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Hydrometry — Calibration of current-meters in straight open tanks

Hydrométrie — Étalonnage des moulinets en bassins découverts rectilignes

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Foreword

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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 3455 was prepared by Technical Committee ISO/TC 113, *Hydrometry*, Subcommittee SC 5, *Instruments, equipment and data management*.

This second edition cancels and replaces the first edition (ISO 3455:1976), which has been technically revised.

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Hydrometry — Calibration of current-meters in straight open tanks

1 Scope

This International Standard specifies the procedure of calibration of current-meters of rotating-element type as well as stationary-sensor type (electromagnetic type) in straight open tanks. It also specifies the types of tank, rating carriage and equipment to be used and the method of presenting the results.

The procedure does not take into account any possible difference existing between the behaviour of a current-meter moving in motionless water and that of a fixed current-meter in turbulent flow.

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2 Normative reference

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 772, *Hydrometric determinations — Vocabulary and symbols*

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

3 Terms and definitions

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

4 Principle of calibration

Calibration of a current-meter means experimental determination of the relationship between liquid 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 carriage and drawn through still water contained in a straight tank of a uniform cross section at a number of steady speeds of the towing carriage. Simultaneous measurements of the speed of the towing carriage 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 equations, the limits of validity of which are stated. In the case of stationary-sensor type current-meters, the velocity indicated by its display unit is compared with the corresponding carriage speed to know the error in measurement.

5 Design criteria for calibration stations

5.1 Dimensions of rating (calibration) 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 the test results are not affected.

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5.1.2 Length

The length of a rating tank can be considered as comprising accelerating, stabilizing, measuring and braking sections.

The length of the accelerating and braking sections depends on the design of the carriage, 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 carriage need to 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 will, therefore, depend on the type of current-meter being calibrated, type of carriage and the way the signals are produced and transmitted.

For example, if measured times both for distance covered by the carriage and for the revolutions counted are accurate to 0,01 s in order to limit the error in time measurement to 0,1 % at the 95 % confidence level, the duration of the test shall be at least 10 s at maximum speed. If the maximum speed is 6 m/s, the measuring section of the tank would be 60 m long. The total length of the tank would be about 100 m of which about 20 m would be for acceleration and stabilizing and 20 m for braking.

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 Equation (1):

$$v_c = \sqrt{gd} \tag{1}$$

where

g is the acceleration due to gravity;

d is the depth of water.

The wave crest produced by the current-meter and its means of suspension, which moves forward with the instrument, causes an increase in the height of the wetted cross section and thus, in accordance with the continuity equation, a reduction of the relative velocity. This phenomenon, known as the Epper effect, may cause an error in calibration within a narrow band in the velocity range from 0,5 v_c to 1,5 v_c. The magnitude of the Epper effect depends on the size of the current-meter(s) and suspension equipment, relative to the cross-sectional area of the tank. It may be little more than the uncertainty of a single calibration point. It is a systematic and not a random error. It may be negligible when a very small current-meter is being calibrated.

The depth 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 the calibration velocities in higher range are attained before the interference or that they exceed it sufficiently for the critical zone to be bridged without extrapolation.

The width of the tank is of importance because the Epper effect is more pronounced in a narrower tank. The width also limits the number of instruments that can be calibrated simultaneously and has an effect on the stilling characteristics (time taken for the water to become reasonably still).

For example, when a field type current-meter on rod suspension is being calibrated in a tank 1,83 m wide in which the depth of water is 1,83 m, the Epper effect is greater at a speed of about 4 m/s ($\sqrt{9,81 \times 1,83}$) and amounts to 0,3 %. The size of the effect dies away on either side of the critical velocity, but is detectable at velocities between 3 m/s and 5 m/s.

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5.2 Rating carriage (trolley)

5.2.1 General

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

5.2.2 Carriage track system

The carriage may run on two parallel rails which must 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 the rails and the wheels of the carriage are free of irregularities, otherwise the carriage will move with irregular motion and cause vibration which may be transmitted to the current-meter(s) and disturb the rating. 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.

Another track system may have toothed belts, mounted on both sides of the tank, driven by the guiding rollers and used for transportation of the carriage. If this system is adopted, it shall be ensured that there is no slippage or sag of the belt and in case the slippage or sag occurs, it shall be possible to remove it manually. The belts shall be strong enough to withstand the load of the carriage they have to transport during calibration and the climatic conditions prevailing at the rating laboratory.

5.2.3 Types of rating carriages

The following types of rating carriages are in common usage.

a) The towed carriage which is moved along the track by a cable driven from a constant speed motor standing apart from the moving carriage. The towed carriage 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 carriage thereby affecting the accuracy of current-meter calibration.

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

The weight of the rating carriage can substantially be reduced by using light but rugged material for its construction. The lightweight carriage can achieve a high rate of acceleration/deceleration resulting in relatively smaller length of tank.

5.2.4 Carriage operation

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

The carriage 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.

The carriage shall have smooth operational capability in both forward and reverse directions.

An interlock shall be provided in the system to ensure that the direction of start up is correct.

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

Normal braking of the carriage shall be accomplished by dynamic braking through the drive system. In addition to normal braking, an alternate brake system shall also be provided on the carriage which would automatically activate during an emergency.

5.2.5 Carriage control

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

The unmanned carriage is operated remotely without any operator on board. An on-board programmable controller unit controls various functions of the carriage, i.e., speed, acceleration, deceleration, braking, etc. The controller exchanges control signals with the supervisory computer, installed in a control room through suitable digital communication system.

5.3 Measuring equipment

5.3.1 General

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

a) distance covered by the carriage;

b) time; and

c) number of signals (pulses) delivered by the current-meter.

The towing speed is calculated from the simultaneous measurement of distance and time and, in case of 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.

For acquisition of calibration data, a strip chart recorder or magnetic tape or a computerized data acquisition system as described in 6.1 may be used.

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 carriage;

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

In the case of use of 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.

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5.3.3 Time measurement

A variety of methods are available by which time can be precisely measured. Two of the most common methods are as follows:

a) a clock giving a contact pulse after one or several seconds (These time pulses are usually recorded on a graph of a strip chart recorder or magnetic tape together with the pulses of the current-meter and distances. The time corresponding to an integral number of pulses from the current-meter is usually determined by interpolation of the time pulse.);

b) electronic clocks, capable of measuring fractions of a second, which time and display a preset number of distance intervals and a corresponding number of pulses from the current-meter.

5.3.4 Current-meter signal measurement

The carriage 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 ten revolutions. The signals received from the current-meter(s) may be counted using the counting device of the current-meter or recorded on strip chart recorder or magnetic tape. 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.

When a recording of current-meter signals is made, the speed of the recording media shall be adjustable so that the separation of the current-meter signal shall be compatible with the speed of the carriage and the required accuracy of the measurement.

In the case of an electromagnetic current-meter, the electrical signals from its sensor are collected by its control unit (7.2.1) and displayed in the form of average value of velocity.

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5.3.5 Measurement uncertainty

The uncertainty of measurement of distance travelled by the carriage shall be within 0,1 % of the actual value at 95 % confidence level.

The uncertainty of measurement of time shall be within 0,1 % of the actual value at the 95 % confidence level.

The uncertainty of measurement of current-meter signals shall be within 0,1 % of the actual value at the 95 % confidence level.

5.4 Other requirements

In order to increase the efficiency of the calibration process, provision of the following ancillary equipment at the rating laboratory is desirable:

a) filtering, dosing and scum-removing equipment for the cleansing of the water and for keeping it free from algal growth;

b) spending beaches, stilling devices or other similar devices to reduce the reflection of disturbance in the water by the end walls of the tank (Alternatively, transverse curtains can be installed at intervals along the tank and lowered to the bottom of the tank before the start of each run.);

c) means for checking that a cable-suspended current-meter is properly aligned at the start of a run and that the current-meter is not swinging when measurements are started shall be available when the installation is operated from a control room [Closed circuit television is useful for this purpose and also for observing the behaviour of the rotating-element current-meters at speeds close to their minimum speed of response (see 7.1.3.1).];

d) means for checking the orientation of the stationary-sensor type current-meters.

e) a hand-held thermometer to measure the temperature of the water in the tank.

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6 Computerized data acquisition and processing system

6.1 Data acquisition

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

The on-board computer used for data acquisition shall take care of simultaneous logging of data of distance covered by the trolley, time and signals received from various types of current-meters being calibrated.

The data acquisition software shall be interactive, user friendly and shall be well designed to accept the following input data:

- date and time of calibration;
- make and type of current-meter;
- serial number of current-meter and each rotor;
- job number allotted by the rating laboratory;
- position of current-meter on the carriage;
- water temperature;
- any other relevant information related to calibration.

The data acquisition system shall be programmable in an industry standard programming system/language and shall comply with the standard communication protocols.

6.2 Data processing

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

Processing software shall support detection of each output pulse of each current-meter and provide filtering of unwanted signals, and it shall also support precise measurement of time duration of the specified number of signals from the current-meter.

The recording and visualisation of the following shall be possible:

- realized speed vs. time;
- programmed speed vs. time;
- realized speed error [1] vs. time;
- simultaneous graphical presentation of carriage displacement, time and output of all the mounted current-meters.

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

1) Realized speed error is the difference between programmed speed and realized speed.

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The software shall be provided to support a database for the calibration document specified in 6.1 and it shall be open and allow future extension/adaptation of the supported functions.

In the case of remote controlled carriage, data processing shall be executed by the supervisory computer in the control room.

7 Calibration procedure

7.1 Calibration of rotating-element current-meters

7.1.1 Instructions for calibration

The instructions to be given by the manufacturer/user of the current-meter to the rating laboratory for calibration shall include:

a) the limits of calibration speeds;

b) details of the means of suspension; for example, rod profile and dimensions, fixing method of electric cables, type of suspension cable, type and mass of sinker weight, position of current-meter with respect to support, etc.;

c) the specification of the oil to be used in case of oil-filled contact systems and bearings;

d) information concerning the desired calibration documents, such as format of the calibration diagrams or tables, units in which the results are to be expressed, etc.;

e) special requirements, if any.

7.1.2 Suspension of the current-meter

Attention shall be paid to the following points:

7.1.2.1 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 is used for the current-meters with oil-filled contact systems and bearings during their servicing prior to calibration.

7.1.2.2 The suspension of the current-meter shall be as specified by the manufacturer/user of the current-meter. This shall usually be the same as that used during field measurement. 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 carriage 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 quarter is eliminated. 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.

7.1.2.3 The current-meter shall be placed at such a depth below the surface of the liquid that the surface influence is negligible. For an axial-flow current-meter, a depth (liquid 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.

7.1.2.4 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.

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7.1.2.5 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.

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

7.1.2.7 Care shall be taken to ensure that the carriage vibrations (especially noticeable at lower speeds) and the rod vibrations (especially noticeable at higher speeds) are low enough not to influence the speed of revolution of the current-meter.

7.1.3 Performance of calibration

7.1.3.1 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 during calibration by gradually increasing the carriage velocity from zero until the rotating element revolves at a constant angular velocity.

7.1.3.2 Number of calibration points

Measurements shall be carried out from the minimum speed of response at a sufficient number of towing velocities to enable the calibration of the current-meter to be defined accurately. It will generally be 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.

In accordance with the current practice followed in a number of rating laboratories, the total number of measuring 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.

7.1.3.3 Stilling time

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

7.1.4 Analysis of data

7.1.4.1 Determination of translation and rotation speeds

If an electronic counter as described in 5.3.3 b) is used, the velocity v of the carriage and the rotation rate n of the current-meter can be calculated by dividing the distance and the number of revolutions by the time.

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If a graph recording as described in 5.3.3 a) is used, the evaluation of v and n can be made in two ways.

a) Lengths corresponding to a certain number of pulses relating to the current-meter, to the distance and time are measured along the recording strip in millimetres as shown in Figure 1.

The values of v and n are obtained from the following equations:

$$v = \frac{\frac{l}{l_2}}{\frac{t}{l_1}} = \frac{l \cdot l_1}{t \cdot l_2} \text{ (m/s)} \quad (2)$$

and

$$n = \frac{\frac{r}{l_3}}{\frac{t}{l_1}} = \frac{r \cdot l_1}{t \cdot l_3} \text{ (r/s)} \quad (3)$$

where

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

t is the number of seconds represented on the chart by a trace of length l_1, in millimetres (mm);

l is the distance between an integral number of distance markers at the side of the tank (or the distance transmitted by the measuring wheel), represented by a trace of length l_2, in millimetres (mm);

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

r is the integral number of revolutions represented by the trace of length l_3, in millimetres (mm).

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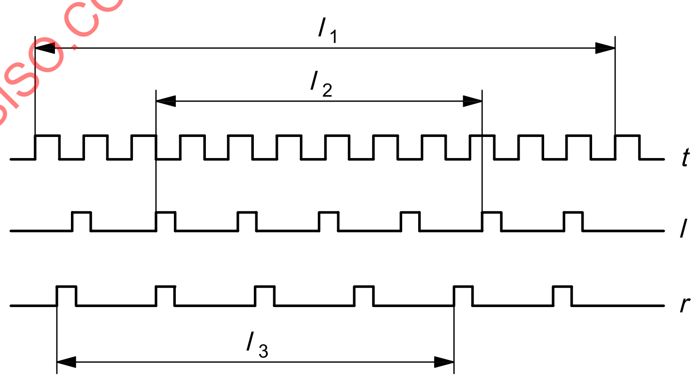


Key

l_1 length (mm) of trace for t seconds
l_2 length (mm) of trace for l metres
l_3 length (mm) of trace for r pulses
t time, in seconds
l distance, in metres
r current-meter, pulses

Figure 1

b) The beginning and the end of the recording segments corresponding to a given number of pulses relating to the current-meter on the one hand and to the distance on the other hand are projected into the time recording line as shown in Figure 2. The interpolation between two time signals allows the exact duration corresponding to the number of rotor turns and to the distance chosen to be determined. This method is particularly suitable with long recording strips. In this case, the values of v and n are obtained from the following equations:

$$n = \frac{N}{t_1} \text{ (r/s)} \tag{4}$$

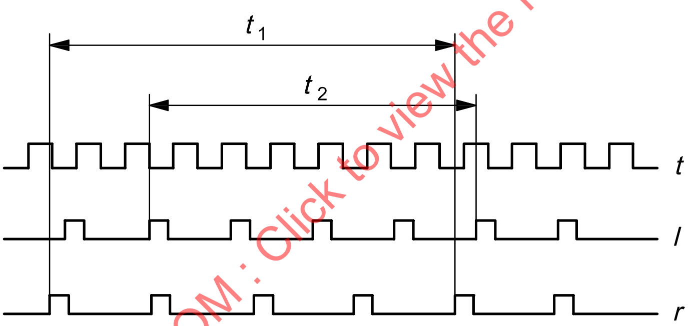
and

$$v = \frac{l}{t_2} \text{ (m/s)} \tag{5}$$

where

t_1 is the time (number of complete intervals and fractional intervals of time multiplied by the duration of one interval) corresponding to N revolutions of the current-meter rotor;

t_2 is the time (number of complete intervals and fractional intervals of time multiplied by the duration of one interval) corresponding to a travel of distance l.



Key

t time, in seconds

l distance, in metres

r current-meter, pulses

Figure 2

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7.1.4.2 Calibration curves

The calibration points are normally entered in a graphic system with the velocity v as the ordinate and the rate of rotation of the rotor n as the abscissa. In the case of propeller current-meter, in order to raise the accuracy of the graphic entries to the highest possible level without having to choose too large a scale, a theoretical rotor pitch is selected which lies close to the calibration curve and only the deviations, $\Delta v = v - kn$, from the auxiliary straight line are entered on the large scale [Figure 3 a)]. The curve of Δv as a function of n can be replaced with adequate accuracy by the straight lines A, B and C whose equations are easy to calculate [Figure 3 b)].

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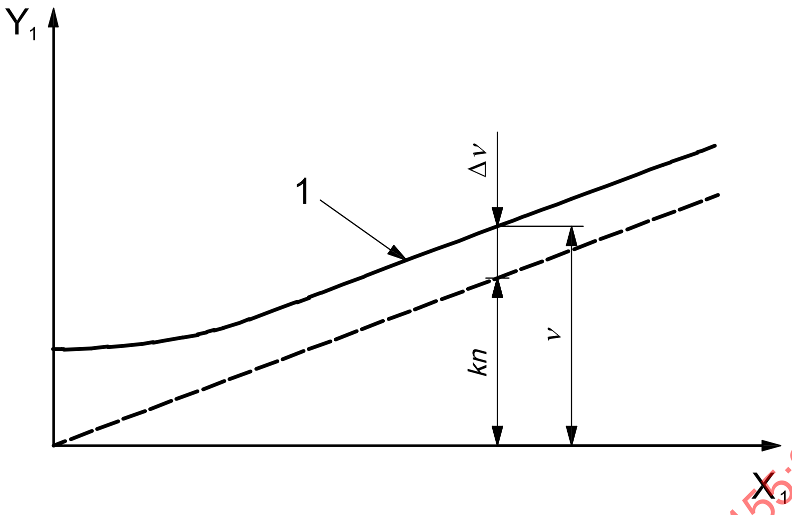
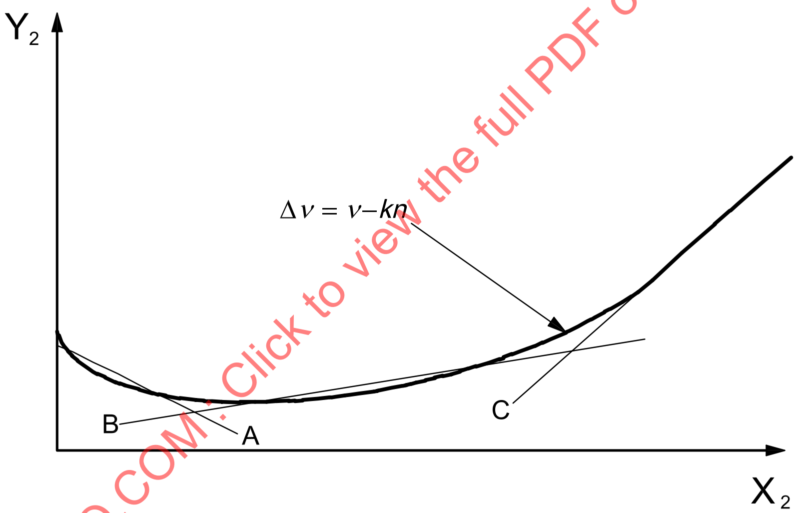


a)



b)

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Key

1 calibration curve

X_1 average rate of revolution of rotor (n), in revolutions per second

Y_1 average velocity of carriage (v), in metres per second

X_2 average rate of revolution of rotor (n), in revolutions per second

Y_2 Δv, in metres per second

Figure 3

7.1.4.3 Calibration equations

The result of calibration of the current-meter is expressed in the form of one or more equations of the straight lines as a best fit for the calibration curve. These equations shall be given in the following form:

$$v = a + bn \tag{6}$$

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 and b are constants determined for each equation.

The equation can also be given in the following form when it is convenient to show the time t corresponding to N rotor turns.

$$v = a + b\frac{N}{t} \tag{7}$$

7.1.4.4 Calibration tables

Calibration (rating) tables are prepared using the experimental values of v and n. The calibration equation(s) as a best fit for the calibration curve can be obtained on computer by adopting a suitable programme. In order to identify and eliminate any spurious value of v or n which is likely to pass to the computer unnoticed, the limiting values for the deviations of individual points from the calibration curve shall be inserted in the computer programme. The calibration tables can be produced in the form suitable to the gauging technique used. In the calibration table, the velocity can be given for every 0,01 r/s or for integer numbers of revolutions in a predetermined time interval or corresponding to a predetermined number of revolutions.

Provision shall also be made in the calibration table to print the observed values of v and n along with the value of percentage deviation of individual observation points from the established mean rating curve so as to know the scatter of each point from the mean curve. As a check for goodness of fit of the calibration curve, standard error of the data shall also be stated as a percentage of mean velocity class and shall be related to the 95 percent confidence limit.

7.1.5 Presentation of results

Results of calibration shall be presented in one of the following forms:

— expressed solely in the form of equations;

— expressed by the calibration equations and also plotted as a calibration curve on the chart;

— calibration table supplied in the form suitable to gauging technique.

In the case of a direct reading current-meter, the calibration results shall be presented in the tabular format giving carriage velocity, corresponding velocity indicated by its display unit and the percentage deviation of each indicated velocity from the carriage velocity.

The following information shall also be included in the result sheet:

a) name and address of the rating laboratory;

b) date of calibration;

c) calibration number;

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