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Measurement of total discharge in open channels — Electromagnetic method using a full-channel-width coil

Mesurage du débit total dans les canaux découverts — Méthode électromagnétique à l'aide d'une bobine d'induction couvrant toute la largeur du chenal

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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.

ISO 9213 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 1, *Velocity area methods*.

This second edition cancels and replaces the first edition (ISO 9213:1992), which has been technically revised.

Measurement of total discharge in open channels — Electromagnetic method using a full-channel-width coil

1 Scope

This International Standard specifies procedures for the establishment and operation of a gauging station, equipped with an electromagnetic flow meter, in an open channel or a closed conduit with a free water surface.

This International Standard is applicable to configurations where an artificial magnetic field is generated through which the entire body of water flows. The induced voltage is sensed in such a way that all elements of the moving water contribute. The equipment described normally requires an electrical mains power supply.

This International Standard is not applicable to devices sampling only part of the flowing body of water (e.g. velocity meters) or to flow meters which operate by using the Earth's magnetic field.

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 748, *Measurement of liquid flow in open channels — Velocity-area methods*

ISO 772, *Hydrometric determinations — Vocabulary and symbols*

ISO 1100-2, *Measurement of liquid flow in open channels — Part 2: Determination of the stage-discharge relation*

ISO 5168:—[1)], *Measurement of fluid flow — Evaluation of uncertainties*

ISO/TR 7066-1, *Assessment of uncertainty in calibration and use of flow measurement devices — Part 1: Linear calibration relationships*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 772 apply.

4 Principles of operation and practice

4.1 This is a velocity-area method of discharge determination. The electromagnetic gauge operates on Faraday's principle of electromagnetic induction. If a length of conductor moves through a magnetic field, a voltage is generated between the ends of the conductor. In the electromagnetic gauge, a vertical magnetic field is generated by means of an insulated coil which is located either above or beneath the channel. The conductor is formed by the water which moves through the magnetic field; the ends of the conductor are represented by the channel walls or riverbanks. The voltage generated is sensed by electrodes on the channel extremities and these are connected to the input of a sensitive voltage-measuring device. The faster the velocity of the water, the greater is the voltage which is generated.

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1) To be published. (Revision of ISO/TR 5168:1998)

4.2 The principle is widely applied to flow meters in circular pipes running full and in this case approximate formulae may be generated theoretically and refinement made by calibration through factory produced models.

The open channel flow meter however does not lend itself to such treatment and hence *in situ* calibration is always necessary.

4.3 Bevir's formula for the potential generated between electrodes placed in a body of conducting fluid moving in a magnetic field is given by Equation (1) and illustrated in Figure 1.

$$E = \int B \times j \times v \times d\tau \tag{1}$$

where

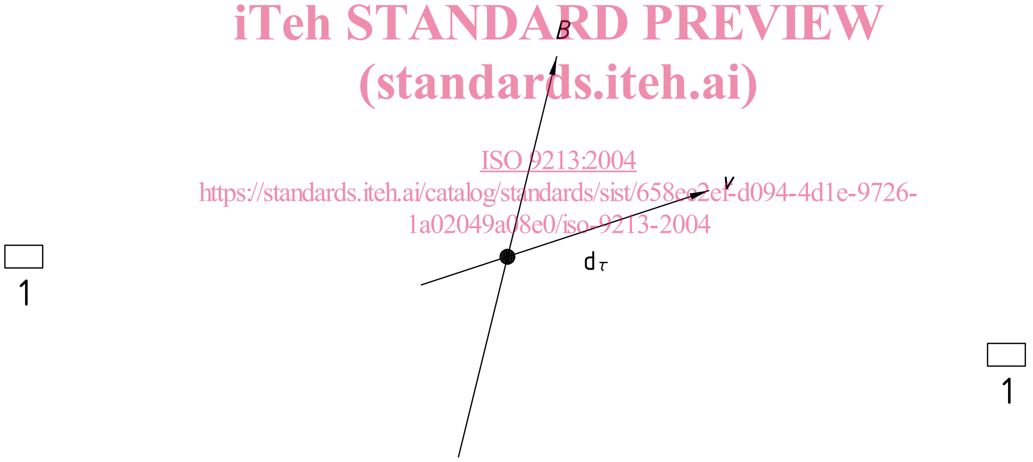
E is the potential between the electrodes;

B is the vector magnetic induction;

j is the vector virtual current between the electrodes;

v is the vector velocity function;

$\mathrm{d}\tau$ is an element of volume.



Key

1 electrode

Figure 1 — Illustration of Bevir's formula

This involves integration between the electrodes over the entire space occupied by the fluid. In practice, the general case is not solvable since the spatial functions are unknown or difficult to determine. In the simple case of a rectangular horizontal channel of width w, expressed in metres, with water flowing with a mean velocity v, expressed in metres per second, in a uniform vertical magnetic field H, expressed in amperes per metre, the induced potential E, expressed in microvolts, is measured at electrodes at the sides and is calculated using Equation (2).

$$E \propto v \times w \times H \tag{2}$$

where

H $= B/\mu$

μ is the magnetic permeability of the fluid.

In practice, numerically,

$$E \cong v \times w \times H$$

4.4 In this simple case, if the water depth is d metres, the flow q, expressed in cubic metres per second, is given by the following equation:

$$q = v \times w \times d = E \times d/H$$

If the field H is produced by an electromagnet in the form of an arrangement of coil(s), then for a given situation, H is proportional to the electrical current I, expressed in amperes, in the coil. Therefore

$$q = K \times E \times d/I$$

where K is a constant.

In practice, this is an oversimplification and a more generally applicable form of the flow formula, taking account of non-uniformities, is

$$q = K \times E \times f(d)/I$$

where $f(d)$ is a polynomial function of d.

Usually, a close approximation is obtained where the polynomial is a quadratic, i.e.

$$q = (E/I) \times (K_1 + K_2 d + K_3 d^2) \qquad (3)$$

4.5 However, there is a sensitivity to non-uniform velocity distribution in the presence of non-uniformities in other parameters. Though the mathematical treatment is complex, for the purposes of this International Standard, it may be stated that if the vertical magnetic field is not uniform then changes to the velocity profile for given flow and depth values will produce an apparent change in the measured induced voltage. This will have the effect of producing an uncertainty in the flow value determined by the flow meter.

The designer of the flow meter should strive to produce a vertical magnetic field as uniform as possible to minimize this uncertainty. A single coil above or below a channel may be sufficient if it is wide compared with the depth of water. Alternatively, better uniformity may be obtained by “saddle-shaped” coils or a pair of coils deployed above and below the channel. The design of coil systems is not covered in this International Standard although some design considerations are given in Annex B.

4.6 With most channels, the material comprising the bed and sides will have an electrical conductivity which cannot be ignored compared with that of the water flowing in the channel (even if the material is concrete). The apparent induced potential is thus reduced in the same way that voltage at the terminals of a battery is less if measured whilst a load is connected. Though attempts have been made to determine the effect and allow for it, these have generally proved unsuccessful. The recommendation is always to line the channel with an electrically insulating material which substantially removes the conduction path through the channel material (see 7.2.3).

Depending on the material used for lining the channel, some form of protection is often required to prevent physical damage by debris being transported along the channel by the flowing water. This protective layer is usually concrete and this itself will have a conductivity when wet which may be different from that of the water. The effect of this is much the same as a layer of silt which may settle on the bed and is described in 4.7.

4.7 A layer of silt settling on the bed (or the protective layer described in 4.6) may have an effect on the induced voltage and hence the flow calculated by the flow meter.

Assuming the magnetic field is fairly uniform then the effect described in 4.5 is negligible.

If the wet silt has a similar conductivity to that of the water, it will be seen as a non-moving (or slowly moving) layer of water. This is similar to a step change in velocity profile and the flow meter should be programmed with an effective bed level beneath the silt (at the level of the insulating liner). If, however, the layer has a very low conductivity (packed clay for example), it will behave like an extension of the liner. In this case, the flow meter should be programmed with an effective bed position at the top of the silt.

In practice the effective bed level should be taken as the level of the insulating liner. However, sometimes an offset (D_0) to the depth (d) measured from the surface to the liner should be applied. D_0 will depend on the thickness and conductive properties of the silt and will have a value between zero and the thickness of the silt. D_0 is obtained by calibration. It is possible, due to thickness or conductivity variations, that the offset may not be constant and this is a source of uncertainty (see Clause 8).

4.8 The value of induced voltage in a practical application is generally in the range of a few tens to hundreds of microvolts.

In comparison, the electrodes will be subject to various other effects which produce voltages unrelated to the flow-induced signal. These interfering voltages (or noise) will have different magnitudes and frequencies and may be far greater than the induced voltage.

Table 1 gives some indication of the magnitude and frequency of sources of interference that are commonly encountered. Differential magnitude is that measured between the electrodes; common mode is between either electrode and ground.

Table 1 — Sources, frequency or rate of change and interference magnitude

Source	Frequency or rate of change	Interference magnitude (differential)	Interference magnitude (common mode)
Electrical power distribution	50 Hz or 60 Hz	5 mV	1,5 V
High (radio) frequency	Much greater than 1 kHz	5 mV	50 mV
Polarization (electrochemical)	0,01 V/min	1 mV	1 V

It is necessary to create a recognizable pattern for the induced voltage to enable it to be detected in the presence of this larger interference. In practice, this is usually done by alternating the direction of the coil current which causes the induced signal to alternate in synchronism. The signal detection circuit is designed to detect this signal and reject the interference. The choice of the alternating frequency is limited on the one hand by considerations of inductive power loss in the coil and on the other by the need to avoid the frequency of interference, particularly 50 Hz or 60 Hz. This is often a problem in the vicinity of power distribution systems using protective multiple earthing (PME). High frequency (HF) interference is not a problem because it is normally significantly higher than the alternating frequency of the coil. A simple input filter removes it.

Polarization is due to electrochemical action between the water and the electrodes. Though large voltages may occur, they are easily removed electronically unless they are fluctuating at a similar frequency to the alternating coil current. This may be the case in foul sewers when wave motion against the electrodes can occur.

In addition, lightning can produce voltages of thousands of volts, which should be withstood to prevent damage to the flow meter input circuitry.

4.9 Since the coil current is alternating, the possibility exists of electrical “breakthrough” or “coupling” to the electrodes or their connecting cables. Since this coupling would be at the same frequency as the coil-switching signal, it would combine with the flow signal in the synchronous detection circuit to produce an offset voltage. The mechanism for this coupling may be capacitive, inductive or conductive. Care should be taken in the layout of the coil and electrode elements of the flow gauge to ensure symmetry to minimize the capacitive and inductive effects. The quality of insulation of cables and joints should be good to avoid conductive coupling between the elements.

Perfect symmetry is difficult to achieve in practice and a small residual voltage (E_0) often occurs adding to or subtracting from the induced flow signal E.

The value of E_0 is usually constant and may be determined by calibration, see Clause 9. However, the purpose of the calibration procedure is to determine the number of coefficients and much complication may be avoided if the value of E_0 can be determined directly. One way of doing this is to perform a zero check with static water in the gauging section. This may be difficult to achieve in a river but can often be done in an artificial channel.

If this is not possible, an indication of whether a significant value of E_0 exists may be obtained by shorting out the electrodes with a wire placed directly between them. This effectively reduces the induced flow signal E to zero. The residual signal may be less than E_0 since the electrode shorting may also partially reduce the coupled signal.

4.10 From Equation (3), the flow formula therefore becomes

$$q = [(E + E_0)/I] \times [K_1 + K_2(d - D_0) + K_3(d - D_0)^2] \quad (4)$$

5 Applications

5.1 The electromagnetic gauge is particularly suited to the measurement of flow in channels where no well-defined stage-discharge relationship exists, for example where weed growth in a natural river channel causes variable backwater effects, and in artificial channels of effluent discharge where little head loss occurs. Other applications could be in measuring the flow of potable water in treatment works or the flow of cooling water in power stations.

5.2 Different versions of the electromagnetic gauge are suitable for measuring flow in rivers, partly filled pipes or culverts carrying storm water, raw effluent or foul sewage.

5.3 The advantages of the method include the following:

a) tolerates weed growth;

b) tolerates entrained air;

c) tolerates temperature stratification;

d) tolerates suspended sediment or floating debris in the water;

e) tolerates deposited sediment or other accretion on the channel bed;

f) tolerates variable backwater;

g) tolerates upstream inflows; however, if the inflow conductivity is significantly different from that of the main channel, there shall be sufficient distance for adequate mixing;

h) can be designed to detect a minimum velocity of about 0,001 m/s;

i) tolerates irregular velocity profiles, depending on the shape of the magnetic field, including skew flow and severe eddy currents in the measurement area;

j) can be suitable for gauging shallow water provided D_0 can be accurately defined (see 4.7);

k) inherently integrates the velocity profile over the entire channel cross-section;

l) affords a wide range of discharge measurements to a typical dynamic range of 1:1 000;

m) does not constrict the flow;

n) can measure reverse flow;

o) does not increase upstream water levels;

p) does not inhibit the passage of migratory fish.

5.4 There are however some disadvantages associated with the method, such as

a) the complexity of the construction, which may involve temporary diversion of flow and lining of the channel;

b) the need for calibration, which may prove substantially complex and may take a significant period of time to complete satisfactorily over the range of measurement required;

c) the need to derive a solution to the formula involved in computing the flow which is mathematically complex;

d) the effects of electrical interference from other sources (see 4.8);

e) the requirement for a reliable electricity supply;

f) the speed of response which is not instantaneous, which precludes its use where fast control operations are required;

g) the effect on accuracy of spatial differences in water conductivity, e.g. caused by saline intrusion.

6 Selection of site

6.1 A site survey should be carried out if necessary as outlined in Annex A to measure any external electrical interference (e.g. power cables, radio stations or electric railways). Areas of high electrical interference should be avoided.

In some cases, the current from the electrical power supply flowing to ground may cause excessive voltages to be detected by the electrodes.

6.2 Owing to the high power consumption of the coil, equipment intended to measure flow continuously cannot reasonably be operated continuously from batteries.

6.3 The site shall afford adequate on-bank working space for handling the membrane and cables during construction (or the preformed coil and rigid liner in the case of a smaller channel) and good access for operation and maintenance.

6.4 The site characteristics shall be such that the calibration of the station can be determined by an alternative method, e.g. current-meter gauging.

6.5 Sites shall be selected where there is no spatial variation in water conductivity. The accuracy of the method will be reduced if the spatial conductivity is not uniform across the section. Gradual variations with time are unimportant provided that the spatial uniformity of the conductivity is maintained. This requirement makes an electromagnetic gauge unsuitable for channels in which fresh water flows over saline water, which often occurs in estuaries. Provided that these requirements are met, the quality of the water will not affect the operation of the gauge. Similarly the conductivity of the water will not affect the operation of a gauge in an insulated channel provided that it exceeds 50 µS/m.

7 Design and construction

7.1 General

The electromagnetic gauging station should consist of the following elements (see Figures 2 and 3):

a) a field coil installed beneath or above the channel, or both;

b) a pair of electrodes, one on each side of the channel;

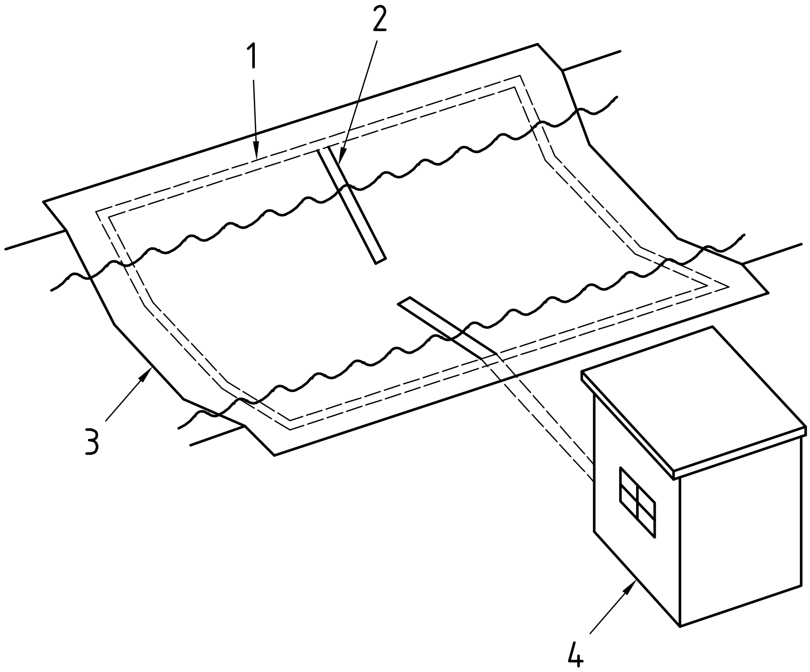
c) an insulating membrane; it may be necessary; this may be necessary to protect the liner with a covering material such as concrete or stone blockwork;

d) an instrumentation unit, including a coil power supply unit;

e) equipment housing;

f) a water-level measuring device (see 7.2.5).

These elements can be separate but some systems combine a number of these elements into one unit.



Key

1 field coil

2 electrodes

3 insulating membrane

4 hut containing instrumentation unit

Figure 2 — Buried coil configuration