International Standard 6418

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Liquid flow measurement in open channels — Ultrasonic (acoustic) velocity meters

Mesure de débit des liquides dans les canaux découverts — Compteurs ultrasoniques (acoustiques) de vitesse

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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.

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

INTERNATIONAL STANDARD **ISO 6418-1985 (E)**

Liquid flow measurement in open channels — Ultrasonic (acoustic) velocity meters

1 Scope and field of application

This International Standard describes the general design, operation, performance and application of ultrasonic (acoustic) velocity meters for measurement of flow in open channels.

While it is recognized that, theoretically, such meters might operate at any frequency, practical considerations tend to limit applications to frequencies above the acoustic range, that is, greater than 15 kHz. However, the term "acoustic" has been applied in practice, in many countries, to meters of this type irrespective of frequency and the term is retained in this International Standard for that reason.

2 References

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

ISO 6416, *Liquid flow measurement in open channels — Measurement of discharge by the ultrasonic (acoustic) method.*

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). Degrees or radians are used in measurement of plane angles.

5 General

The ultrasonic (acoustic) velocity meter is a device which utilizes acoustic transmission to measure the average velocity along a line between one or more opposing sets of transducers. This device provides continuous measurement of velocity and is useful particularly in circumstances in which regulated flows, navigation or tidal influences, for example, render velocity measurements by traditional methods either difficult, less accurate or impossible.

6 Principle of operation

Several ultrasonic (acoustic) velocity meter systems have been developed using variations of the same basic theory. Common to each is the measurement of water velocity by determination of the travel times of sound pulses moving in both directions along a path diagonal to the flow. The water velocity measured by the system is the average component of the velocity along the acoustic path (see figure 1). The primary methods used are the total travel time method, the sing-around method, the difference frequency method and the differential travel time method.

6.1 Travel time method

The velocity of a sound pulse in moving water is the algebraic sum of the acoustic propagation rate and the component of water velocity along the acoustic path (see figure 1). The travel time of an acoustic pulse, originating from a transducer at point A and travelling in opposition to the flow of water along the path AB, can be expressed as

$$t_{AB} = \frac{L}{c - v_p} \qquad \ldots \quad (1)$$

Similarly, the travel time for a pulse travelling with the current from B to A is

$$t_{BA} = \frac{L}{c + v_p} \qquad \ldots \quad (2)$$

Equations (1) and (2) can be combined and solved for v_p:

$$v_p = \frac{L}{2}\left(\frac{1}{t_{BA}} - \frac{1}{t_{AB}}\right) \qquad \ldots \quad (3)$$

As

$$v_p = v_L \cos\alpha \qquad \ldots \quad (4)$$

then

$$v_L = \frac{L}{2\cos\alpha}\left(\frac{1}{t_{BA}} - \frac{1}{t_{AB}}\right) \qquad \ldots \quad (5)$$

where

c is the velocity of sound in still water;

L is the length of the acoustic path AB;

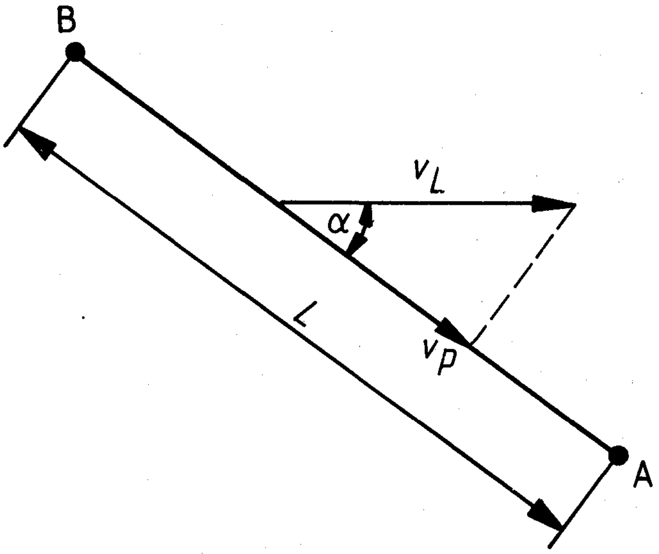

Figure 1 — The direction of acoustic path relative to flow velocity

t_{AB} is the travel time from A to B;

t_{BA} is the travel time from B to A;

v_p is the component of the measured average water velocity along the acoustic path;

v_L is the average water velocity at the elevation of the acoustic path parallel to the axis of the channel;

α is the angle between the mean direction of flow and the acoustic path.

In this type of system, corrections for changes in the propagation rate of sound are automatically compensated for by the treatment of the data.

Travel times are measured sequentially for pulses originating at A and travelling against the current, and then for pulses originating at B and travelling with the current. Accuracy of a system of this type depends on the precision with which the individual travel times can be measured. Errors in indicated velocities are a linear function of timing errors in either direction.

6.2 Sing-around method

The sing-around method, sometimes referred to as the pulse-repetition frequency system, is being used by several developers. Cumulative measurements of travel times are made by using the received pulse at the far end of an acoustic path to trigger a second transmittal pulse at the originating transducer. Arrival of the second pulse triggers the next transmission, and the system is allowed to continue operation in this repetitive pattern. Transit time of the acoustic wave is resolved either by measuring the total time for a fixed number of cycles or by reducing the cycling rate to a continuous pulse-repetition frequency. Where a single pair of transducers is employed, such systems usually measure transit times for a given period in one direction along the acoustic path and then in the other direction. Sometimes, two pairs of transducers are used, tuned to different frequencies and operating simultaneously.

The quotients $1/t_{BA}$ and $1/t_{AB}$ in equation (5) are the pulse-repetition frequencies for acoustic transmission in each direction that are measured.

6.3 Difference frequency method

A train of ultrasonic pulses is transmitted by each transducer in turn. The transducers at both banks act as receivers detecting the pulses emitted by the opposite transducers. Each receiving transducer controls the frequency of the oscillator which generates the pulse train for the opposite transmitting transducer. The period of each of the frequencies f_1 and f_2 is adjusted to be a function of the transit time of the pulse (see figure 5). The oscillator controlled by the pulses travelling with the flow will have a higher frequency than that controlled by the pulses travelling against the flow. The two frequencies are then compared by the signal processing equipment and a frequency difference derived for a specified period of time, this period being chosen as a function of the cross-sectional area of the flow. By careful choice of the counting time, the pulse count is a direct reading of discharge in desired units.

6.4 Differential travel time method

The differential travel time method differs from the other methods previously considered in that the difference in the time of arrival of acoustic pulses, triggered simultaneously at each end of the path, is directly measured. When two transducers transmit signals simultaneously towards each other, the flow of water in the path will increase the speed of one signal and decrease the other. The signal transmitted in the downstream direction arrives first and is used to start a time clock; the signal transmitted in the opposite direction arrives later and is used to stop the clock. The time increment recorded is thus the differential between the total travel times involved, a differential that is linearly proportional to the water velocity. In this system, the measure of average total travel time in each direction shall also be recorded to compensate for changes in the speed of sound in water.

NOTE — In the methods described above, for a meter operating in the multipath mode, each pair of transducers is operated in sequence, thereby obtaining the individual path velocities. This applies to all methods described in 6.1 to 6.4.

6.5 Measurement of time

One of the most important points in any of the ultrasonic (acoustic) velocity meter systems is the accurate measurement of time. Four differing signal-recognition methods have been employed by various designers. They are

a) the leading-edge detection method;

b) a method that utilizes the differential of the voltage time pulse train;

c) a method that recognizes the first "zero" crossover after the first peak above a given threshold level;

d) a method comparing phase relations of the received and transmitted signals.

7 Characteristics of sound in water

The utility of sound waves, not only in air but also in water, results from the fact that they are a form of energy having well-defined characteristics. This energy may be controlled with great accuracy and may be transmitted from place to place. Because of these two properties, sound waves may be used as a vehicle for carrying information.

Sound waves are generally classified into three regions:

— the range of frequencies of less than 50 Hz is termed subsonic;

— the audible range between 50 and 15 000 Hz is termed sonic;

— the range of frequencies greater than 15 000 Hz is termed ultrasonic.

7.1 Speed of sound in water

Sound speed is dependent upon the density and elasticity of the medium and independent of frequency. The density is defined as the mass per unit volume. It is written as

$$\varrho = m/V$$

where

ϱ is the density;

m is the mass of a given volume;

V is the given volume.

The elasticity of water, as affecting the propagation of acoustic waves, is defined as the ratio of some given change in pressure to the accompanying fractional change in volume. Thus defined, it is known specifically as the volume elasticity or as the bulk modulus. It is written as

$$E = \frac{p_{\text{w}} - p_{\text{wo}}}{(V_{\text{o}} - V)/V_{\text{o}}}$$

where

E is the modulus of elasticity;

p_{wo} is the initial value of the hydrostatic pressure of the water;

$p_{\text{w}} - p_{\text{wo}}$ is the change in hydrostatic pressure;

V_{o} is the initial volume;

$V_{\text{o}} - V$ is the change in volume.

The propagation speed, c, is expressed as

$$c = \sqrt{E/\varrho}$$

The density of water increases with concentration of dissolved and/or suspended solids, with pressure or depth below the surface, and with temperature, reaching a maximum at 4 °C. The elasticity is affected to a much greater proportional degree than is the density; consequently, when both vary due to some common cause, the speed of sound increases or decreases as the elasticity increases or decreases.

The speed of sound in fresh water varies from approximately 1 400 m/s to slightly above 1 500 m/s over the ambient temperature range to give a total change of approximately 7 %.

7.2 Transmission of sound in water

Of the acoustic energy transmitted, only a portion reaches the target; the remainder is lost for various reasons. This loss in signal strength associated with transmission of sound energy through water is called propagation loss. It consists of spreading loss and attenuation loss.

7.2.1 Spreading loss

Spreading loss is the reduction in acoustic intensity due to the increase in area over which the given acoustic energy is distributed. Spreading loss is independent of frequency.

In the ideal situation, spreading occurs in accordance with the inverse square law applicable, in general, to all forms of radiant energy. Spreading losses depend upon the relation between the path length and the diameter of the ultrasonic transducer.

7.2.2 Attenuation loss

Attenuation loss is the reduction in acoustic intensity due to the resistance of the medium to the transmission of acoustic energy. It is analogous to the loss suffered by electric energy transmitted over a wire line, where there is no spreading loss. Attenuation loss varies directly with the square of the frequency.

7.2.2.1 Scattering

Scattering is the modification of the direction in which acoustic energy is propagated, caused by reflections from the innumerable foreign bodies in the water. These bodies, which may include microscopic air bubbles and suspended particulate matter, as well as visible bubbles and suspended matter, present abrupt changes in specific acoustic impedance, causing the signal to be reflected and scattered.

7.2.2.2 Absorption

Absorption is the process by which acoustic energy is converted into heat by the friction between the water molecules as a sound wave in water is attended by repeated compressions and expansions of the medium.

7.3 Reverberation

Reverberation is the energy returned by reflectors other than that which it is desired to observe. Reverberation of sound in water is analogous to the familiar optical effect which impairs the utility of automobile headlights on a foggy night.

8 Instrument performance criteria

The performance of an ultrasonic velocity meter depends not only upon the underwater and electronic assemblies but also upon the selection, to match the site conditions, of a suitable operation frequency, and output power, and upon the sensitivity of the system.

8.1 Underwater assembly

The underwater portions are generally difficult and expensive to install and service and, at times, may not be accessible at all.

8.1.1 Transducers and cabling

The transducers shall be sufficiently rugged to withstand handling and the effect of the operational environment. They shall be constructed of highly corrosion-resistant materials and treated with an inhibitor against organic growth.

All interconnecting cabling to and from transducers shall be armoured and/or protected from damage during installation and operation (see clause 10).

Provision shall be made for simple replacement of transducers and/or cable in the event of failure or damage.

8.1.2 Mounting assembly

An assembly shall be provided for rigidly mounting the acoustic transducers (see clause 10) and provision may be made for movement in the vertical plane.

Means shall be provided for precise alignment of transducers.

8.2 Electronic assembly

The electronic assembly can be considered to consist of four elements: the transmitter, the receiver, the timer and the data processor.

8.2.1 Transmitter

In general, the operating frequency used in a particular application depends upon the acoustic path length, the minimum clearance between the acoustic path and adjacent acoustic reflectors (for example, surface and bottom), and the expected suspended sediment load and/or amount of entrained air. Ideally, the highest possible operating frequency and the greatest transmitter power consistent with reliable operation should be used as this increases system timing accuracy and also allows closer spacing between the acoustic path and the surface or bottom of the channel. However, sound attenuation by water and scattering by particulate matter and entrained air increases with frequency. While increasing transmitter power helps to some extent, there is an upper limit achievable. Thus a compromise shall be reached which will provide sufficient accuracy while at the same time operating reliably under adverse absorption/scattering conditions. Annex A provides approximate ranges of frequencies and path lengths normally used in acoustic velocity measuring systems.

An important factor shaping scattering losses is the ability of the acoustic pulse to preserve its amplitude over its entire path. This mainly depends upon the relation between the shape and dimensions of the transducer and the acoustic path length:

$$L_0 = \frac{D^2 - \lambda^2}{4\,\lambda} \ ; \ \sin\gamma = 1{,}22\,\frac{\lambda}{D}$$

where

L_0 is the distance through which the beam has a nearly cylindrical shape;

D is the diameter of the emitter;

λ is the wavelength;

γ is the angle between half power points.

8.2.2 Receiver

The highest receiver gain possible within the constraints of ambient electrical and acoustic noise shall be used.

The signal-to-noise ratio shall be as high as possible, consistent with the propagation environment.

The signal recognition method employed shall provide a sufficiently reliable recognition of a repeatable point on the pulse to give the travel time accuracy required.

The receiver shall be designed so that a signal which is insufficiently strong to meet the specified accuracy of measurement is not used to compute velocity.

8.2.3 Timer

The time base frequency of the timer shall be sufficiently high to provide the timing discrimination necessary to obtain the specified accuracy.

The time base accuracy and stability shall be such as to provide for the measurements of travel times to the required accuracy.

8.2.4 Data processor

Internal automatic means for continuously checking the accuracy of time measurement and computational accuracy shall be provided. Provision shall be made to prevent erroneous readings during acoustic interruptions caused by river traffic, aquatic life or gradual degradation of components. The data processor may determine whether an item of data is valid or not and display this signal on the instrument console.

Means shall also be provided to test transmitter output and receiver sensitivity during system operation. The data processor shall also provide an analogue or digital output to facilitate on-site recording of the data, their remote transmission or both at the same time.

9 Site selection

When possible, ultrasonic velocity measurement sites should be chosen in a section of channel which is relatively straight over a distance equivalent to several times the width of the channel upstream and downstream, to ensure that the direction of flow can be determined accurately. If it is not possible to determine the direction of flow accurately, it may be necessary to use two acoustic paths crossed usually at 90° to each other in order to resolve the downstream component of velocity.

Sites with high amounts of entrained air, such as just below hydro-electric plants, should never be selected. Similarly, sites with high concentrations of suspended sediment are undesirable.

In the absence of special techniques that permit an acoustic path to be located closer than that indicated in annex A, the clearance between the acoustic path and adjacent acoustic reflectors (surface and bed) should be not less than the stated minimum.

Sites where thermal or density gradients exist should be avoided if possible, since such gradients can cause the acoustic path to deflect from the theoretical straight line. While this has a negligible effect on the path length, it does mean that the wrong path may be measured; and, in extreme cases, the acoustic signal may be lost.

In order to determine the mean direction of the current, it is possible to move one of the transducers along the bank to a position opposite to the other transducer until the indicated velocity is zero. The acoustic path would then be perpendicular to the flow.

10 Instrument installation

The acoustic transducers shall be rigidly mounted (see 8.1.2).

The cables to the transducers shall be protected from damage caused by moving debris or ice (see 8.1.1).

The acoustic path length and elevation shall be accurately determined.

The transducers shall be aligned with each other so that the maximum signal is received.

The angle of the acoustic path with respect to flow shall be accurately determined.

The electronic assembly should be installed in accordance with the manufacturer's instructions.

11 Operation manual

A comprehensive operation and service manual, giving full instructions and, where necessary, illustrations, shall be supplied with each system. The manual should include any maintenance and fault-finding information deemed desirable. A list of recommended spare parts should also be provided.

12 Calibration

Calibration consists of entering the as-built path lengths and path angles into the data processor unit to produce a correctly scaled velocity output. It is also possible to check the velocity meter with other devices such as rotating element current meters. However, the inherent accuracy of the instrument velocity measurement is very high, and calibration is usually more of a system checkout than a true calibration.

In order to check whether the electronics are operating correctly, as far as the linearity of the results is concerned, it is necessary only to reverse the connections to the transducers and check that the measured value remains the same although its sign is reversed.

13 Uncertainties and systematic errors

Accuracy is affected by several factors, which are indicated separately below.

13.1 Timing accuracy

Timing accuracy is dependent on received signal-to-noise ratio, operating frequency, time base accuracy, time base frequency and signal recognition discrimination.

In general, signal-to-noise ratio and operating frequency are made as high as possible, consistent with the propagation environment.

The time interval measurement is normally performed by a digital counter and crystal oscillator. Since long-term accuracy of crystal oscillators is in the range of 10 to 50 ppm (parts per