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An American National Standard

Standard Test Method for Velocity Measurements of Water in Open Channels with Electromagnetic Current Meters [1]

This standard is issued under the fixed designation D 5089; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the use of single-axis or dual-axis electromagnetic current meters for the measurement of water velocities in open channels.

1.2 This test method covers only these components and appurtenances of portable open-channel current-meter systems, which are customarily required when an operator is in attendance.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1129 Terminology Relating to Water [2]

D 2777 Practice for Determination of Precision and Bias of Applicable Methods of Committee D19 on Water [2]

D 3858 Test Method for Open-Channel Flow Measurement of Water by Velocity-Area Method [2]

D 4409 Test Method for Velocity Measurements in Open Channels with Rotating-Element Current Meters [2]

2.2 *ISO Standards:*

ISO 3454 Liquid Flow Measurement in Open Channels—Sounding and Suspension Equipment [3]

ISO 3455 Liquid Flow Measurement in Open Channels—Calibration of Rotating Element Current Meters in Straight Open Tanks [3]

3. Terminology

3.1 *Definitions:* For definitions of terms used in this test method refer to Terminology D 1129.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *boundary layer*—a relatively thin layer of viscous influence adjacent to the probe (or any solid) surface caused by the requirement that the water velocity must be zero at the wall.

3.2.2 *cosine response*—the ability of a meter, placed at an angle to the oncoming flow, to sense the component of velocity parallel to its axis.

3.2.3 *turbulence*—irregular condition of flow in which the various quantities show a random variation with time and space coordinates so that statistically distinct average values can be discerned.

4. Summary of Test Method

4.1 Electromagnetic liquid flow current meters are based on the Faraday principle of electromagnetic induction, which states that voltage is proportional not only to flow speed but also to the magnetic flux density and the distance between electrodes. In the application of the electromagnetic liquid current meter, a conductor (water) moving in a magnetic field (created from within the sensor) generates a voltage that is proportional to the rate of flow of water through the magnetic field. This variable voltage lies in a plane that is perpendicular to both the water velocity vector and the magnetic field vector and is sensed by pairs of electrodes.

5. Significance and Use

5.1 This test method is particularly used for measuring the velocity at a point in an open channel as part of a velocity-area traverse to determine the flowrate of water. To this end it should be used in conjunction with Test Method D 3858. A single axis probe with cosine response will suffice for most of these applications.

5.2 This test method is also useful in applications where the velocity itself (rather than a volumetric flowrate) is the desired end product.

6. Interferences

6.1 As with any intrusive flow measuring device, electromagnetic current meter sensors may be fouled by pieces of debris of the type that can cling to or wrap around the sensor which could affect measurement accuracy, and sensors may be damaged by heavy debris in very high velocity flow.

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[1] This test method is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.07 on Sediments, Geomorphology, and Open-Channel Flow.

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[2] *Annual Book of ASTM Standards*, Vol 11.01.

[3] "Measurement of Liquid Flow in Open Channels," *ISO Standards Handbook 16*, 1983. Available from American National Standards Institute, 25 W. 43rd St., 4th floor, New York, NY 10036..

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6.2 Electromechanical flow sensors can be affected by oil or other materials coating the sensor.

6.3 Electromagnetic flow sensors can be affected by external electrical noise such as that caused by nearby heavy electrical equipment, and by voltage gradients caused by nearby galvanic corrosion, or nearby power lines. Cables and connectors should be properly shielded to reduce noise problems.

6.4 Although electromagnetic velocity meters are in principle capable of measuring substantially lower velocities than rotating element current meters, measurement of near-zero velocities may be hampered by noisy output signals caused by spurious electrical and magnetic noise, by fouling, by zero-drift, and by calibration uncertainties. Where external electrical noise creates uncertainty in sensed velocities, the electromagnetic meter may not be the appropriate velocity instrument for the site.

7. Apparatus

7.1 *Electromagnetic Current Meter*:

7.1.1 The current meter consists of an electromagnet to generate a magnetic field perpendicular to the flow to be measured, electrodes to sense the generated voltage, a housing or supporting structure, and a voltage readout. The sensor can have either one pair of electrodes or two orthogonal pairs of electrodes depending upon whether it is a single-axis or multi-axis instrument.

7.1.2 The current meter must have a self-contained power source for the electromagnet and for any other electrical components. This power source must have sufficient duration for normal field-work requirements. The power cells shall be either rechargeable or readily replaceable by an operator in the field.

7.1.3 The readout may be either in terms of electrical units or directly in velocity. If the former, the manufacturer must supply convenient velocity conversion tables with the instrument. Readouts may be either analog or digital with a readout capability of giving velocity accurate to ± 0.01 ft/s (0.305 cm/s).

7.1.4 Optionally the current meter system may include a chart recorder or other type of data recording, storage or transmission device in parallel with the manual readout. One of these options is required only if the current meter is to be used unattended. Specifications for these devices are beyond the scope of this test method.

7.1.5 Optionally the current-meter system may include direction-sensing equipment. Specifications for this equipment are beyond the scope of this test method.

7.1.6 The current meter shall include a means by which the user can check its internal operation. However, it is emphasized that checks of this type do not constitute full calibrations.

7.1.7 All components of the current-meter system shall be made of materials that have corrosion resistance consistent with the intended application. Fabrication material must be selected to preclude galvanic corrosion, which could create electronic interference and degrade accuracy readings of the device.

7.1.8 The manufacturer must inform the user of any limits on ambient temperature, depth, velocity, or other parameters beyond which the instrument should not be used.

7.2 *Suspension*:

7.2.1 The current meter can be suspended in the channel either rigidly, referred to herein as rod mounting, or flexibly, as by cable and weight or other type of mooring. As a minimum, current meters intended for open-channel use shall be equipped with appropriate fittings for either rod mounting or cable suspension; but it is preferable that general purpose current meters be adaptable to both types of suspension. The cable should be adequate to support sounding weights and also be properly electronically shielded to prevent interference with operation of the meter or transmission of signals from meter to readout equipment, or both.

7.2.2 The rating of a current meter may depend upon the geometry of the suspension system in the immediate vicinity of the velocity sensor. Therefore, if the manufacturer does not furnish the suspension system with which the meter was calibrated, he shall provide all specifications necessary for the user to mount the meter in a manner consistent with its calibration.

7.2.3 Although "rod mounting" can describe any rigid suspension, in this context it frequently refers to a rod held vertically against the channel bottom by an operator standing over a small channel (or wading in a larger channel). The connection for rod mounting shall provide, in conjunction with the rod, rigidity and vibration-free performance at the highest velocity claimed for the meter, and shall provide for adjustable sensor position (depth) along the rod. The rod diameter shall be in the range of 0.5 to 1.0 in. (12.7 to 25.4 mm).

7.2.4 Although cable suspension can describe any flexible mooring, in this context it frequently refers to a (nearly) vertical cable which is weighted at its end and which can be winched to place the current sensor at any desired depth. Descriptions of and requirements for suspension equipment appropriate for stream gaging are available in ISO 3454. This test method includes only those elements which directly affect the current-meter performance.

7.2.4.1 The connection between the sensor and cable must permit the sensor to assume its normal operational position. The sensor must be stable with respect to the flow and be able to maintain its proper attitude; this can be accomplished by design of sensor shape, use of fins, or by other means. If detachable fins or other appurtenances are provided, the manufacturer must provide calibrations both with and without this equipment.

7.2.4.2 The weight used in a cable-and-weight suspension should be heavy enough to avoid excessive downstream deflection of the cable, particularly in deep and swift waters. If some deflection is unavoidable, tables for air-line and wet-line corrections are available. [4] The weights should offer minimal resistance to the flow and should be able to maintain a stable and level position. They should be so shaped and placed that

[4] Buchanan, T. J., and Somers, W. P., "Discharge Measurements at Gaging Stations," Book 3, Chapter A8 of *Techniques of Water Resources Investigations of the U.S. Geological Survey*, U.S. Government Printing Office, 1969.

the current meter is not affected by eddies shed by the weight, blockage, or other instabilities.

7.2.4.3 It is preferable that the weight be mounted below the current meter. This permits the weight to serve as a sounding device for depth determination and as protection for the sensor. The suspension cable should be reverse wound to avoid spinning of the immersed current meter and weight.

8. Sampling

8.1 Sampling, as defined in Terminology D 1129, is not applicable in this test method. Sampling to obtain average velocities in a cross section for purpose of flowrate determination is covered in Test Method D 3858.

9. Calibration

9.1 Calibrate each electromagnetic current meter individually in water over the expected operating range of velocity that the meter will be used. Recalibration intervals will depend upon experience with specific instruments and applications. A general guideline would be to recalibrate a new instrument before the start of a "field season," or every 200 h of usage. Recalibrations must be performed at any time that data appears to be doubtful or repairs are made.

9.2 Calibrations must be made with the suspension in the immediate vicinity of the sensor identical to that which will be used in the field, unless it can be shown that the differences do not affect the rating.

9.3 The manufacturer must supply an estimate of the accuracy and precision of the rating, along with the method of calibration (towing tank or water flow facility) and information on cosine response in azimuth and tilt, as appropriate.

9.4 Details on calibration requirements may be found in ISO 3455 and in Test Method D 4409.

10. Procedure

10.1 Check the internal electrical performance (7.1.6) and *in-situ* zero (11.4.1), and clean the electrodes and sensor, at intervals determined by experience. In the absence of other guidelines it is recommended that these procedures be done at least daily. Follow manufacturer's instructions to avoid damage by frequent cleaning. Avoid application of oil or heavy hydrocarbons to electrodes.

10.2 For velocity-area traverses refer to Practice D 3858 for information on velocity sampling point and sampling times. However, the meter must be capable of averaging velocity over a 40 to 70 s period to account for pulsations in the water flow.

10.2.1 If a rod suspension is used with an electromagnetic current meter with cosine response, orient the current meter to measure the flow perpendicular to the cross section. Even if the flow at that measuring station is not perpendicular to the cross section, no errors will occur since the instrument (provided its cosine response is adequate) will detect the perpendicular component.

10.2.2 If a cable-and-weight suspension is used and the flow is not perpendicular to the cross section, independently determine the angle of the current with respect to the perpendicular and multiply the measured velocities by the cosines of the angles so determined.

10.3 Users must develop, through trials, information such as required warm-up time, water-acclimatization time, battery life, and charging frequency for the instrument, if recommended values are not furnished by the manufacturer.

11. Precision and Bias

11.1 Determination of the precision and bias for this test method is not possible, both at the multiple and single operator level, due to the high degree of instability of open channel flow. Both temporal and spatial variability of the boundary and flow conditions do not allow for a consent standard to be used for representative sampling. A minimum bias, measured under ideal conditions, is directly related to the bias of the equipment used and is listed in the following sections. A maximum precision and bias cannot be estimated due to the variability of the sources of potential errors listed in 11.3 and 11.4 and the temporal and spatial variability of open-channel flow. Any estimate of these errors could be very misleading to the user.

11.2 In accordance with 1.6 of Practice D 2777, an exemption to the precision and bias statement required by Practice D 2777 was recommended by the results advisor and concurred with by the Technical Operations Section of the Committee D-19 Executive Subcommittee on June 7, 1989.

11.3 The potential bias of the current meter can be estimated from information furnished by the manufacturer. Detailed tests on some meters have indicated root mean square (rms) errors of 0.03 to 0.15 ft/s (1 to 5 cm/s) under good conditions. However, under field conditions numerous error sources are recognized and are cited in the following sections. Most of the resulting errors have not been quantified and only cautionary statements can be made.

11.4 *Potential Errors*:

11.4.1 The zero of the electromagnetic water current meter is subject to minor random variations over long-term use, owing to electrochemical interactions between the changing magnetic field and the electrode-water interface. While the zero-drift specification provided by manufacturers is considered to be a long-term source of error, in actual practice the zero can shift in a small amount of time (even a few minutes) and thus have a substantial effect on low velocity measurements. To determine the zero drift the sensor should be placed in a large container of still water. If the reading is "0," then no drift has occurred. If it is suspected that there is flow within the container, the sensor can be rotated 180° about its sensing axis and a second reading made. The difference between the two readings can be attributed to the zero offset of the instrument.

11.4.2 Changes in the calibration can occur if the sensor electrodes become severely contaminated or are insulated from the water. This usually occurs when there are large amounts of oil or chemicals present in the water. Meter electronics, may change with time and temperature requiring repair or recalibration, or both.

11.4.3 *Superposed Motions*:

11.4.3.1 Unsteady motions superposed on a steady velocity can result either from the motion of a moored platform or from wave-induced (or similar) motions past a stationary current meter.

11.4.3.2 In the case of oscillations that are co-directionally superposed on the axial steady motion, the accuracy of an instantaneous velocity measurement depends on the essential equivalence of the boundary layer and wake structures to those existing at the same steady velocity. In the case of oscillations in horizontal or vertical planes, the sensor is effectively subjected to a flow at an angle to its axis and accuracy further depends upon its cosine response. Insufficient information is available to quantify these effects, which will depend upon flow kinematics and sensor shape. To correctly measure velocities the sensor must be oriented parallel to flow lines. Some information pertinent to spherical sensors is available. [5]

11.4.3.3 The effects of turbulence depends upon its intensity and scale relative to the sensor. [4] The error in general cannot be quantified but it is likely to exist to the extent that the tubulence affects the boundary layer or wake; users should be aware of this possibility, particularly for meters that have been calibrated in still water (towing tank).

11.4.4 *Horizontal Directivity Response*—The two-axis electromagnetic water velocity sensor should be capable of accurately resolving the water velocity vector into its two orthogonal components, V_x and V_y. In actual practice, however, placing the sensor in the flowing water creates a flow pattern that causes imperfection in the directivity response. Ideally, the response should be such that when the probe is rotated, the readings V_x and V_y plot a circle about the probe. In general, the most common response curve is not a perfect circle but is a circle that exhibits decreased sensitivity at the midpoints of each of the four quadrants.

11.4.5 *Boundary Effects*— Like mechanical meters, electromagnetic current meters should not be placed in close proximity to boundaries. The distance one should be placed from the boundary is a function of the sensor size, but at a minimum should be three to four sensor diameters away from a boundary. In general, there is inadequate data available to provide proper corrections for use of sensors near boundaries.

12. Keywords

12.1 discharge measurements; open channel flow; water discharge; water velocity

[5] Aubrey, D. G., et al., "Dynamic Response of Spherical Electromagnetic Current Meters," *Proceedings of Oceans 84*, MTS-IEEE, Washington, DC, September 1984.

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