INTERNATIONAL STANDARD

ISO 3455

Third edition
2021-01

Hydrometry — Calibration of current-meters in straight open tanks

Hydrométrie — Étalonnage des moulinets en bassins découverts rectilignes

Reference number
ISO 3455:2021(E)

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Published in Switzerland

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 5, *Instruments, equipment and data management*.

This third edition cancels and replaces the second edition (ISO 3455:2007), which has been technically revised.

The main changes compared to the previous editions are as follows:

— a subclause for calibration of acoustic current-meters for point velocity measurement has been added;

— clauses referring to outdated tracking systems like track systems using tooth belts have been removed;

— clauses referring to outdated technique for data acquisition like strip chart recorder or magnetic tapes have been removed;

— the clause for computerized data acquisition and processing system has been removed;

— the clause discussing the Epper effect has been removed.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Hydrometry — Calibration of current-meters in straight open tanks

1 Scope

This document specifies a calibration method for mechanical type, electromagnetic type and acoustic type hydrometric current-meters used for point velocity measurement of flowing water. The method requires towing the instrument through still water in a straight open tank. It includes measuring apparatus, the calibration procedure, the method of presenting the results and the uncertainties associated with the method.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 772, *Hydrometry — Vocabulary and symbols*

ISO 2537, *Hydrometry — Rotating-element current-meters*

ISO/IEC Guide 98-3*Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Principle of calibration

4.1 Statement of the principle

Calibration of a current-meter means experimental determination of the relationship between water velocity and either the rate of revolution of the rotating element or the velocity directly indicated by the current-meter. For this purpose, the current-meter is mounted on a towing cart and drawn through still water contained in a straight tank with a uniform cross section at a number of steady speeds of the towing cart. Simultaneous measurements of the speed of the towing cart and the rate of revolution of the rotating element or the velocity indicated by the current-meter are made. In the case of rotating-element current-meters, the two parameters are related by one or more formula(e), the limits of validity of which are stated. In the case of stationary-sensor type current-meters, containing no rotating elements, the velocity indicated by its display unit is compared with the corresponding cart speed to know the error in measurement.

4.2 Accuracy of the method

4.2.1 Overall uncertainty on the velocity measurement

The towing method gives an absolute measurement of water speed, which in principle only requires position and time measurements. This method can be considered as very accurate if the precautions listed in 4.2.2 are taken.

4.2.2 Requirements for accurate measurements

The towing method gives an accurate measurement of water speed provided that:

a) the position, the timing and means for starting and stopping it achieve the necessary accuracy;

b) residual currents in the water are small.

5 Infrastructure

5.1 Dimensions of the towing tank

5.1.1 General

The dimensions of the tank and the number and relative position of current-meters in the tank cross section shall be chosen so that their effects on the test result are minimized.

5.1.2 Length

The length of a rating tank comprises of accelerating, stabilizing, measuring and braking sections.

The length of the accelerating and braking sections depend on the design of the cart, the maximum acceleration and deceleration achievable at maximum payload, and the maximum speed at which the payload is to be towed along the tank. Safety requirements of the cart should be taken into account while working out the length of the braking section. The length of the measuring section shall be such that the calibration error, which is composed of inaccuracies in the measurement of time, distance covered and rate of revolution, does not exceed the desired tolerance at any velocity. The required length, therefore, depends on the type of current-meter being calibrated, type of cart and the way the signals are produced and transmitted.

5.1.3 Depth and width

The depth of the tank can have an influence on the test results which cannot be regarded as negligible, more particularly when the towing speed coincides with the velocity of propagation of the surface wave. The dependence of this critical velocity, v_c, on tank depth is given by the Formula (1):

$$v_c = \sqrt{gd} \quad (1)$$

where

g is the acceleration due to gravity;

d is the depth of water.

Depending on the size of the current-meter(s) and the cross section of the suspension equipment relative to the cross-sectional area of the tank, the wave crest produced by the current-meter and its means of suspension may cause an error in calibration within a narrow band in the velocity range from 0,5 v_c to 1,5 v_c. It is a systematic and not a random error.

The depth and width of the tank shall therefore be chosen to suit the size and the maximum velocity limits of the current-meters to be calibrated. Care shall be taken to ensure that either high calibration velocities are attained before the interference or that they exceed it sufficiently for the critical zone to be bridged without extrapolation.

5.2 Towing cart

5.2.1 General

During calibration, the current-meter is suspended below the cart and immersed in the water at a specified depth and the cart travels along the length of the tank at known and accurate speeds in the measuring section.

5.2.2 Cart track system

The cart may run on two parallel rails which shall be accurately aligned with both the length of the tank and the surface of the water in the tank. It is essential that the rails are straight and that both the rails and the wheels of the cart are free of irregularities in order to avoid irregular motions of the cart. The material and hardness of the rails and the driving wheels should be chosen so that there shall not be undue wear and tear of the wheels. In the case of rubber tire wheels, provision shall be made to lift the wheels above the rail surface when not in use for a long time.

5.2.3 Types of towing carts

The following types of towing carts are in common usage.

a) The towed cart which is moved along the track by a cable driven from a constant speed motor standing apart from the moving cart. The towed cart may be lighter in construction with the consequent advantage of high acceleration and quick braking, but the elasticity of the towing cable can cause irregularities in the running of the cart thereby affecting the accuracy of current-meter calibration.

b) The self-propelled cart which is moved along the track by internally mounted electric motor(s). The power to the cart may be fed by a trailing wire track system, by an overhead conductor system or other systems specially designed for the purpose. The self-propelled cart is heavier in construction as it carries the driving motors. This results in greater inertia of the cart and assists in smoothing out the running irregularities of the cart.

5.2.4 Cart operation

The cart shall travel smoothly and at constant speed in the measuring section of the towing tank ensuring that oscillatory motion is not transmitted to the current-meters under calibration.

The cart shall have smooth operational capability. Vibration of the tow cart should be avoided.

The cart shall remain stable during acceleration, deceleration and braking. There shall not be any forward/backward or sideways rocking, or slippage during peak acceleration/deceleration and during normal operation at any speed in specified range.

During calibration, the measuring equipment, sensors and other instruments shall not be affected by noise and spurious signals induced by the main power supply or cart drive and control system or otherwise by electrical equipment installed in the rating tank building and vicinity.

In addition to normal braking, an alternate brake system shall also be provided on the cart which would automatically activate during an emergency.

5.2.5 Cart control

The cart may be manned or unmanned. In the case of a manned cart, an operator on-board controls various functions of the cart.

The unmanned cart is operated remotely without any operator on board.

5.3 Measuring equipment

5.3.1 General

The calibration of a current-meter calls for the simultaneous recording of the following three parameters:

a) distance covered by the cart;

b) time; and

c) signal (pulses) delivered by the current-meter or velocity processed by the meter control unit.

The towing speed is calculated from the simultaneous measurement of distance and time. In case of a rotating-element current-meter, the rate of current-meter revolutions (rotations) is obtained by the simultaneous measurement of the number of signals (pulses) and the time.

5.3.2 Distance measurement

Different methods are available for measurement of distance to the specified measurement uncertainty (see 5.3.5). Two of the most common methods are as follows:

a) the establishment of light barriers (markers) at regular intervals along the length of the tank which actuate mechanical or optical pulse transmitters fitted to the cart;

b) the use of measuring wheels with mechanical or photoelectric pulse transmitters/optical encoders which are drawn along the track by the cart.

In the case of using a measuring wheel, it shall be ensured that there is no slippage during travel. An additional method of precise speed measurement shall also be provided to check the accuracy of the measuring wheel on a regular basis.

5.3.3 Time measurement

The time of travel of the cart is normally measured by an electronic counter with an in-built accurate time reference, for example a quartz crystal. A period can thus be read to 1 ms or better. This equipment should be checked periodically against a reference device traceable to a national time standard.

5.3.4 Current-meter velocity measurement

The cart shall be provided with a suitable recording device for the measurement of current-meter signals.

In the case of rotating-element current-meters, the sensor of the current-meter shall generate a clear and positive signal corresponding to the rotor revolutions. Normally, as per the design of the system, the signals are generated once per revolution, twice per revolution, or in some cases, once for five revolutions or even once for 10 revolutions. The signals received from the current-meter(s) may be counted using the counting device of the current-meter. In measuring the number of current-meter revolutions in a given time, it is important to measure between identical points on the current-meter signal. It shall be ensured that none of the signals are missed.

In the case of an electromagnetic or acoustic current-meter, the electrical signals from its sensor are processed by its control unit.

5.3.5 Sources of error related to infrastructure

5.3.5.1 General

Sources of error (sources of uncertainty) shall be treated according to ISO/IEC Guide 98-3 (GUM). Only the principal sources of systematic and random errors are considered below.

5.3.5.2 Error due to the distance measurement

The following influence factors can contribute to the measurement uncertainty of the distance measurement method:

— systematic uncertainty of the reference distance measuring method;

— thermal expansion on measuring wheels;

— repeatability of the distance measurement method;

— detection/counting of impulses from pulse transmitter or encoders.

5.3.5.3 Error due to timing measurement

The following influence factors can contribute to the measurement uncertainty of the timing measurement method:

— systematic uncertainty of the reference timing measuring method;

— drift of the time reference.

5.3.5.4 Error due to residual currents in the water

The water in the tank is never completely still and residual currents from various origins are always present. The following influence factors can contribute to the upper limit on residual currents:

— standing waves (surface gravity waves) linked to the dimensions of the tank and due to previous measurements or disturbances in the water;

— thermal convection currents due to temperature gradients.

5.3.5.5 Error due to environmental conditions

The ambient temperature fluctuation should be as low as possible, and direct sunlight should be avoided, to minimize the influence on the tank's measurement system and to reduce the creation of thermal convection currents.

Electromagnetic interference generated by drive units and drive unit controls such as frequency converters and power rails, especially if these are located directly on the tow carts, may have an influence on the device under test and sensitive electronic devices.

Magnetic inductive flow meters may be affected by ferro magnetic structures like steel beams or reinforced concrete in the near surrounding.

5.3.5.6 Random errors

The repeatability with which the cart speed can be determined depends on the repeatability of the distance measurement method and on the timing accuracy. For any installation, this may be determined experimentally by setting the cart speed to a fixed value and performing a series of runs to provide a series of estimations of the cart speed.

This is repeated for several different cart speeds and from the standard deviation of each series of measurements, the 95 % confidence limits may be evaluated.

The repeatability of the rate of revolution of the rotating element or the velocity indicated by the current-meter for different cart speeds can be determined in a similar way.

5.4 Data acquisition

In order to facilitate automation and greater accuracy in measurement, a computerized data acquisition system may be provided.

The data acquisition software shall accept any relevant information related to calibration.

Velocity measurement devices use a wide range of data collection and transfer methods. The calibration facility should ensure that their equipment does not interfere with the data transfer signal.

5.5 Data processing

The data processing software shall be customized to process the calibration curves, calibration formula(e) and calibration tables as described in 7.1.4.

Generic functions/tools like least square estimation, statistical functions, and tabulation for rating tables shall be provided in the processing software.

5.6 Other requirements

In addition, provision of the following ancillary equipment at the towing tank facility is recommended:

a) artificial beaches, stilling devices or other similar devices to reduce the reflection of disturbance in the water by the end walls of the tank;

b) means for checking the orientation of the stationary-sensor type current-meters;

c) one or more thermometers to measure the temperature of the water in the tank;

d) conductivity measurement device if magnetic inductive instruments are calibrated.

6 Calculation of uncertainty

The uncertainty associated with a measurement is obtained by combining the uncertainties arising from the sources described in 5.3.5 in accordance to GUM.

As an example, Formula (2) can be used for estimating the combined uncertainty of velocity.

$$U = \left[u_d^2 + u_t^2 + u_c^2\right]^{\frac{1}{2}} \quad (2)$$

where

u_d is the uncertainty of distance measurement;

u_t is the uncertainty of the timing measurement;

u_c is the uncertainty due to residual currents.

Formula (2) is an example and is not claiming to be complete. It does not include all uncertainty factors.

7 Calibration procedure

7.1 Calibration of rotating element current-meters

7.1.1 Suspension of the current-meter

Attention shall be paid to the following points.

— Before the current-meter is immersed in water, it shall be checked for cleanliness, lubrication and for its mechanical and electrical functioning. It shall also be ensured that oil, as recommended by the manufacturer or used by the customer in the field, is used for the current-meters with oil-filled contact systems and bearings during their servicing prior to calibration. If damage is observed during the initial visual inspection, consider first running the current-meter in an as received state so any potential historic error can be quantified.

— The suspension of the current-meter shall be as specified by the manufacturer/user of the current-meter and shall usually be the same as that used during field measurements. If during the field measurements, the current-meter is attached near the lower end of the rod, it shall be mounted in the same position on the cart during calibration. Should this not be the case, the current-meter shall be mounted far enough from the end of the rod to ensure that any influence from this part of the rod is eliminated. Material stiffness of the rod should be chosen so vibrations have no effect on the measurement. If the signal cable is laid outside the rod during field measurements, a similar cable, attached in the same way, shall be used for the calibration. It should be noted that loose signal cables can influence the calibration result. Suitable time should be allowed for the instrument to climatize to the ambient water temperature.

— The current-meter shall be placed at such a depth below the surface of the water that the surface influence is negligible. For an axial-flow current-meter, a depth (water level to rotary axis) twice the diameter of the rotary element is generally sufficient. A cup-type current-meter shall be immersed to a depth of at least 0,3 m or one and a half times the height of the rotor, whichever is greater. At higher towing speeds, there may be separation of flow behind certain rod profiles, causing a decrease in the angular velocity as if a thicker rod were used. This disturbance can often be eliminated by increasing the immersion depth, or by providing the rod with a flaring at the water surface.

— If several current-meters are calibrated at the same time, care shall be taken to ensure that there is no mutual interference, or that the mounting is exactly reproduced in order that the interferences between the current-meters are the same during calibration and during measurement.

— A rod-supported current-meter shall be rigidly attached to the rod so that it is aligned parallel to the direction of travel. A cable suspended current-meter shall be aligned with the direction of travel at the start of each run.

— If the current-meter is of the type which is capable of swivelling in a vertical plane, its balance shall be checked and, if necessary, adjusted before calibration tests are started.

7.1.2 Performance of calibration

7.1.2.1 Minimum speed of response

The minimum speed of response (also called the threshold, or stall velocity) of a rotating-element current-meter is defined as the minimum speed at which the rotor of the current-meter attains continuous and uniform angular motion. It is determined by increasing the cart velocity until the rotating element revolves at a constant angular velocity.

7.1.2.2 Number of calibration points

Measurements shall be carried out from the minimum speed of response at a sufficient number of towing velocities to realize the systematic characteristics of the current-meter. It is generally necessary to carry out tests at closer velocity intervals at the lower end of the range because the largest errors expressed as percentage usually occur in this range. For example, 0,10 m/s intervals should be provided at the lower end of the range, 0,25 m/s intervals in the middle of the range and 0,5 m/s at the upper end of the range. Measurements should be carried out over the whole range of velocities for which the current-meter is designed or is intended to be used.

The total number of calibration points shall be as follows:

a) 8 to 12 for calibration up to 2,5 m/s;

b) 12 to 18 for calibration up to 5 m/s;

c) 18 to 24 for calibration up to 8 m/s.

7.1.2.3 Stilling time

The waiting period between two cart runs shall be chosen so that residual velocities are negligible compared with the following test velocity. The time needed for the water to settle or still depends on the dimensions of the tank, the use of damping devices, the previous test velocity and distance covered, the size and shape of the current-meters and the suspension equipment immersed in the water. The stilling time after each travel of the cart shall therefore be decided and observed by the operator of the towing cart.

7.1.3 Data analysis

7.1.3.1 Velocity *v* and the rotation rate *n*

The velocity v of the cart can be calculated by dividing the length of the measurement section by the time. The rotation rate n of the current-meter can be calculated by dividing the number of revolutions by the time.

In the case of a direct reading current-meter, the rotation rate n is replaced by the corresponding velocity indicated by its display.

7.1.3.2 Determination of outliers

By using graphical or mathematical methods any spurious value of v or n should be identified and eliminated.

7.1.3.3 Calibration formulae

The result of calibration of the current-meter is expressed in the form of one or more formula(e) as a best fit for the calibration points.

The best fit for the calibration points can be derived graphically or by using mathematical analysis. For example, many techniques for carrying out regression analysis have been developed. The most common technique is the simple or the polynomial linear regression. In this approach the calibration points are often fitted using the least squares approach, but it may also be fitted in other ways. The result of the regression is a function shown as Formula (3):

$$v = f(n) \tag{3}$$

where

v is the velocity, in metres per second (m/s);

n is the number of revolutions of the current-meter rotor per second (r/s).

Most familiar is Formula (4):

$$v = a + bn \tag{4}$$

where

v is the velocity, in metres per second (m/s);

n is the number of revolutions of the current-meter rotor per second (r/s);

a, b are constants determined for each function.

7.1.4 Presentation of results

The following information shall be provided:

a) calibration formula(e);

b) uncertainty of measurement;

c) name and address of the rating laboratory;

d) date of calibration;

e) make and type of current-meter;

f) serial number of the current-meter and each rotor;

g) validity range;

h) type of meter suspension (rod mounted, or cable suspended);

i) if applicable specification of the weight for cable suspended meters;

j) minimum speed of response;

k) temperature of the water in the rating tank.

Among others, the following information can also be included in the result sheet:

l) calibration graph [graph of the calibration formula(e) with calibration points];

m) calibration table [calibration (rating) tables with values of v and n and other information like absolute or percentage deviation indicating the accuracy of the calibration formula(e)];

n) calibration number;

o) spin time in case of cup-type current-meter in accordance with ISO 2537;

p) details of sinker weight, if used during calibration;

q) position of the current-meter in the cross section of the tank;

r) any remarks, for example, statements of any modifications made to the current-meter such as the fitting of spare parts;

s) viscosity of the bearing oil;

t) signature of a responsible member of the staff at the rating laboratory;

u) any drawings and/or photographs illustrating the layout of the calibration arrangement.

7.2 Calibration of electromagnetic current-meters

7.2.1 Instructions for calibration

Before the sensor is immersed in water, it shall be checked for cleanliness, damage and for its electrical function. If damage is observed during the initial visual inspection, consider first running the current-meter in an as received state so any potential historic error can be quantified.

Prior to calibration, the sensor head of the current-meter shall be soaked in water for a period of at least 30 min.

For calibration, the sensor shall be mounted on the mounting bracket of the cart in such a way that it shall be immersed in tank water at the specified depth and the orientation of the current-meter body shall be perfectly horizontal.

In case of electromagnetic current-meters, acquisition of measurement at zero speed is essential to know its zero offset. (The reading shown by the current-meter at zero velocity is known as its zero offset.) Hence, before the start of the calibration test, a reading of the current-meter should be taken in still water to determine the zero offset. If the instrument provides a zero-point calibration functionality, this should be applied in advance.

During calibration, care shall be taken to establish a sufficient number of different calibration velocities to ensure that the performance of the current-meter is satisfactory.

If the instrument is specified for output of negative velocities, the calibration in reverse direction is recommended.

The record of the average velocity determined by the electromagnetic current-meter and the average velocity of the cart shall simultaneously be taken over the same period of time of cart travel.

7.2.2 Mounting the electromagnetic current-meter

The electromagnetic current-meter sensing head shall be kept scrupulously clean and free of contamination by grease. The manufacturer instructions regarding cleaning method shall be followed.

Great care shall be taken to orient the current-meter body horizontally, especially in the case of elongated body shapes and where electrodes are located on only one face of the current-meter body. Placement of the current-meter sensing head shall be in a location shielded or free from magnetic fields generated by the cart drive motor and power rails.

Tank water shall be adequately conductive to ensure satisfactory performance of the current-meter. The conductivity of tank water shall be measured and recorded in the calibration certificate. Adequate electrical grounding of the current-meter, cart and tank water shall be ensured to prevent grounding loops.

7.2.3 Number of calibration points

The number of calibration points should be selected according to 7.1.2.2.

The readings from the current-meter and the linking of these with the readings of the cart shall vary based on the type of display unit since

a) the current-meter readings can be in the form of rapidly changing numbers on a digital display,

b) the current-meter readings can be in the form of an averaged value taken over a period defined by the current-meter electronic unit; unrelated to the cart speed measurement period, and

c) the current-meter reading can be a value which has been generated by averaging the electronic measurements over a period of time, the start of which may be user defined.