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

This standard is issued under the fixed designation D 4409; 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 describes the design and use of cup-type or vane-type vertical axis current meters and propeller-type horizontal axis current meters for measuring water velocities in open channels.

1.2 This test method is intended primarily for those meters customarily used in open-channel hydraulic (as distinguished from oceanographic) applications with an operator in attendance.

1.3 This test method is intended primarily for current meters that measure one component or filament of flow.

1.4 *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 D-19 on Water[2]

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

2.2 *ISO Standards:*

ISO 2537 Liquid Flow Measurement in Open Channels—Rotating Element Current Meters[3]

ISO 3454 Liquid Flow Measurement in Open Channels—Direct Depth 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 other terms used in this test method, refer to Terminology D 1129.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *current meter*—an instrument used to measure the speed or velocity of flowing water at a point.

3.2.2 *Price-type current meters*—generic name for specific vertical axis meters with a rotating element consisting of six conical cups and constructed as described in Refs **(1-3)**.[4]

3.2.3 *spin test*— a test performed to check the bearings of a current meter. This test is used primarily with vertical axis current meters.

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

4. Summary of Test Method

4.1 The angular velocity of the rotating element is a function of water speed at the point of immersion. This angular velocity is determined from the meter output and its functional relation to the water speed is determined by calibration.

5. Significance and Use

5.1 This test method describes the design and use of various types of current meters. These current meters are commonly used to measure the velocity at a point in an open channel cross section 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.

6. Interferences

6.1 As with any intrusive flow measuring device, rotating element current meters are subject to damage by debris, especially in high velocity flows, and to fouling by floating materials such as aquatic growths and sewage.

6.2 Owing to bearing friction, each rotating element current meter has a limiting low velocity below which it does not function reliably. This velocity is different for each type of

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

[3] Published by International Standards Organization and available from American National Standards Institute, 11 W. 42nd St., 13th floor, New York, NY 10036.

[4] The boldface numbers refer to the list of references at the end of this test method.

meter but, in general, % errors tend to become large as the velocities decrease below 0.1 to 0.2 ft/s (0.03 to 0.06 m/s).

7. Apparatus

7.1 *Current Meters*— Rotating element current meters consist of a rotating element with shaft and bearings, a mechanism for detecting and registering revolutions, and a frame which supports the foregoing elements and provides for suspension of the meter and the insertion of stabilizing fins if needed. Current meters covered by this test method do not customarily incorporate direction-measuring devices.

7.1.1 *Rotor Configuration*—Horizontal-axis meters have propeller-type rotors comprised of two or more blades. Interchangeable elements of different pitch or diameter can be used to cover a wider range of velocities. Vertical-axis meters have a rotating wheel made up of several cup-type or vane-type elements. Rotors employing six conical cups (for example, Price-type meters) are frequently used but other configurations are permissible provided the following requirements are met:

7.1.1.1 The relation between velocity and rotation rate must be stable, that is, there should be no significant uncertainties in the meter's rating curve due to unstable flow separations at the cups or similar hydrodynamic causes.

7.1.1.2 If fractions of revolutions are to be registered, the angular movement of the rotor must be the same during each measured fraction.

7.1.2 *Bearings*:

7.1.2.1 Bearing design shall permit the meter to be used in sediment-laden water, without affecting the accuracy of the meter.

7.1.2.2 If a particular oil is required for bearing lubrication, the supplier shall furnish it with the instrument. Information for obtaining replacement oil shall also be furnished.

7.1.2.3 At the highest velocity claimed for the meter, properly maintained bearings shall function without adversely affecting meter performance for a period of time customarily associated with normal use or for the period of time between recommended recalibrations. If bearing replacement is needed to meet this requirement, such replacement shall be possible in the field.

7.1.2.4 At the lowest velocity claimed for the meter, properly maintained bearings shall function consistently and not contribute to undue deviations in meter response.

7.1.2.5 No breaking-in period for the bearings shall be required after meter delivery.

7.1.3 *Registering Revolutions*—The current meter shall be equipped with a mechanism which detects and signals either single revolutions of the rotor or known fractions or multiples thereof. This detection can be by mechanical-electric contact, by magnetic, optical, or other methods, and shall produce a signal which is audible, visible, or recordable by other means.

7.1.3.1 A mechanical-electric contact device shall not add in any significant manner to the internal friction at the lowest velocity claimed for the meter.

7.1.3.2 The contact device must always actuate the signal at precisely the same position in each revolution (fraction or multiple).

7.1.3.3 If the revolution count is to be made manually by the operator, the audible or visual signals (as distinguished from recorded signals) shall not occur at a frequency greater than 3, and preferably 2.75, cps.

7.1.3.4 A timing device is a necessary adjunct to the meter so that the revolution rate can be determined from the revolution count. In the simplest configuration this system can consist of a manual stopwatch for timing audible or visual signals.

7.1.3.5 If the current meter system has a direct readout in velocity units, the user must be furnished an accuracy statement which includes the readout. Also, the user must be provided with a procedure to check for system malfunctions.

7.1.4 *Frame*—The frame houses the current-meter elements and provides for suspending the meter in the flow. Depending upon the intended use of the meter, the frame can be designed for suspension by rigid rod only, by cable-and-weight only, or it can provide for both types of suspension.

7.1.4.1 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 meter position along the rod. Fixed rod position is necessary for some applications, such as for measuring through ice cover. Rods must be provided with suitable fixtures to accommodate fins as specified in 7.1.4.3.

7.1.4.2 The connection for cable suspension shall permit the meter to swivel in a vertical plane so that it can seek and maintain a horizontal orientation.

7.1.4.3 *Fins*—Meters to be suspended by cable must provide for stabilizing fins to be inserted into the frame. Provision shall be made for balancing the meter-fin unit about its pivot while immersed in water, so that it can operate in a level position at all velocities claimed for the meter.

7.1.5 *Other General Requirements*:

7.1.5.1 The meter design and construction shall be sufficiently sturdy for normal field use and the materials shall be usable in normally encountered fresh and saline waters without undue corrosion or wear.

7.1.5.2 The meter shall offer low resistance to the flow and must be able to maintain a stable position with respect to the flow.

7.1.5.3 Meter parts shall be interchangeable among other meters of the same model and manufacturer. The manufacturer shall state which parts can be replaced without requiring recalibration.

7.1.5.4 Design features which permit minor repairs or parts replacement by the user in the field are encouraged. Any special purpose tools needed for such repairs or replacement shall be furnished with the meter.

7.1.5.5 For high-inertia, vertical-axis meters, spin test durations shall be recommended for effective use of the meters at their lowest claimed velocity. See Refs **(1-3)** for Price-type meters. Users shall be provided with alternative procedures for qualitative indications of internal friction in meters that are not amenable to spin testing.

7.1.5.6 The user shall be provided with the means (detailed dimensions, templates, or forms) to ascertain gradual changes in rotor configuration, where appropriate. See also 10.2.

7.1.5.7 Information on depth (pressure) limitation on meter submergence and on temperature effects, if any, on meter performance shall be furnished by the manufacturer.

7.2 *Suspension Equipment*—Description and requirements for suspension equipment are available in Refs **(2, 3)** and ISO 3454. This test method includes only those elements which directly affect the meter performance.

7.2.1 *Rods*—The rod for which the meter rating is valid, if not furnished with the meter, shall be precisely specified with regard to dimensions and configuration.

7.2.2 *Cable and Weight*:

7.2.2.1 The cable suspension system for which the meter rating is valid, if not furnished with the meter, shall be precisely specified with regard to dimensions and configuration, including dimensions of the sounding weight, its distance from the meter, connecting strap details, cable dimensions, etc.

7.2.2.2 The weight shall offer minimal resistance to the flow and should be able to maintain a stable and level position. It shall be so shaped that the current meter is not subject to shed eddies or other instabilities; and it shall be heavy enough to avoid excessive downstream deflection of the cable, particularly in deep and swift currents. If some deflection is unavoidable, tables for air-line and wet-line corrections are available.

7.2.2.3 The suspension cable preferably shall be reverse-lay sounding cable to minimize torque on the immersed meter and weight. However, even this type of cable may cause or allow meter yaw and subsequent meter registration errors for Price-type current meters in velocities below 1.00 ft/s (0.305 m/s).

7.2.2.4 For protection of the meter it is preferable that the weight be mounted below the meter.

8. Sampling

8.1 Sampling, as defined in Terminology D 1129, is not applicable in this test method. Sampling to obtain a reliable measurement of average velocity in a cross section is covered in Test Method D 3858.

9. Calibration

9.1 *General Calibration Requirements*:

9.1.1 The range of calibration velocities ideally includes the minimum and maximum velocities claimed for the meter. Practically, most calibration (rating) facilities cannot achieve this range of velocities and are limited to 0.10 ft/s (0.03 m/s) to 12 ft/s (3.66 m/s). Calibrations at those minimum and maximum possible velocities, along with enough intervening points, typically describe a rotation rate-velocity relation that brackets values commonly found in flowing streams. For the rare cases where current meters are used to measure faster velocities, linear upward extension can be made with minimal accuracy degradation. Downward extrapolation may result in larger errors, due to variable stall rates of individual meters. Provide the rating to the user in the form of an equation, table, or graph. Furnish an estimate of the accuracy.

9.1.2 Make individual calibrations, using the same suspension with which the meter is to be used in the field. See 7.2.1 and 7.2.2.1.

9.1.3 If a propeller meter is intended to respond only to the velocity component along the meter axis, provide calibration information on this capability for the usable range of approach angles claimed for the meter.

9.1.4 Recalibrate meters when their performance is suspect. Some organizations establish routine recalibration policies, such as annually or based on hours of use. In the case of instruments made to stringent specifications, repairs and parts replacement may be made without recalibration requirements.

9.2 *Towing Tank Calibration*—Current meters usually are calibrated (rated) in a towing tank. Guidelines for this type of calibration are given in ISO 3455.

9.3 *Water Tunnel Calibration*—Current meters also can be calibrated in flowing water—in a facility that provides a uniform velocity distribution in a test area large enough to avoid blockage effects, provided that the accuracy of the system is demonstrably high. If this procedure is used, provide some indication of the scale and intensity of the turbulence.

9.4 *Group Ratings*— A rating equation provided by a manufacturer for a specific type of current meter is sometimes used in place of an individual calibration equation.

9.4.1 Base group ratings can be made, based on individual ratings of a significant number of meters with specified type of suspension **(4)**. Preferably both new and well-maintained used meters should be included. Make the size, make-up, and standard deviation of the sample known to the user.

9.4.2 A group rating pertains only to current meters manufactured in a specific manner. Any change in the manufacturing process requires reexamination of the group equation and appropriate adjustment if needed.

10. Field Use and Maintenance

10.1 *Spin Tests* (see also 7.1.5.5):

10.1.1 Make spin tests for meters that are amenable to spin tests at least once during each day's use. More frequent testing is recommended when velocities are low, when silt concentration is high, or a meter malfunction is suspected.

10.1.1.1 Spin tests must be made with the meter supported in a level and wind-free environment. The spin shall meet the specified duration after a firm manual start and shall come to a gradual stop. Spin duration information must be supplied by the manufacturer for a specific meter. Some organizations provide spin duration requirements for meter types that they use extensively, such as those given in Refs **(1-3)** for open-cup metal rotor Price-type meters.

10.1.1.2 Repair or replace meters which fall short of the specified spin duration.

10.1.2 For meters that are not amenable to spin testing, users must develop alternative tests for monitoring performance if such tests were not provided by the manufacturer under 7.1.5.5.

10.2 Examine the meters for obvious rotor dents or deformations after each use. Such rotor damage can affect the rating and may be an indicator of additional, less visible damage to the meter mechanism. Rotor replacement, repair or replacement of other parts, and recalibration, either alone or in some combination, will be required.

10.3 Examine the meters periodically during the course of a discharge measurement, for debris or damage which may affect performance of the meter, in addition to checks before and after use.

10.4 Provide instructions for routine maintenance, such as disassembly, cleaning, or lubrication after each use. Clean, lubricate, and check after each day's use, in default of more specific instructions. See Ref **(1)** for Price-type meter maintenance.

10.5 Make provisions to minimize wear on bearings or stress on other meter parts during transport and storage. Provide a suitable carrying case to protect the meter when not in use.

10.6 Field use and operational methods are described in Test Method D 3858.

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 the temporal and spatial variability of open-channel flow. Any estimate of these errors could be very misleading to the user.

11.2 Under the allowances made in 1.5 of Practice D 2777 – 86, these precision and bias data do meet existing requirements for interlaboratory studies of Committee D-19 test methods. An exemption to the precision and bias statement required by D 2777 was recommended by the Results Advisor and concurred with by the Technical Operations Section of the D-19 Executive Subcommittee on June 15, 1990.

11.3 The towing-tank performance of an individually calibrated current meter can be described by its rating equation to within 1 % of the actual velocity with slightly higher deviations possible at the low velocities. However, in field use numerous error sources are recognized. The resulting errors have not been completely quantified but the following paragraphs are cited as possible sources of errors.

11.3.1 *Turbulence and Pulsations*—Current meters are usually calibrated by towing in still water but are used in turbulent flowing water. The effect of small scale (relative to cup size) turbulence on vertical axis meters has not been fully evaluated **(5)**. Flows with obviously intense turbulent eddying shall be avoided where possible. Based on present knowledge, turbulence effects cannot be quantified but can be minimized with the use of a low inertia propeller-type meter with blades of high aspect ratio (square of the difference between outer diameter and hub diameter divided by blade area) **(6)**.

11.3.2 *Platform Motions*— Guidelines on errors introduced by vertical motions, such as those associated with wave-induced boat motions, are given for selected vertical-axis and horizontal-axis meters in Ref **(7)**. Generally these errors become more important with lower stream velocities.

11.3.3 *Velocity Gradients*—Cup-type vertical axis meters can be expected to over-register or under-register (with reference to the velocity at the axis) in the presence of a lateral velocity gradient, depending upon whether the velocity increases toward the open or closed face of the cup or drag element **(8)**. Velocity-gradient effects on propeller-type meters have not been investigated.

11.3.4 *Boundaries*—Current meters can be affected by solid boundaries because of the flow gradients existing there and because of a direct proximity effect. Price and Pygmy-meter surface restrictions are cited in Ref **(2)**. Proximity effects on propeller meters are generally less than those of vertical axis meters **(9)**.

11.3.5 *Velocity Direction*—Current meters shall be oriented with the oncoming velocity filament to avoid misalignment errors. If a velocity component in another direction is required, the angle between the meter and the desired direction shall be measured independently and a cosine factor applied. Misalignment errors due to vertically angled flows cannot be corrected for in most meters. Price AA-type meters tend to underregister when the pitch angle with respect to the flow streamline exceeds 2.5 degrees **(10)**. Flows with obvious vertically angled velocity filaments shall be avoided where possible **(11)**. Exceptions are propeller meters equipped with component propellers (see 9.1.3).

11.3.6 *Temperature*— Response of some meters can be affected by temperature-induced viscosity changes in meter lubricating oil. See Ref **(9)** and 7.1.5.7.

11.3.7 The errors and uncertainties presented in 11.3 must be considered in addition to errors and uncertainties inherent in the rating equation.

12. Keywords

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

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