ASME MFC-16–2014
(Revision of ASME MFC-16–2007)

Measurement of Liquid Flow in Closed Conduits With Electromagnetic Flowmeters

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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The American Society of Mechanical Engineers
Two Park Avenue • New York, NY • 10016 USA

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The American Society of Mechanical Engineers
Two Park Avenue, New York, NY 10016-5990

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FOREWORD

This Standard was prepared by Subcommittee 16 of the ASME Committee on the Measurement of Liquid Flow in Closed Conduits. The chair of the subcommittee is indebted to the many individuals who contributed to this document.

Electromagnetic flowmeters were introduced to the process industries in the mid 1950s. They quickly became accepted flowmeters for difficult applications. Subsequent improvements in technology and reductions in cost have transformed these flowmeters into one of the leading contenders for general use in water-based and other electrically conducting liquid applications.

Due to differences in design of the various electromagnetic flowmeters in the marketplace, this Standard cannot address detailed performance limitations in specific applications. It covers issues that are common to all meters, including application considerations.

The flow industry has been changing from the use of the names "primary" and "secondary" to "sensor" and "transmitter." Previous editions of ASME MFC-16 did use primary and secondary in their figures and text. This new edition uses the sensor and transmitter terminology.

Suggestions for improvement of this Standard will be welcomed. They should be sent to The American Society of Mechanical Engineers; Attn: Secretary, MFC Standards Committee; Two Park Avenue; New York, NY 10016-5990.

This revision was approved an an American National Standard on January 28, 2014.

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Measurement of Fluid Flow in Closed Conduits

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Secretary, MFC Standards Committee
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Proposing Revisions. Revisions are made periodically to the Standard to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the Standard. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this Standard. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

Proposing a Case. Cases may be issued for the purpose of providing alternative rules when justified, to permit early implementation of an approved revision when the need is urgent, or to provide rules not covered by existing provisions. Cases are effective immediately upon ASME approval and shall be posted on the ASME Committee Web page.

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Subject:	Cite the applicable paragraph number(s) and the topic of the inquiry.
Edition:	Cite the applicable edition of the Standard for which the interpretation is being requested.
Question:	Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. The inquirer may also include any plans or drawings that are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in this format may be rewritten in the appropriate format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

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MEASUREMENT OF LIQUID FLOW IN CLOSED CONDUITS WITH ELECTROMAGNETIC FLOWMETERS

1 SCOPE

This Standard is applicable to industrial electromagnetic flowmeters and their application in the measurement of liquid flow. The electromagnetic flowmeters covered by this Standard utilize an alternating electrical current (AC) or pulsed direct-current (pulsed-DC) to generate a magnetic field in electrically conductive and electrically homogeneous liquids or slurries flowing in a completely filled, closed conduit.

This Standard does not cover the following:

- insertion-type electromagnetic flowmeters
- electromagnetic flowmeters used in surgical, therapeutic, or other health and medical applications
- applications of industrial flowmeters involving nonconductive liquids
- highly conductive liquids (e.g., liquid metals)

2 REFERENCES

The following document forms a part of this Standard to the extent specified herein. The latest edition shall apply.

ISO 13359, Measurement of conductive liquid flow in closed conduits — Flanged electromagnetic flowmeters — Overall length

Publisher: International Organization for Standardization (ISO) Central Secretariat, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Genève 20, Switzerland/Suisse

3 DEFINITIONS AND SYMBOLS

3.1 Definitions

accuracy of measurement: closeness of the agreement between the result of a measurement and a true value of the measurand.

NOTE: Accuracy is a qualitative concept; for the quantitative concept, see *uncertainty.*

calibration: the experimental determination of the relationship between the quantity being measured and the device that measures it, usually by comparison with a standard, then (typically) correcting the output of that device to bring it to the desired value, within a specified tolerance, for a particular value of the input.

flowmeter sensor: includes the flow tube, process connections, electromagnetic coils, and electrodes. Flowmeter sensor is also known by other names, e.g., flowmeter sensor device, sensor device, and sensor.

flowmeter transmitter: includes the electronic transmitter, measurement of the emf_v, and, in most cases, the power for the electromagnet coils of the flowmeter sensor.

meter factor: the number determined by liquid calibration that enables the output flow signal to be related to the volumetric flow rate under defined reference conditions; often expressed as the reciprocal of mean *K*-factor.

uncertainty (of measurement): parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand.

verification: provision of objective evidence that a given item fulfills requirements.

EXAMPLE: Use of independent flow calibration to confirm that performance properties and/or legal requirements of a measuring system are met.

3.2 Symbols

See Table 3.2-1.

4 THEORY AND MEASUREMENT TECHNIQUE

Industrial electromagnetic flowmeters are composed of the following basic components (see Fig. 4-1):

(a) a nonmagnetic tube with a nonconductive inner surface

(b) a magnetic field passing through the tube and perpendicular to the axis of the tube at the center of the flow tube

(c) a minimum of two electrodes on opposite sides of the tube in a cross-sectional plane passing through the center of the flow tube, the straight line between these two electrodes being perpendicular to the magnetic field at the center of the flow tube

4.1 Flow-Related Electromotive Force

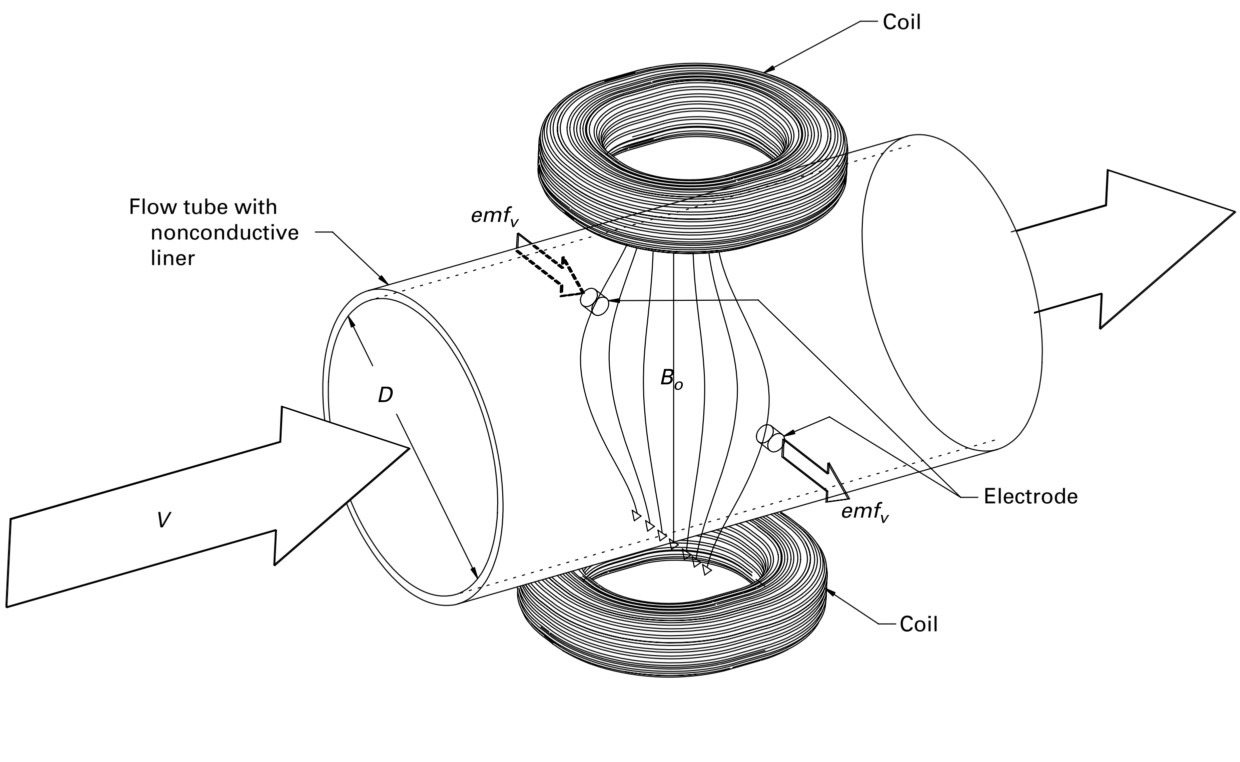
Faraday's law of induction applied to this physical configuration predicts the generation of an electromotive force (a voltage) between the electrodes when a

Table 3.2-1 Symbols

	Quantity	Dimensions [Note (1)]	SI Units	U.S. Customary Units
C	A dimensionless parameter that depends on the specific design of the flowmeter (see section 4)	. . .	. . .	. . .
D	Inner diameter of the flow tube	L	m	in.
K	Meter factor, typically determined by liquid flow calibration	$M^{-1}LT^{2}I$	m^3/s/volt	ft^3/sec/volt
V	Flow velocity	LT^{-1}	m/s	ft/sec
B_o	Average magnetic field between the electrodes	$MT^{-2}I^{-1}$	tesla	. . .
q	Flow rate, volumetric	L^3T^{-1}	m^3/s	ft^3/sec
emf	Electromotive force	$ML^2T^{-3}I^{-1}$	volt	volt
emf_c	Electrochemical electromotive force	$ML^2T^{-3}I^{-1}$	volt	volt
emf_v	Velocity-related electromotive force	$ML^2T^{-3}I^{-1}$	volt	volt
emf_t	Transformer-related electromotive force	$ML^2T^{-3}I^{-1}$	volt	volt
emf_F	Electromotive force per Faraday's Law	$ML^2T^{-3}I^{-1}$	volt	volt

NOTE:
(1) Dimensions: M = mass, L = length, T = time, I = current.

Fig. 4-1 Industrial Electromagnetic Flowmeters



conductive liquid flows through the flow tube. This electromotive force is

$$emf_v = CDB_oV \tag{4-1}$$

where

B_o = magnetic field at the center of the flow tube, tesla
C = a dimensionless parameter that depends on the specific design of the flowmeter
D = inner diameter of the flow tube, m
emf_v = electromotive force, V
V = flow velocity (average axial liquid velocity in a cross-sectional plane of the flow tube), m/s

For added details on the theory and measurement techniques related to electromagnetic flowmeters, see Nonmandatory Appendix A.

4.2 Interfering Sources of Electromotive Force

In addition to the above flow-related electromotive force, emf_v, two other sources of electromotive force exist in modern industrial electromagnetic flowmeters that may interfere with the measurement of emf_v. They are the electrochemical electromotive force, emf_c, and the sensor transformer electromotive force, emf_t. Since both of these may be similar to or larger than emf_v in magnitude, using an alternating electromagnetic field and interval sampling techniques avoids interference to the flow signal, emf_v, from these other two sources. Figure 4.2-1 illustrates three basic methods for alternating the electromagnetic field. For additional information about both emf_c and emf_t, see Nonmandatory Appendix A.

4.3 Types of Electrodes

An alternating electromagnetic field generates an alternating emf_v. The following types of electrodes are used with an alternating electromagnetic field:

(a) wetted electrodes that protrude through the pipe wall/liner into the flow stream [see Fig. 4.3-1, illustration (a)]

(b) nonwetted (capacitive) electrodes located behind or within the tube wall/liner [see Fig. 4.3-1, illustration (b)]

4.4 Calculation of Volumetric Flow Rate

From eq. (4-1), the flow velocity is given by

$$V = emf_v/CDB_o$$

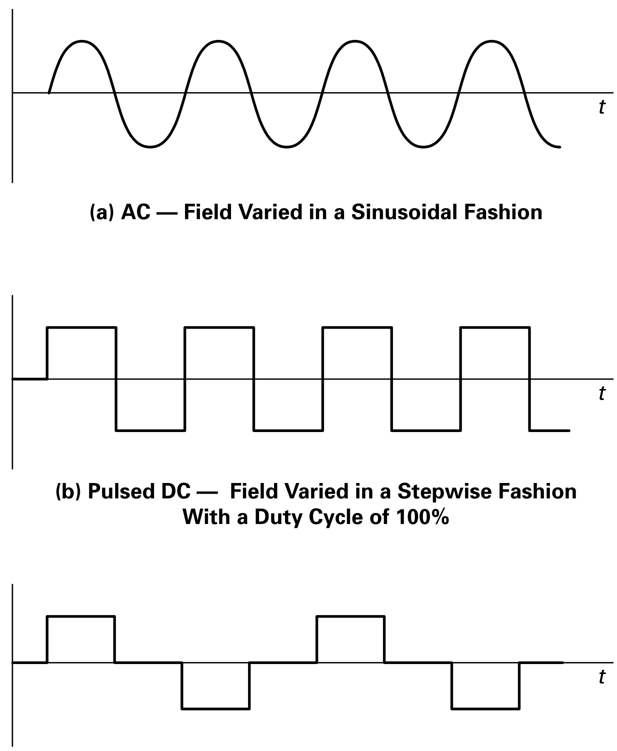
The volumetric flow rate, q, is calculated by

$$q = \pi D^2 V/4$$

Combining these two equations,

$$q = \pi D \cdot emf_v/4CB_o$$

Fig. 4.2-1 Examples of Electromagnetic Field (B_o) Variation With Time

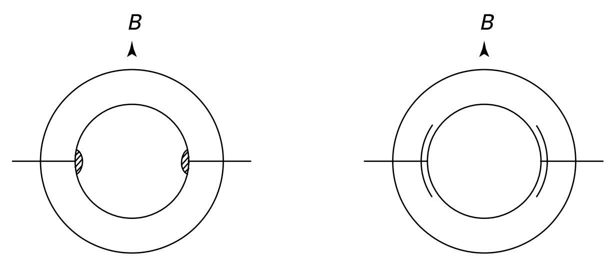


(a) AC — Field Varied in a Sinusoidal Fashion

(b) Pulsed DC — Field Varied in a Stepwise Fashion With a Duty Cycle of 100%

(c) Pulsed DC — Field Varied in a Stepwise Fashion With a Duty Cycle Less Than 100%

Fig. 4.3-1 Examples of Electrodes for an Electromagnetic Flowmeter



(a) Wetted **(b) Nonwetted**

Because the diameter, D, dimensionless parameter, C, and the magnetic field, B_o, are fixed in each individual meter, these values can be grouped together in a single factor that is determined through calibration. Thus,

$$q = K \cdot emf_v$$

where

K = meter factor, $m^3/s/V$

5 FLOWMETER DESCRIPTIONS

5.1 Flowmeter Sensor

The flowmeter sensor must be designed and selected to be an integral portion of the piping system (see para. 6.4). It consists of the following:

(a) a flow tube with a nonconductive inside surface
(b) a means for integrating it into the pipeline
(c) electromagnetic field coils
(d) two or more sensing electrodes that may be wetted or nonwetted (see Fig. 4.3-1)
(e) a housing to protect the coils and electrodes from damage and moisture

It may also include grounding electrodes or grounding rings, which are used to ground the process and the flowmeter sensor together, as required by the application, piping system, or design of the flowmeter. Nonconductive piping systems or piping systems with a nonconductive liner, in particular, require some method of grounding the process to the flowmeter.

Some special application flowmeter sensors are independently powered from regular AC circuits. These flowmeter sensors must contain the needed circuitry for this power arrangement. These special application flowmeter sensors have power requirements beyond that available from normal application flowmeter transmitters.

Flowmeter sensors come in a variety of sizes depending on the flow rate; some inside diameters are as small as 0.04 in. (1 mm), while others can be over 100 in. (2 500 mm).

Flanges are the most common method of attaching the flowmeter sensor to the pipeline. Other attachment methods include victaulic couplings or tri-clamp connections. Another variation of the flowmeter sensor is a wafer flowmeter that is installed between the pipeline flanges. ISO 13359 specifies overall length (lay length face to face) for flanged electromagnetic flowmeters. The lay lengths specified in the ISO document are for lower-pressure systems rather than higher-pressure systems. The manufacturer shall provide a reasonable clearance between the rear face of the flange and the meter housing for installation and removal.

5.2 Flowmeter Transmitter

The flowmeter transmitter consists of the electronic transmitter and its housing, which may be mounted either integral with the flowmeter sensor or remotely. If the flowmeter transmitter is mounted remotely from the flowmeter sensor, it may be necessary to have separate electrical connection housing, terminals, and preamplifier mounted on the flowmeter sensor. The flowmeter transmitter measures the emf_v voltage at the electrodes of the flowmeter sensor, provides the output from the meter, and in most cases provides power to the coils.

5.3 Flowmeter Transmitter Outputs

The output from the flowmeter transmitter may include one or more of the following: an analog signal (i.e., 4–20 mA DC), a pulse output (frequency), or a digital signal. The outputs can be scaled to represent units of flow. The digital signal can be used to connect to one of the various bus protocols (manufacturer dependent). Other optional outputs include solid-state or mechanical contact closures that can be used for totalizing or system control. Some designs also offer the option of visual indication of flow rate and/or totalized flow in numerical or graphical form.

6 APPLICATION CONSIDERATIONS

6.1 Process Liquid

6.1.1 Liquid Electrical Conductivity. Electrical conductivity is a simple way of expressing the ability of a liquid to conduct electricity. If the electrical conductivity of the liquid is uniform and above a specified minimum value, usually between 5 μS/cm and 20 μS/cm, the meter output will generally be independent of the liquid conductivity. The manufacturer shall specify the minimum liquid conductivity required for the flowmeter to function.

If the conductivity gradient is not uniform throughout the meter, flow measurement errors will occur. Thoroughly mix nonhomogeneous flow streams. Heterogeneous liquids, such as slurries or pulp stocks, composed of small particles uniformly distributed in a liquid, are electrically homogeneous liquids.

6.1.2 Noisy Flow Signal. Expect excessive flow signal noise in the following situations:

(a) when measuring the flow of a slurry or pulp stock
(b) when triboelectric effects are present (see para. 6.2.3)
(c) with large variations in liquid conductivity
(d) with air entrained in the liquid
(e) with incomplete chemical mixing
(f) with improper wiring methods

6.2 Effects of Process Properties and Flow Profiles

6.2.1 Velocity Profile Effect. Pipe fittings (such as bends, valves, reducers, etc.) located upstream or downstream of the flowmeter may cause distortions in velocity profile. The distorted flow patterns may influence the performance of the meter (see para. 6.4.1.1).

6.2.2 Slippage. When solids move at velocities different from the flowing liquid, slippage occurs. In vertical installations with an upward flow direction, settling solids can cause the electromagnetic flowmeter to underregister or, in extreme cases, appear as zero or reverse flow. Conversely, in vertical installations with a normally downward flow direction, settling solids can cause the electromagnetic flowmeter to over-register. Consult the manufacturer for all slurry applications.

6.2.3 Triboelectric Effect. The triboelectric effect (static electricity) is an electrical phenomenon with friction charging the materials. The triboelectric effect in electromagnetic flowmeters occurs when certain materials (typically nonconducting, e.g., silicates and petroleum-based liquids or solids) deposit an electrical charge on the electrodes of the meter. These charges can introduce errors and/or electrical noise. Consult the manufacturer when applications include nonconductive particles.

6.3 Flowmeter Sensor — Sizing Considerations

6.3.1 General Considerations. Many electromagnetic flowmeters have relatively wide turndown, so it is generally feasible to select a flowmeter sensor of the same size as the adjacent piping. Liquid velocity range, upstream and downstream piping, and other flow considerations should be the basis in choosing the meter diameter for a given application.

6.3.1.1 Manufacturer-Specified Accuracy. Manufacturers must specify the flowmeter accuracy over the liquid velocity range of the flowmeter sensor. If a low-velocity condition exists, it may be desirable to size the meter at less than the nominal process piping size to increase the velocity (see para. 6.4.2.4).

6.3.1.2 Pipe Mismatch. Nonuniform entrance and exit conditions, such as inlet–outlet and liner internal diameter (ID) mismatches, may cause changes in the velocity flow profile, which may cause additional flow measurement errors. Of particular concern is the "jet effect" that occurs when the pipe immediately preceding and following the flowmeter sensor has an ID less than that of the flowmeter sensor (see para. 6.4.2.4).

6.3.1.3 Abrasive Slurries. Excessive wear should be a consideration for increasing the pipe diameter in the measuring section of the piping (i.e., the flowmeter sensor, and the preceding and following piping) to reduce the liquid flow velocity.

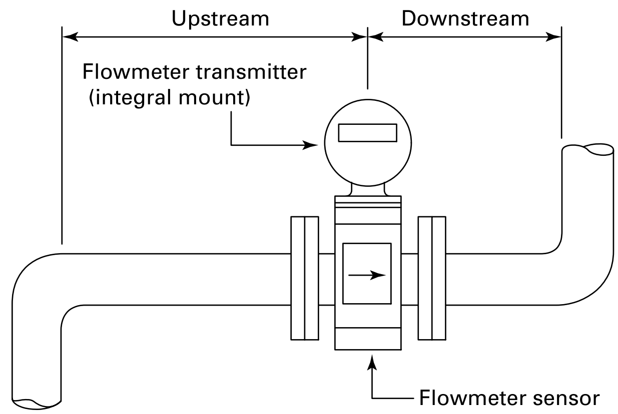
NOTE: Excessive liner wear can be caused by an asymmetrical flow profile (see para. 6.2.1), improper liner material selection (see para. 6.5.2), or horizontal installation of the flowmeter sensor (see para. 6.4.1.3).

In particular, the upstream edge of the liner may be subject to wear from abrasive slurries. To minimize this upstream edge wear, it is beneficial to match the internal diameter of the flowmeter sensor and the near upstream piping. The installation of metal protection rings reduces the wear on the edge of the liner.

Ceramic liners may have less wear from abrasive slurries.

Consult the manufacturer for guidance regarding materials of construction and installation experience for applications with abrasive slurries.

Fig. 6.4-1 Electromagnetic Flowmeter System



6.3.1.4 Fast-Settling Slurries. Velocities through horizontally mounted flowmeters should keep slurry solids in suspension. If solids are prone to settle during no-flow conditions, there must be sufficient velocity to flush the settled materials from the flowmeter sensor at startup.

6.3.2 Special Process Considerations. There may be situations where it is desirable to size the flowmeter at other than the pipe size. When this is the case, consider process liquid properties and the velocity ranges of the flowmeter. As a matter of practice, applications utilizing small meters [½ in. (12 mm) and less] are more sensitive to pipe mismatch effects than larger meters.

6.4 Flowmeter Sensor — Location, Installation, and Maintenance

In order to meet the manufacturer-specified accuracy, electromagnetic flowmeters require straight pipe upstream and downstream of the flowmeter sensor, as shown in Fig. 6.4-1. Flowmeter manufacturers specify piping requirements in piping diameters. The piping diameters specified depend on the type of disturbance upstream of the flowmeter. Manufacturers may specify measurement of these piping diameters from the flange end of the flowmeter or from the center of the flowmeter.

6.4.1 Flowmeter Sensor Location and Orientation. Generally, there are no restrictions on flowmeter sensor orientation (horizontal, vertical, or inclined); however, it is essential that the flowmeter sensor be full of the process liquid to ensure proper performance.

Location and orientation of the flowmeter sensor with respect to the process piping affect the performance of the flowmeter. Consider the points in paras. 6.4.1.1 through 6.4.1.5.

6.4.1.1 Piping Effects. When a flow velocity profile is different from that of the profile for the original flow calibration, the electromagnetic flowmeter may exhibit a change in performance. The arrangement and location of pipe fittings, valves, pumps, etc., upstream and downstream of the flowmeter sensor, are the main factors that influence the velocity profile. The manufacturers must specify upstream and downstream lengths of straight pipe of the same diameter as the flowmeter sensor for proper performance.

Swirling flow can introduce flow measurement errors. Consider the use of a swirl-reducing flow conditioner with known or suspected swirling flow.

6.4.1.2 Full Pipe Requirements. It is necessary that the flowmeter sensor and process pipe remain full of the process fluid. Install the flowmeter sensor in one of the following locations:

- a horizontal pipe run (with a slight upward slope or an upward turn)
- a low point of a pipe run
- a vertical pipe run with the flow upward

Avoid installation in a high point of a pipe run or in a vertical run with the flow down.

If the meter is not full, the application is beyond the scope of this Standard and the meter performance may have increased uncertainty.

6.4.1.3 Electrode Position — Horizontal Installations. Since gas bubbles in a horizontal pipe tend to rise and may collect at the top of the pipe, the flowmeter sensor should be mounted so that neither the sensing nor the grounding electrodes are located at or near the top of the pipe. Similarly, since solids in a horizontal pipe tend to settle and collect at the bottom of the pipe, the flowmeter sensor should be mounted so that neither the sensing nor the grounding electrodes are located at or near the bottom of the pipe.

6.4.1.4 In-Situ Zero Checking. To check AC-pulsed systems' zero in-situ, manufacturers require that the flowmeter sensor remain completely filled with stationary liquid. For DC-pulsed meter systems, review the manufacturer's instructions.

6.4.1.5 Location With Regard to Electrical Interference. It is important to locate the flowmeter sensor away from any electromagnetic or electrostatic fields. These fields can cause disturbances in normal operation. Therefore, it is important to locate the flowmeter sensor away from transformers, large electrical motors, and communication equipment. See paras. 6.4.3 and 6.7.

6.4.2 Installation of Flowmeter Sensor

6.4.2.1 Installation Design. Consider designing the piping system with access for installation and removal of the flowmeter sensor. Follow local piping codes and user-specified procedures during construction and installation to minimize the strain on the flowmeter sensor. The installation should allow ready access to all mechanical and electrical connections.

6.4.2.2 Handling of the Flowmeter Sensor. Use slings on lifting lugs on the flowmeter exterior. Avoid lifting by means that could damage the interior of the flowmeter sensor, pressure boundary, electrodes, electrical connections, or the meter liner. This includes, but is not limited to, lifting the meter by means of a forklift tine, chain, or rope being passed through the meter body. Consult the manufacturer for detailed installation instructions.

6.4.2.3 Pipe Alignment and Connections. Piping allowances must account for the length of the meter, gaskets, and grounding rings. Align the upstream and downstream connecting pipes. Support the flowmeter system to minimize vibration.

6.4.2.4 Transition Piping. When the pipeline is a different diameter than that of the flowmeter sensor, it is advisable to use concentric reducers or expanders, upstream and downstream, to effect a gradual transition from one diameter to another. They should be installed at locations that conform to the manufacturer's recommended minimum upstream and downstream straight pipe run. Note that in many applications, shallow-taper reducers provide lower permanent pressure loss and flow profile disturbance effects than standard reducers or expanders. Consult the manufacturer for recommended meter installation.

6.4.3 Electrical Considerations

6.4.3.1 Flowmeter Sensor, Flowing Liquid, and Process Piping Electrical Potential. The metered liquid, the flowmeter sensor, and the flowmeter transmitter should be at the same electrical potential. The preferred potential is earth potential (grounded). The manufacturer's instructions for interconnections between the flowmeter sensor and flowmeter transmitter devices should be followed as defined.

The electrical connection between the process liquid and the flowmeter sensor body may be achieved by contact with the connecting pipe, or by conductive grounding (earthing) rings. Since proper grounding is essential, special consideration must be given if lined or nonconductive pipe is used. Consult the manufacturer for detailed grounding instructions. See para. 6.7.

6.4.3.2 Cathodic Protection. If a pipeline is cathodically protected to reduce or eliminate corrosion, precautions are necessary to ensure that the cathodic current does not affect the performance and stability of the flow measurement system. In such cases, the relevant electrical codes, user's practice, and manufacturer's recommendations must be followed.

6.4.4 Coatings and Deposits. If materials are deposited from the process liquid onto the electrodes or the walls of the meter tube, the performance of the meter will be affected. Correct flow-tube sizing for optimum flow velocity, and changing the flow profile, can minimize electrode coating. Provision can be made for cleaning the electrodes by electrical, chemical, ultrasonic, or mechanical methods during the system design. This can often be accomplished with the flowmeter installed, but sometimes the meter must be removed. Manufacturers should be consulted for the various options available.

6.5 Flowmeter Sensor — Materials of Construction

6.5.1 General Guidelines. Materials used for construction are selected based on their ability to withstand both internal and external conditions.

(a) Internal

(1) abrasion — high velocity flows with sand or silt

(2) chemical — corrosive liquids

(3) pressures — vacuum can cause liner separation

(4) temperature — rapid changes will crack some liners

(b) External

(1) submersible — vault or low-lying areas may require watertight housings

(2) buried — groundwater and cathodic protection

(3) chemical — corrosive liquids

(4) exposure — temperature extremes, ultraviolet light, corrosive atmosphere

6.5.2 Liner Materials. The liner must electrically isolate the flowmeter sensor. The selection of liner material is based on its ability to resist damage/wear from the process media. Some examples and general application guidelines for liner materials are found in Nonmandatory Appendix B.

6.5.3 Electrode Materials. The electrodes material is selected based on ability to resist oxidation, corrosion, or pitting by the process. Examples of electrode materials include stainless steel, Hastelloy® C, platinum, platinum/iridium, tantalum, titanium, and zirconium.

6.6 Flowmeter Transmitter — Installation

The flowmeter transmitter should be installed in an accessible position with regard being given to the manufacturer's specifications.

6.7 Electrical Installation

If the flowmeter transmitter is not mounted directly to the flowmeter sensor, the signal cable between the flowmeter sensor and flowmeter transmitter must meet the manufacturer's specifications and the user's area electrical specifications.

6.8 Safety

6.8.1 Electrical Safety. The flowmeter sensor and flowmeter transmitter of the metering system must be designed, manufactured, and certified to meet or exceed the electrical classification for the area in which the meter will be installed.

Cabling supplied by manufacturers to connect sensors and transmitters must meet or exceed user safety codes and electrical classifications for the installation area.

6.8.2 Mechanical Safety. The meter body, which is an integral portion of the piping system, must be designed, manufactured, and certified to meet or exceed user specified requirements and industry standards for piping codes (i.e., ASME B31 series, etc.). Maximum possible and normal operation pressures, temperatures, and vibrations must be considered when specifying the mechanical requirements of the flowmeter sensor. Piping supports need to be incorporated into the system in order to accommodate the added weight of the meter and resist excessive vibration.

7 EQUIPMENT MARKINGS

7.1 Introduction

The flowmeter sensor and flowmeter transmitter should be marked either directly or on an attached nameplate.

7.2 Flowmeter Sensor

Mark the following:

- instrument type and serial number
- liner material
- electrode material
- maximum rated process temperature
- maximum rated process pressure (at a specified process temperature)
- voltage, frequency, and power requirements, if independently powered
- environmental protection rating
- flow direction indication
- manufacturer's name
- nominal diameter
- calibration factors
- special process information (i.e., reclaimed water)
- electrical classification, if applicable (e.g., FM, UL)

7.3 Flowmeter Transmitter

Mark the following:

- instrument type and serial number
- voltage, frequency, and power requirements
- output signals, if applicable
- environmental protection rating
- manufacturer's name
- electrical classification, if applicable (e.g., FM, UL)

8 CALIBRATION

8.1 Overview

The purpose of the calibration process is to ensure that the flow rate indicated by the electromagnetic flowmeter system agrees with a reference flow rate within the manufacturer-specified accuracy at reference conditions. This may be specified as a percent of reading, a percent of full scale, or a combination of both. Refer to Nonmandatory Appendix C for more detail on the differences.

Calibration and verification are defined in para. 3.1.

8.2 Liquid Calibration of the Flowmeter Sensor

The electromagnetic flowmeter should be liquid calibrated by the manufacturer. In addition, user's requirements may dictate a calibration source other than that of the manufacturer. Wherever the calibration is performed, it should be done using standards that are traceable to NIST or some other recognized national or international standard. These standards should be more precise than the electromagnetic flowmeter system.

NOTE: The method of computing the flowmeter sensor signal based on electromagnetic field strength measurements and on physical dimensions, commonly referred to as "dry calibration," is beyond the scope of this Standard.

8.2.1 Calibration Conditions. The ambient temperature range, liquid temperature range, liquid conductivity range, supply voltage, and pipeline diameter used in calibration should be stated as the reference conditions.

Manufacturer-specified accuracy may be improved when the flowmeter sensor system, sensor and transmitter, are calibrated together as a system.

8.2.2 Calibration Facilities. The flowmeter calibration facilities, either gravimetric or volumetric based, shall be traceable to NIST or some other recognized national or international standard. Measurement and test equipment used during the calibration shall have this traceability.

The calibration system used to calibrate the electromagnetic flowmeter should have an uncertainty of one-third or less of the stated uncertainty of the flowmeter being calibrated. Any deviation from this rule should be documented.

Calibrations and calculations shall be in accordance with the applicable standards listed in section 2 and Nonmandatory Appendix E.

8.2.3 Calibration Procedure. The flowmeter sensor should be calibrated in a facility in accordance with para. 8.2.2. The flowmeter sensor and flowmeter transmitter can be calibrated as a system or separately.

The data collected during the testing is used to calculate the calibration factors for the flowmeter system. When the flowmeter sensor and flowmeter transmitter are not calibrated together, the sensor calibration data is used to adjust the flowmeter transmitter.

A copy of the calibration data shall be available to the user.

Minimum requirements for the calibration data are as follows:

- test date
- sensor serial number
- indicated flow
- actual flow
- difference between reference flow and meter-indicated flow
- manufacturer-specified accuracy
- calibration factor(s)
- fluid temperature

8.3 Calibration of the Flowmeter Transmitter

8.3.1 Electronic Calibration of the Flowmeter Transmitter Voltage Inputs and Coil Drive. Where a flowmeter sensor is used with a flowmeter transmitter that is not calibrated as a system, the flowmeter transmitter voltage inputs and coil drive should be calibrated against standards traceable to NIST or some other recognized national or international standard.

8.3.2 Electronic Calibration of the Flowmeter Transmitter User Outputs. The flowmeter transmitter user outputs should be calibrated against standards traceable to NIST or some other recognized national or international standard.

NONMANDATORY APPENDIX A
ADDED DETAILS REGARDING THEORY AND MEASUREMENT TECHNIQUE

A-1 THEORY

The underlying principle on which all electromagnetic flowmeters are based is Faraday's law of induction. For a system with moving conductive paths, such as a flowing conductive liquid, Faraday's law states that the electromotive force (emf_F) generated in the flowmeter is the sum of two terms — one proportional to the rate of change of the magnetic field (emf_t) and the other proportional to the Lorentz force (emf_v). The electromotive force emf_t arises from the fact that the magnetic flowmeter also acts as a transformer (see para. A-2.2). The electromotive force emf_v is the *emf* related to the fluid velocity. In particular,

$$emf_F = emf_t + emf_v$$

$$= A_{eff} \bullet dB/dt + DF_L \quad \text{(A-1)}$$

where

A_{eff} = effective area of the electrode leads through which the magnetic field, B, passes, m^2
dB/dt = rate of change in time of the magnetic field, tesla/s
D = inner diameter of the flow tube, m
F_L = effective Lorentz force per unit charge, N/coulomb

The effective Lorentz force per unit charge in an electromagnetic flowmeter is

$$F_L = CB_oV \quad \text{(A-2)}$$

where

B_o = magnetic field at the center of the flow tube, tesla
C = a proportionality constant that depends on the specific design of the flow tube and, to a limited extent, on the velocity profile of the fluid flowing through the flowmeter
V = flow velocity (average axial liquid velocity over the cross-section), m/s

Assuming the measurement of emf_v can be isolated from the transformer term, emf_t (see section A-2), the first term on the right side of eq. (A-1) can be set to zero. In this case, the electromotive force generated in an electromagnetic flowmeter is given by

$$emf_F = emf_v = CDB_oV \quad \text{(A-3)}$$

A-2 MEASUREMENT TECHNIQUE

A-2.1 Electrochemical Electromotive Force, emf_c

In addition to the *emf* generated by the Lorentz force, emf_v (i.e., the flow signal), an electrochemical electromotive force, emf_c, is produced in the flowmeter sensor. It originates from electrochemical reactions between the electrodes (which are commonly metallic) and the process fluid (an electrolyte), similar to the reaction in a battery. Since emf_c varies slowly over time, an alternating electromagnetic field is used to avoid the interference of emf_v with emf_c. Reversing the direction of the electromagnetic field will reverse the direction of emf_v but not emf_c; thus, the two signals may be differentiated.

A-2.2 The Electromagnetic Flowmeter Explained as a Transformer

The electromagnetic flowmeter constructed as shown in Fig. 4-1 also acts as a transformer. The transformer primary is the coils that create the magnetic field in the process fluid. The transformer secondary is formed by a loop comprising the wires connecting the electrodes to the transmitter (or transmitter device) and the process fluid itself, since it is conductive. Hence the single-loop secondary of the transformer lies within the magnetic field of the transformer primary, and therefore the secondary will see a voltage proportional to the rate of change of the magnetic field (see section A-1). Since the transformer secondary is also the voltage sensing circuit, both the transformer voltage, emf_t, and the flow signal, emf_v, will be present on the electrode wires.

A-2.3 Transformer Electromotive Force, emf_t

Unfortunately, alternating the electromagnetic field to differentiate the effect of emf_v from emf_c introduces an unwanted electromotive force that is proportional to the rate of change of the magnetic flux in the "transformer" primary (see section A-1 and para. A-2.2). To help diminish this effect, A_{eff} is made as small as possible by an appropriate layout of the leads from the electrodes.

The influence of the residual emf_t on the flow measurement can be further reduced to acceptable levels by appropriate measurement techniques. In the case of AC meters, emf_t is 90 deg out-of-phase with emf_v, and hence its influence can be reduced by phase-sensitive detection techniques, using the phase of the electromagnetic field, or a related electrical quantity, as the reference. In the case of pulsed-DC meters, the measurement of emf_v is made during the time when ideally the electromagnetic field is not changing in time, and hence emf_t approaches zero.

NONMANDATORY APPENDIX B
LINER MATERIAL GUIDELINES

See Table B-1.

Table B-1 Liner Material Guidelines

Material Classification	Liner Material	Typical Temperature Range	Comments
Elastomers	Hard rubber	0°C to 90°C (32°F to 195°F)	• Water, wastewater, alcohols, acids and bases, and metallic salt solutions • Possible attack by high concentrations of free halogens, aromatic and halogenated hydrocarbons, and high concentrations of oxidizing chemicals
	Natural rubber	−20°C to 70°C (−4°F to 160°F)	• Water, wastewater, alcohols, acids and bases, and metallic salt solutions • Possible attack by high concentrations of free halogens, aromatic and halogenated hydrocarbons, and high concentrations of oxidizing chemicals
	Synthetic rubber	−20°C to 70°C (−4°F to 160°F)	• Water, wastewater, alcohols, acids and bases, and metallic salt solutions • Impact and abrasion resistant
	Neoprene	0°C to 100°C (32°F to 212°F)	• Water, wastewater, alcohols, acids and bases, and metallic salt solutions • Possible attack by high concentrations of free halogens, aromatic and halogenated hydrocarbons, and high concentrations of oxidizing chemicals
	Polyurethane	−50°C to 50°C (−58°F to 125°F)	• Water, wastewater, alcohols, acids and bases, and metallic salt solutions • Impact and abrasion resistant
Fluorinated hydrocarbons	PTFE (Teflon®)	−50°C to 180°C (−58°F to 360°F)	• Water, wastewater, most alcohols, acids and bases, and metallic salt solutions • Possible collapse under subatmospheric or vacuum conditions
	PFA (Neoflon®)	−50°C to 180°C (−58°F to 360°F)	• Water, wastewater, most alcohols, acids and bases, and metallic salt solutions • Possible collapse under subatmospheric or vacuum conditions
	ETFE (Tefzel®)	−40°C to 120°C (−40°F to 250°F)	• Water, wastewater, most alcohols, acids and bases, and metallic salt solutions • Possible collapse under subatmospheric or vacuum conditions
Fluorinated plastics	Polyamide	0°C to 65°C (32°F to 150°F)	• Water, wastewater, some alcohols, some acids and bases, and some metallic salt solutions
	Chlorinated polyester	0°C to 120°C (32°F to 250°F)	• Water, wastewater, some alcohols, some acids and bases, and some metallic salt solutions
Ceramics	Aluminum oxide	−65°C to 180°C (−85°F to 360°F)	• Water, wastewater, alcohols, many acids and bases, and caustic and metallic salt solutions • Vacuum resistant and abrasion resistant; thermal shock may cause cracking
Others	Vitreous enamel	0°C to 150°C (32°F to 300°F)	• Water, wastewater, alcohols, acids and bases, and caustic and metallic salt solutions • Thermal shock may cause cracking
	Epoxy	−60°C to 110°C (−75°F to 230°F)	• Water, wastewater, some alcohols, acids and bases, and metallic salt solutions • Vacuum, impact, and abrasion resistant

GENERAL NOTE: Users must use caution and consider the characteristics of selected wetted parts material and influence of process fluids. The use of inappropriate materials can damage or destroy the meter, result in the leakage of process fluids, contaminate the process fluids, and/or cause injury to personnel. Be extremely careful with highly corrosive, reactive, or dangerous process fluids such as strong acids and bases.

NONMANDATORY APPENDIX C
MANUFACTURER-SPECIFIED ACCURACY

C-1 SUMMARY

Manufacturers of electromagnetic flowmeters state their accuracy specification in several ways — as a percentage of reading, a percentage of full scale, a sum of the two (combination), or a divided range. A divided range combines the reference accuracy, percentage of reading, and an absolute accuracy together. The reference accuracy applies to some range of flow rates; below that range, an absolute accuracy applies. Figure C-1 and Table C-1 explain the differences between how these accuracy specifications are stated.

Fig. C-1 Percent Error Examples

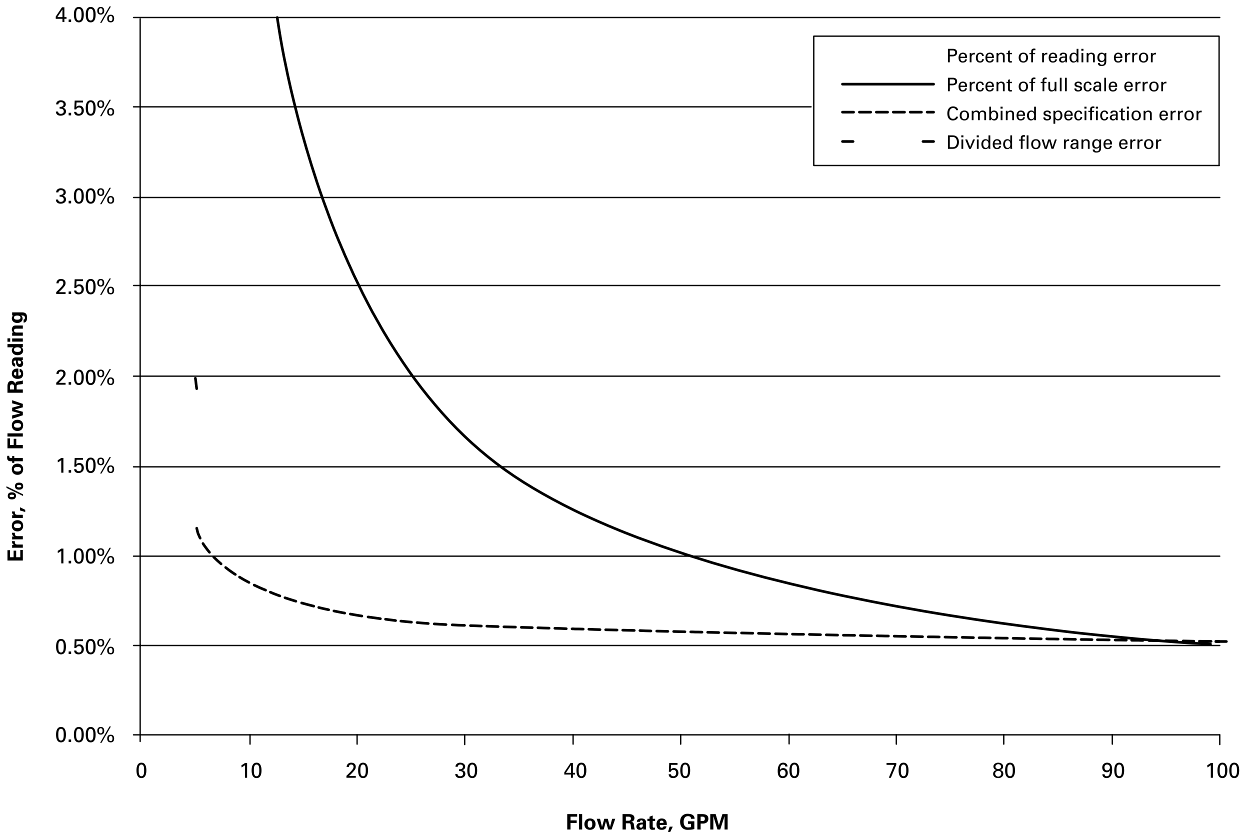


Table C-1 Comparison of Manufacturer-Specified Accuracy Statements

Type of Accuracy Specification	Accuracy Statement
% of reading	± 0.X% of reading
% of full scale	± 0.X% of full scale
Combination	± 0.X% of reading ± 0.X% of full scale ± 0.X% of reading ± 0.X ft/sec
Divided range	± 0.X% of reading (> X ft/sec) ± 0.XX ft/sec (0.X–X ft/sec) Undefined < 0.X ft/sec

NONMANDATORY APPENDIX D CALCULATION EXAMPLES

D-1 TABLES

Tables D-1, D-2, and D-3 show the "true" flow rate and the expected error bands around the "true" flow rate.

A few sample manufacturer-specified accuracy statements are shown.

Table D-1 Example 1

Accuracy Statement	Error Calculation	Maximum Allowable Error, GPM	Range of Expected Readings, GPM	
			Min.	Max.
±0.5% of reading	100 × 0.005 =	0.5	99.50	100.50
±0.5% of full scale	100 × 0.005 =	0.5	99.50	100.50
±0.5% of reading + 0.1% of full scale	100 × 0.005 + 100 × 0.001 =	0.6	99.40	100.60

GENERAL NOTES:
(a) True flow rate is 100 GPM.
(b) Full scale setting is 100 GPM.

Table D-2 Example 2

Accuracy Statement	Error Calculation	Maximum Allowable Error, GPM	Range of Expected Readings, GPM	
			Min.	Max.
±0.5% of reading	50 × 0.005 =	0.25	49.75	50.25
±0.5% of full scale	100 × 0.005 =	0.50	49.50	50.50
±0.5% of reading + 0.1% of full scale	50 × 0.005 + 100 × 0.001 =	0.35	49.65	50.35

GENERAL NOTES:
(a) True flow rate is 50 GPM.
(b) Full scale setting is 100 GPM.

Table D-3 Example 3

Accuracy Statement	Error Calculation	Maximum Allowable Error, GPM	Range of Expected Readings, GPM	
			Min.	Max.
±0.5% of reading	10 × 0.005 =	0.05	9.95	10.05
±0.5% of full scale	100 × 0.005 =	0.50	9.50	10.50
±0.5% of reading + 0.1% of full scale	10 × 0.005 + 100 × 0.001 =	0.15	9.85	10.15

GENERAL NOTES:
(a) True flow rate is 10 GPM.
(b) Full scale setting is 100 GPM.

NONMANDATORY APPENDIX E
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