made.

8.2.2 The calibration of the gauging station in this case consists of setting the transducers at an elevation which gives the average velocity in the cross-section for modal river flow. When the stage changes, however, the transducers will no longer give the average velocity. They will underestimate for an increase in stage and overestimate for a decrease in stage.

8.2.3 If the mean (or modal) stage is known and the vertical velocity distribution is logarithmic, then the average velocity (or discharge) will be found by placing the transducers at approximately 0,6 D_m from the surface where D_m is the modal depth of flow above the mean bed level, the latter being obtained across the diagonal cross-section between the transducers and levelled-in to the station bench mark (see 7.7). The actual position will be found from the vertical velocity curve.

8.2.4 If the mean (or modal) stage is not known, D_m may be obtained from a histogram of stages over a suitable period of time (see figure 6).

8.2.5 Usually the vertical velocity distribution is not known and is found by using the facility of the movement of the transducers in the vertical plane.

8.2.6 Vertical distribution of line velocity is obtained by setting the transducers at chosen levels and measuring the line velocity at each level. Such distributions are obtained for each of several stages of flow (see table 2). In table 2 the data are given for an example with 15 such distributions each comprised of 7 path velocities. Values of $\frac{\overline{V}}{V_d}$ for respective values of $\frac{d}{D}$ from 0,1 to 0,9 are then obtained where $\overline{V}$ is the mean velocity for each curve, V_d is the line velocity at distance d from the surface and D is the depth of flow (see table 3).

8.2.7 A curve of relation is then drawn by plotting mean $\frac{\overline{V}}{V}$ values against $\frac{d}{D}$ values (see figure 5 and table 3, columns 1 and 17). $\frac{\overline{V}}{V_d}$ is the adjustment factor or coefficient C_V by which the ultrasonic velocity at any distance d from the surface is greater or less than the average velocity in the cross-section.

8.2.8 The curve in figure 5 also provides the optimum elevation of the transducers at the value of $\frac{d}{D}$ when $C_V = 1$ (see annex B). The curve will have some scatter depending on the geometrical similarity of the vertical discharge curves and the standard deviation should be computed for each value of $\frac{d}{D}$ at the 95 % confidence level (see table 3, column 18).

When the stage changes, the appropriate values of C_V may be found from figure 5 by entering the curve at the new value of $\frac{d}{D}$.

8.2.9 In practice, it is more convenient, for data processing purposes, to prepare a second curve of C_V against stage or depth D based on the actual transducer position (see table 4, figure 6 and annex B). It may be found advantageous at some stations, however, to place the transducers at an elevation which is not necessarily the one which provides the average velocity at the mean stage, but the procedure is similar.

8.2.10 The main application of the self-calibrating system is its use where velocities are too low to be measured by current-meter and the range in stage is small. Spot checks should however be made by current-meter when possible. The bed elevation should be checked regularly, especially at stations where there is any suspicion of change, and the new depth should be input into the system.

8.3 Movable transducers in a multipath system

8.3.1 The multipath system consists of two or more transducer paths. These may be fixed or designed to move in the vertical plane or on an incline; generally the fixed system is preferable.

8.3.2 The multipath system is used when the range of stage is considered to be outside the limit of a single-path system or when the vertical velocity profile departs substantially from the logarithmic distribution and a single-path velocity would no longer correlate with the mean velocity in the cross-section.

8.3.3 The number and location of measuring paths will depend on the stage-frequency distribution, the relative importance attached to accurate measurements at high or low stage and the quadrature convention used to calculate the mean velocity (or discharge).

8.3.4 The objective of multipath measurement is to measure the velocity across each path simultaneously and continuously. Since this is impracticable, the procedure is normally to take a single measurement across each path sequentially and to repeat this sequence, for example, at intervals of 1 s.

8.3.5 In the normal measuring mode, a preselected increment of depth is associated with each path and the mean velocity (or discharge) is obtained by summing contributions calculated for each increment using an appropriate quadrature convention. *This average value is then displayed and recorded and data* acquisition automatically recommences.

8.3.6 A series of stored reference water levels ensures that only those measuring paths which are submerged to greater than some minimum depth below the surface are used.

8.3.7 A system that uses a cross-path, even if it is at the same level as its companion path, should be considered to be a multipath system.

Multipath and single-path systems are both direct measuring systems if path lengths and angles are accurately known. Multipath systems define the vertical velocity distribution and need little or no calibration. Single-path systems need to be rated more often by other methods; however, even many single-path systems may require little or no calibration. All systems need to be spot checked by alternative methods.

9 Operation

9.1 The production of a satisfactory record depends on the station being maintained in full operating order at all times. This requires proper maintenance of the station, its equipment and its calibration.

9.2 The instructions given in the manufacturer's manual should be followed in carrying out checks. Fault warning lights should be checked and any sign of malfunction reported. Since the system consists of sophisticated electronic hardware, it is advisable for the operator to pursue a training course usually provided by the manufacturer. Small malfunctions may then be attended to by the operator. On other occasions, there may be no alternative but to call in the manufacturer.

9.3 A reliable source of electrical energy is required to operate the system.

9.4 Careful attention should be given to ensuring that any spurious data which require subsequent editing are noted on site visits.

9.5 *All equipment at the station should be capable of re*starting automatically in the event of an electricity supply failure or a voltage draw-down.

9.6 Since the system also records negative flow, every opportunity should be taken to carry out a check calibration when this occurs.

9.7 When it is known that the bed elevation varies with time, arrangements should be made for regular bed surveys to be carried out as necessary and corrections applied to cross-section and mean velocity coefficients.

9.8 In a multipath system the failure of any paths should not abort the system. If such failure occurs, arrangements should be made in the electronics to use adjacent paths if discharge is being computed or to record velocities independently from those paths functioning.

10 Uncertainties in measurement

10.1 The principles laid down for the estimation of the uncertainty in a single determination of discharge are given in ISO 5168.

10.2 The uncertainty in the measurement of line velocity may be obtained as follows, letting $t_1 = t_{AB}$ and $t_2 = t_{BA}$ (see figure 3):

$$V_L = \frac{L}{2 \cos \theta} \left(\frac{1}{t_2} - \frac{1}{t_1} \right)$$

Let $\cos \theta = \frac{S}{L}$

where S is the distance one transducer is downstream of the other, then

$$V_L = \frac{L^2}{2S} \left(\frac{1}{t_2} - \frac{1}{t_1} \right) \qquad \ldots \quad (1)$$

The percentage uncertainty of line velocity, X_{V_L}, is obtained by determining the total differential of equation (1) and dividing it by the line velocity V_L:

$$X_{V_L} = \frac{\delta V_L}{V_L} = 2 \frac{\delta L}{L} - \frac{\delta S}{S} + \left(\frac{t_1 \times t_2}{t_1 - t_2} \times \frac{\delta t_1}{t_1^2} \right) - \left(\frac{t_1 \times t_2}{t_1 - t_2} \times \frac{\delta t_2}{t_2^2} \right) \qquad \ldots \quad (2)$$

As the individual uncertainty can be positive or negative with the same probability, the squares of the components of the total uncertainty are added to obtain

$$X_{V_L}{}^2 = 4 X_L{}^2 + X_S{}^2 + \left(\frac{t_1 \times t_2}{t_1 - t_2} \right)^2 \left(\frac{X_{t_1}{}^2}{t_1^2} + \frac{X_{t_2}{}^2}{t_2^2} \right) \ldots \quad (3)$$

where

X_{V_L} is the percentage random uncertainty in the ultrasonic line velocity;

X_L and X_S are the percentage uncertainties in measuring distances L and S;

X_{t_1} and X_{t_2} are the percentage uncertainties in measuring the times of transit of t_1 and t_2.

All uncertainties are assessed at the 95 % probability level.

10.3 The uncertainty in calculating the average velocity from the measured line or path velocity depends on the method of calibration used. The uncertainty in the derived discharge depends on this and on the uncertainty in the measured cross-sectional area.

10.3.1 Line velocity method

The estimation of the uncertainty in average velocity and hence discharge for the line velocity method involves a regression analysis and may be carried out in accordance with ISO 1100/2 (see also figure 4).

10.3.2 Self-calibration method

The estimation of the uncertainty in the average velocity, X_Q, and hence discharge for the self-calibration method involves estimating the uncertainties in X_{V_L} as above, with the uncertainty in depth of flow, X_d, the uncertainty in breadth, X_b, and the uncertainty resulting from the limited number of velocity paths used, X_p (see annex C, example 4):

$$\text{then } X_Q = \pm \left(X_{V_L}{}^2 + X_d^2 + X_b^2 + X_p^2 \right)^{1/2} \qquad \ldots \quad (4)$$

10.4 The only systematic uncertainties which need to be considered are instrument uncertainties in depth, in breadth and in θ. If these can be kept to within 0,1 % each, they can therefore be neglected as being small compared with the random uncertainty. If this is not the case, adjustment should be made (see also 10.7).

10.5 For a single-path system, in addition to the above uncertainties in X_Q, the uncertainty due to the change in stage requires consideration (see figure 6), and the discharge should be modified accordingly (systematic error), before the uncertainty calculation is carried out.

10.6 The value of C_V in the curve in figure 6 will also have a random uncertainty which requires assessment by the user for each station. This may be performed by calculating the standard deviation of the C_V values for the corresponding $\frac{d}{D}$ values in table 3 (see 8.2.8).

10.7 The principle of the ultrasonic system depends on the river velocity being parallel to the banks, that is, normal to the cross-section. Minor intermittent variations of the assumed angle θ between the transmission path and the line velocity, V_L, are always present as stated in clause 8 and are compensated for in the calibration. However, when systematic oblique flow occurs and θ varies by ± 1° or more, an adjustment (systematic error) should be made to the velocity (or discharge) as recorded by the system. Figure 7 shows ϕ as being the angle of shift due to oblique flow and table 5 gives adjustment factors for various values of θ and ϕ. The true angle between the direction of flow and the path is $\theta + \phi$. Table 5 shows that when ϕ is positive (as shown in figure 7) the recorded ultrasonic velocity (or discharge) is too low and, conversely, when ϕ is negative, the recorded ultrasonic velocity (or discharge) is too high (examples of estimating uncertainties are given in annex C). It should be noted that oblique flow in this context refers to cross-flow at the elevation of the transducer path(s) whereby the ultrasonic system records a velocity which is either too large or too small depending on the direction of the cross-flow. Oblique flow at any horizontal section in the vertical may be compensated by equal and opposite oblique flow at another horizontal section. If oblique flow is suspected in a single-path system, it is recommended that angle θ be investigated in the first instance. This may be done by setting up a portable ultrasonic system, where the transducers are placed opposite each other on each side of the river so that a reading of zero velocity may be obtained. The true angle θ is then the angle made by a line drawn perpendicular to this zero line and the transducer flight path. Alternatively, a cross-path technique may be used to estimate the angle of oblique flow ϕ. One path is taken across the existing transmission path and the other is taken at a different section, but at the same depth, with its transmission path diagonally across the first (see figure 8). If the areas of flow at the two sections are the same, then the angle ϕ may be obtained from the difference, if any, of the two path velocities. If the areas of flow are not the same, then the path velocities should be weighted by an area factor before comparison (see annex D). If oblique flows vary with stage and/or discharge, a cross-path should be permanently fixed and the output of this path incorporated into the computation of mean velocity.

It is preferable not to establish ultrasonic stations where undesirable secondary currents occur. However, if it is necessary to set up a station, a multipath system should be used so that there are enough paths to compensate for the effects of secondary currents at different levels.

10.8 Generally, the uncertainty in a single determination of discharge using the single-path ultrasonic method should be of the order of ± 5 % to ± 10 %. The uncertainty in a single determination of discharge using the multipath system should generally be better than ± 5 %. However, the uncertainties associated with the ultrasonic method, as with other methods, depend on site conditions and the final uncertainty in any installation may be either more or less than the values quoted above. Examples in calculating uncertainties using the ultrasonic method are given in annex C.

Annex A

Frequency versus path length and clearance

Table 1 — Values of path length, clearance and operating frequency

Typical minimum path length, L	Typical minimum clearance, h	Operating frequency for ± 0,015 m/s uncertainty
m	m	kHz
300	3 to 5	50 to 100
150	2 to 3	100 to 200
80	1	200 to 300
30	0,3	300 to 500
10	0,15	500 to 1 000
3	0,1	1 000 to 2 000

NOTES

1 Minimum clearance h is based on requiring any multiple reflected signals to arrive at least one wavelength behind the direct arrival.

2 If the detection system is designed for the signals to arrive one half wavelength behind the direct arrival, the above minimum clearances may be somewhat reduced.

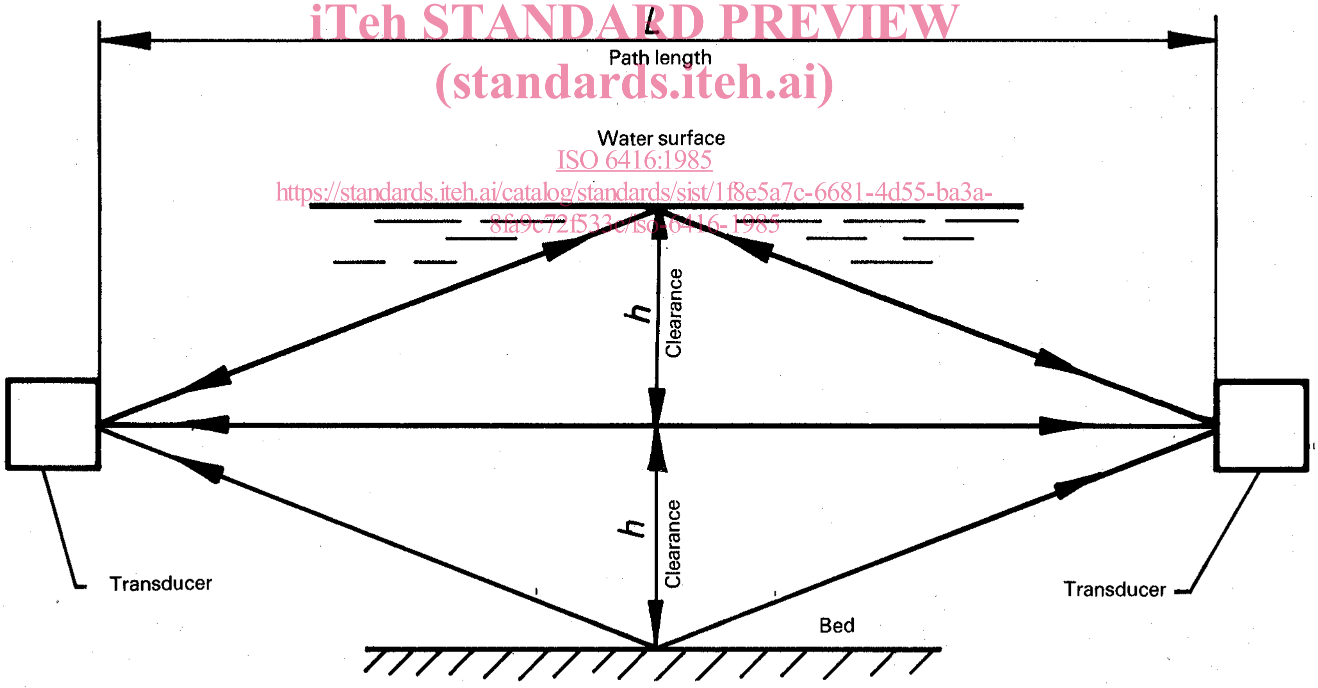

Figure 1 — Signal interface from surface and bed