ASME MFC-16–2007
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Measurement of Liquid Flow in Closed Conduits With Electromagnetic Flowmeters

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers
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This Standard will be revised when the Society approves the issuance of a new edition. There will be no addenda issued to this edition.

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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 an accepted flowmeter for difficult applications. Subsequent improvements in technology and reductions in cost have transformed this flowmeter 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.

Suggestions for improvements to this Standard are encouraged. They should be sent to: Secretary, ASME MFC Committee, the American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990.

ASME MFC-16–2007 was approved by the American National Standards Institute (ANSI) on March 26, 2007.

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Measurement of Fluid Flow in Closed Conduits

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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.

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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 will be rewritten in this 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 specifically does not cover insertion-type electromagnetic flowmeters, meters used to measure flow in partially filled pipe, or those used in surgical, therapeutic, or other health and medical applications. It also does not cover applications of industrial flowmeters involving nonconductive liquids or highly conductive liquids (e.g., liquid metals).

2 REFERENCES

All references are to the latest published edition of these standards. The following is a list of publications referenced in this Standard.

ASME B16 Series, Standards for Valves, Fittings, Flanges, and Gaskets

ASME MFC-1M, Glossary of Terms Used in the Measurement of Fluid Flow in Pipes

Publisher: The American Society of Mechanical Engineers (ASME), Three Park Avenue, New York, NY 10016-5990; Order Department: 22 Law Drive, P.O. Box 2300, Fairfield, NJ 07007-2300

ISO 13359, Measurement of Conductive Liquid Flow in Closed Conduits — Flanged Electromagnetic Flowmeters — Overall Length

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

3 DEFINITIONS AND SYMBOLS

(a) Paragraph 3.1 lists definitions from ASME MFC-1M used in ASME MFC-16.

(b) Paragraph 3.2 lists definitions specific to this Standard.

(c) Paragraph 3.3 lists symbols used in this Standard (see Table 1).

3.1 Definitions From ASME MFC-1M

accuracy: the degree of freedom from error; the degree of conformity of the indicated value to the true value of the measured quantity.

precision: the closeness of agreement between the results obtained by applying the experimental procedure several times under prescribed conditions. The smaller the random part of the experimental errors that affect the results, the more precise is the procedure.

rangeability (turndown): flowmeter rangeability is the ratio of the maximum to minimum flow rates or Reynolds number in the range over which the meter meets a specified uncertainty (accuracy).

repeatability: the closeness of agreement among a series of results obtained with the same method on identical test material, under the same conditions (same operator, same apparatus, same laboratory, and short intervals of time).

uncertainty (of measurement): the range within which the true value of the measured quantity can be expected to lie with a specified probability and confidence level.

3.2 Definitions for ASME MFC-16

bias: the systematic errors (i.e., those that cannot be reduced by increasing the number of measurements taken under fixed flow conditions).

flowmeter primary: includes the flowtube, process connections, electromagnetic coils, and electrodes. Flowmeter primary is also known by other names such as: flowmeter primary device, primary device, primary etc.

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

linearity: linearity refers to the constancy of the meter factor over a specified range, defined by either the pipe Reynolds number or the flow rate.

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.

3.3 Symbols

See Table 1.

Table 1 Symbols

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

NOTES:
(1) Dimensions: M = mass, L = length, T = time, I = current.
(2) Symbols defined specifically for this Standard.
(3) Symbols identical to ASME MFC-1M.

4 THEORY AND MEASUREMENT TECHNIQUE

A partial sketch of an industrial electromagnetic flowmeter is shown in Fig. 1.

Figure 2 shows a typical installation of the electromagnetic flowmeter.

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 conductive liquid flows through the flowtube. This electromotive force is

$$emf_v = C \cdot D \cdot B_o \cdot V \qquad (1)$$

where

- B_o = magnetic field at the center of the flowtube, Tesla
- C = a dimensionless parameter that depends on the specific design of the flowmeter and to a limited extent on the velocity profile. The velocity profile sensitivity of C also depends on the specific design of the flowmeter (see paras. 6.2.2 and 6.4.1.1).
- D = inner diameter of the flowtube, m
- emf_v = electromotive force, volt
- V = flow velocity. The average axial liquid velocity in a cross-sectional plane of the flowtube, m/s.

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

4.2 Electrochemical Electromotive Force

In addition to the flow-related electromotive force, emf_v, an electrochemical electromotive force, emf_c, is present between the electrodes. The emf_c is an electrochemical *emf* produced in the flowmeter primary similar to that generated in a battery. It can be similar in magnitude to emf_v and changes slowly. In order to reduce emf_c, which would be a measurement bias, an alternating electromagnetic field is used. There exist a number of variations of the basic AC and DC fields shown in this Standard. See para. A-2.1 for additional information. This electrochemical voltage, which varies slowly in time, is substantially reduced in magnitude by utilizing an alternating electromagnetic field.

The manner in which the electromagnetic field is varied includes the following:

(a) AC — field is varied in a sinusoidal fashion [see Fig. 3, illustration (a)]

(b) DC — field is varied in a stepwise fashion [see Fig. 3, illustrations (b) and (c)]

4.3 Types of Electrodes

An alternating electromagnetic field generates an alternating emf_v. Two types of electrodes can be used with an alternating electromagnetic field

(a) wetted electrodes that protrude through the pipe wall/liner into the flow stream [see Fig. 4, illustration (a)]

(b) nonwetted (capacitive) electrodes located behind or within the tube wall/liner [see Fig. 4, illustration (b)]

4.4 Calculation of Volumetric Flow Rate

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

$$V = emf_v / C \cdot D \cdot B_o$$

Fig. 1 Basic Components of an Electromagnetic Flowmeter

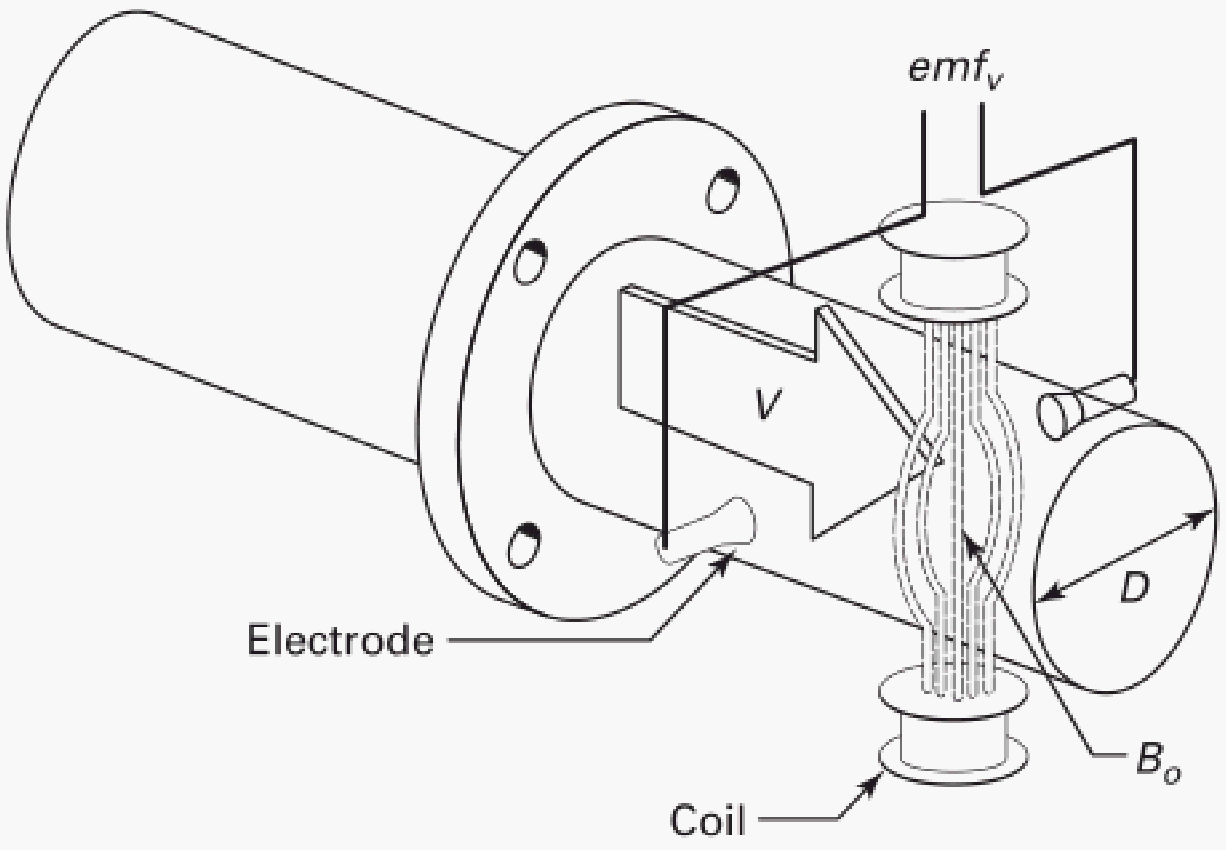
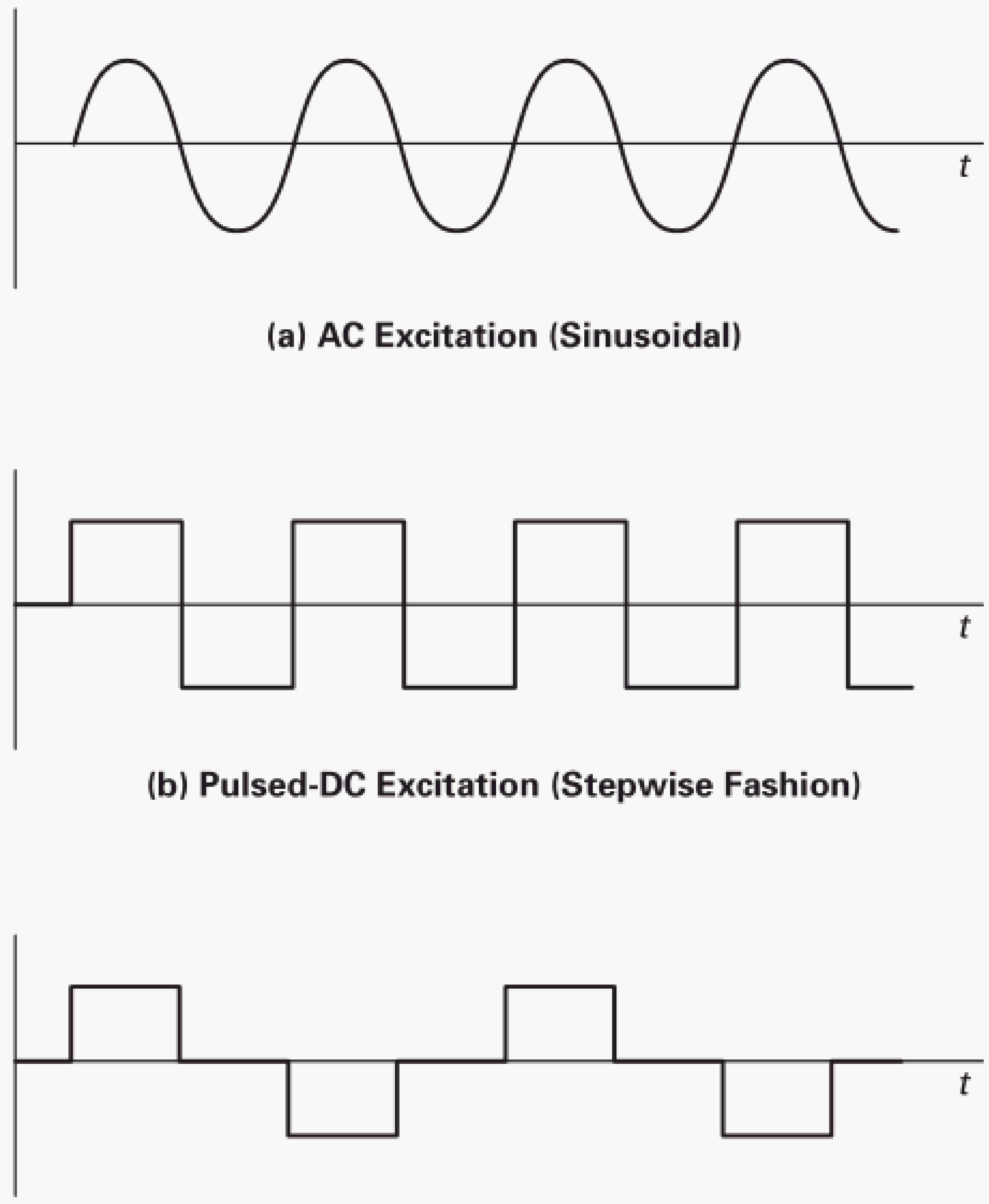


Fig. 3 Examples of Electromagnetic Field (B_o) Variation With Time



(a) AC Excitation (Sinusoidal)

(b) Pulsed-DC Excitation (Stepwise Fashion)

(c) Pulsed-DC Excitation (Stepwise Fashion)

Fig. 2 Electromagnetic Flowmeter System

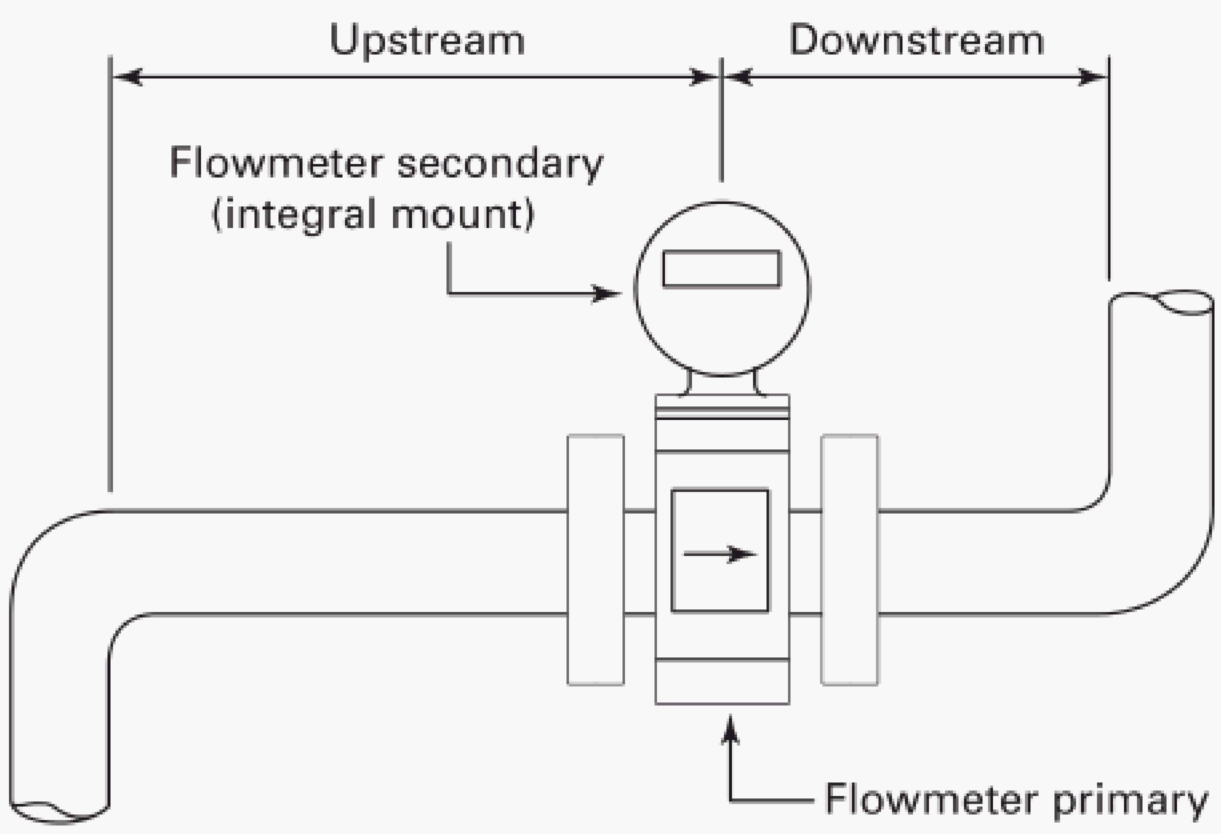
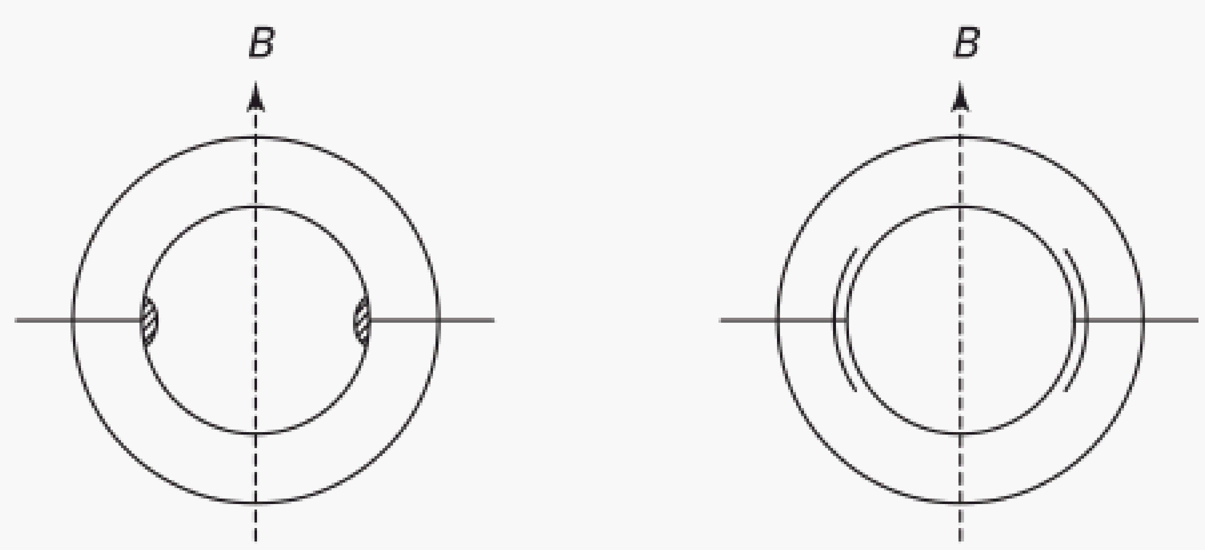


Fig. 4 Examples of Electrodes for an Electromagnetic Flowmeter



(a) Wetted

(b) Nonwetted

The volumetric flow rate, q, is calculated by

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

Combining these two equations

$$q = \pi \cdot D \cdot emf_v/4 \cdot C \cdot B_o \qquad (2)$$

Since 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,

$$q = K \cdot emf_v \qquad (3)$$

where
K = meter factor, $m^3/s/volt$

5 FLOWMETER DESCRIPTIONS

5.1 Flowmeter Primary

The flowmeter primary must be designed and selected to be an integral portion of the piping system (see para. 6.8.2). It consists of the following:

(a) a flowtube 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)
(e) a housing to protect the coils and electrodes from damage and moisture

It may also include grounding electrodes or grounding rings. They are used to ground the process and the flowmeter primary 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 primaries are independently powered from regular AC circuits. These flowmeter primaries must contain the needed circuitry for this power arrangement. These special application flowmeter primaries have power requirements beyond that available from normal application flowmeter secondaries.

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

Flanges are the most common method of attaching the flowmeter primary to the pipeline. Other attachment methods include victaulic couplings or tri-clamp connections. Another variation of the flowmeter primary 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 ISO 13359 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 Secondary

The flowmeter secondary consists of the electronic transmitter and its housing, which may be mounted either integral with the flowmeter primary, or remotely. If the flowmeter secondary is mounted remotely from the flowmeter primary, it may be necessary to have a separate electrical connection housing, terminals, and preamplifier mounted on the flowmeter primary. The flowmeter secondary measures: the emf_v voltage at the electrodes of flowmeter primary, provides the output from the meter, and in most cases provides power to the coils. The coils may be either AC or pulsed-DC powered, depending on the design of the meter.

The output from the flowmeter secondary 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. If the electrical conductivity of the liquid is uniform, and above a specified minimum value, the meter output will generally be independent of the liquid conductivity. The minimum liquid conductivity required for the flowmeter to function should be obtained from the manufacturer.

If the conductivity gradient is not uniform throughout the meter, flow measurement errors will occur. Nonhomogeneous flow streams must be mixed sufficiently to assure uniform electrical conductivity throughout the measurement region. Heterogeneous liquids, such as a slurries or pulp stocks, composed of small particles uniformly distributed in a liquid, may be considered an electrically homogeneous liquid.

6.1.2 Noisy Flow Signal. Excessive flow signal noise may be encountered in the following situations:

(a) when measuring the flow of a slurry or pulp stock
(b) when triboelectric effects are present (see para. 6.2.4)
(c) with large variations in liquid conductivity
(d) with air entrained in the liquid
(e) with incomplete chemical mixing

6.2 Effects of Process Properties and Flow Profiles

6.2.1 Sizing Based on Accuracy and Velocity. The linearity of industrial electromagnetic flowmeters may be affected by the distorted velocity profile that is present at low pipe Reynolds numbers. The effect should be included in the manufacturer's specifications.

6.2.2 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).

6.2.3 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.

6.2.4 Triboelectric Effect. The triboelectric effect (static electricity) is an electrical phenomenon where materials become electrically charged due to the effects of friction. The triboelectric effect in electromagnetic flowmeters occurs when certain materials (typically nonconducting, such as silicates, petroleum-based liquids or solids, etc.) deposit an electrical charge (either positive or negative) on the electrodes of the meter. These charges can either introduce errors or electrical noise, or both. Consult the manufacturer when applications include nonconductive particles.

6.3 Flowmeter Primary — Sizing Considerations

6.3.1 General Considerations. Many electromagnetic flowmeters have a relatively wide turndown, so it is generally feasible to select a flowmeter primary of the same size as the adjacent piping. However, it should be noted that liquid velocity range, upstream and downstream piping, and other flow considerations should be the basis in choosing the meter diameter for a given application. Consideration must be given to both the maximum and minimum flow rates if the end-user requires the meter to perform as specified by the manufacturer.

6.3.1.1 Accuracy. Manufacturers must specify the meter accuracy over the liquid velocity range of the flowmeter primary. 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 primary has an ID less than that of the flowmeter primary (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. 6.2.2), improper liner material selection (see para. 6.5.2), or horizontal installation of the flowmeter primary.

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 primary and the near upstream piping. Metal protection rings can also be installed to reduce the wear on the edge of the liner.

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

6.3.1.4 Fast-Settling Slurries. Velocities must be sufficient to keep slurry solids in suspension when the meter is mounted horizontally. Furthermore, if solids are prone to settle during no-flow conditions, there must be sufficient velocity to flush the settled materials from the flowmeter primary at startup (see para. 6.4.1.3).

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, the process liquid properties and velocity range of the flowmeter must be considered. As a matter of practice, applications utilizing small meters [12 mm (½ in.) and less] are more sensitive to pipe mismatch effects than larger meters and should be given special consideration.

6.4 Flowmeter Primary — Location, Installation, and Maintenance

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

The performance of electromagnetic flowmeters may be influenced by the location and orientation of the flowmeter primary with respect to the process piping. Consequently, paras. 6.4.1.1 through 6.4.1.5 should be considered.

6.4.1.1 Piping Effects. When a flow velocity profile is different from that of 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 primary, are the main factors that influence the velocity profile. The manufacturer must specify upstream and downstream lengths of straight pipe of the same diameter as the flowmeter primary for proper performance.

Swirling flow can introduce flow measurement errors. When swirling flow is suspected or known to exist, it may be advisable to use a swirl-reducing flow conditioner.

6.4.1.2 Full Pipe Requirements. The flowmeter primary must be installed to assure that it is completely filled with the liquid being metered. For instance, it may be difficult to ensure completely filled conduit in a vertically installed flowmeter with downward flow. 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 primary should be mounted so that no sensing or 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 primary should be mounted so that no sensing or grounding electrodes are located at or near the bottom of the pipe.

6.4.1.4 In-Situ Zero Checking. If the flowmeter zero is to be verified in-situ, some meter manufacturers require that the flowmeter primary remain completely filled with stationary liquid.

6.4.1.5 Location with Regard to Electrical Interference. Under many field situations, electrical interference will not affect performance of the flowmeter. However, it is advisable that the meter be installed in an area with minimal radio frequency and electromagnetic "noise," e.g., away from heavy machinery and/or equipment operating at high voltage or current (see paras. 6.4.3 and 6.7).

6.4.2 Installation of Flowmeter Primary

6.4.2.1 Installation Design. When designing the piping system, access for installation and removal of the flowmeter primary should be provided. Refer to local piping codes and user-specified procedures during construction and installation to minimize the strain on the flowmeter primary. The installation should allow ready access to all mechanical and electrical connections.

6.4.2.2 Handling of the Flowmeter Primary. Slings on the meter exterior or lifting lugs should be used on the flowmeter primary. Lifting by any means that could damage the interior of the flowmeter primary, pressure boundary, electrodes, electrical connections, and/or the meter liner must be avoided. 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. The upstream and downstream connecting pipe must be aligned with the flowmeter primary. The system should be adequately supported to reduce vibration.

6.4.2.4 Transition Piping. When the pipeline is a different diameter than that of the flowmeter primary, 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 the recommended meter installation.

6.4.3 Electrical Considerations

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

The electrical connection between the process liquid and the flowmeter primary 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 accuracy 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 insulating or conducting materials are deposited from the process liquid onto the electrodes or walls of the meter tube, the performance of the meter will be affected. Provision should be made for cleaning the electrodes by: electrical, chemical, ultrasonic, or mechanical methods. Often, this can be accomplished with the flowmeter installed, but sometimes the meter must be removed. The manufacturer should be consulted for the various options available.

6.5 Flowmeter Primary — Materials of Construction

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

(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 and ultraviolet light

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

6.5.3 Electrode Materials. The electrode material is selected based on its ability to resist oxidation, corrosion, or pitting by the process. Examples of electrode materials include

(a) stainless steel

(b) Hastelloy® C

(c) platinum

(d) platinum/iridium

(e) tantalum

(f) titanium

(g) zirconium

6.6 Flowmeter Secondary — Installation

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

6.7 Electrical Installation

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

6.8 Safety

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

Cabling supplied by the manufacturer to connect primaries and secondaries 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 B16 Series, etc.). Maximum possible and normal operation pressures, temperatures, and vibrations must be considered when specifying the mechanical requirements of the flowmeter primary. 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

The flowmeter primary and flowmeter secondary should be marked either directly or on an attached nameplate.

7.1 Flowmeter Primary

(a) instrument type and serial number

(b) liner material

(c) electrode material

(d) maximum rated process temperature

(e) maximum rated process pressure (at a specified process temperature)

(f) voltage, frequency, and power requirements, if independently powered

(g) environmental protection rating

(h) flow direction indication

(i) manufacturer name

(j) nominal diameter

(k) meter factor

(l) special process information (i.e., reclaimed water)

7.2 Flowmeter Secondary

(a) instrument type and serial number

(b) voltage, frequency, and power requirements

(c) output signals (if applicable)

(d) environmental protection rating

(e) manufacturer name

8 CALIBRATION

8.1 Overview

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

8.2 Liquid Calibration of the Flowmeter Primary

The electromagnetic flowmeter should be liquid calibrated by the manufacturer. User's requirements may dictate a calibration source other than that of the manufacturer. Wherever the calibration is performed, it should be done using equipment that is traceable to the National Institute of Standards and Technology (NIST), or some other recognized national or international standard. This equipment should be more precise than the flowmeter system.

The method of computing the flowmeter primary 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 primary and secondary flowmeters should be calibrated under specified reference conditions. The ambient temperature range, liquid temperature range, liquid conductivity range, supply voltage, and the pipeline diameter should be stated as the reference conditions.

Flowmeter system measurement accuracy will be improved when the primary and secondary flowmeters are calibrated together as a system.

8.2.2 Calibration Facilities. The flowmeter calibration facilities are either gravimetric or volumetric based, and traceable to NIST or some other recognized national or international standard. Measurement and test equipment used during the calibration shall also 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 shall be in accordance with the applicable standards (see section 2 and Nonmandatory Appendix E). Calculations and documentation of uncertainties should be in accordance with ASME MFC-2M.

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

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

The calibration data is used to calculate the meter factor of the flowmeter system. When the flowmeter primary and flowmeter secondary are not calibrated together, the flowmeter primary calibration data is used to adjust the flowmeter secondary.

8.3 Calibration of the Flowmeter Secondary

8.3.1 Electronic Calibration of the Flowmeter Secondary Voltage Inputs and Coil Drive. Where a flowmeter primary is used with a flowmeter secondary that is not calibrated as a system, the flowmeter secondary 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 Secondary User Outputs. The flowmeter secondary user outputs should be calibrated against equipment traceable to NIST or some other recognized national or international standard.

NONMANDATORY APPENDIX A ADDITIONAL 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 is the *emf* related to the transformer. The electromotive force emf_v is the *emf* related to the fluid velocity. In particular

$$emf_F = emf_t + emf_v$$

$$emf_F = A_{eff} \cdot dB/dt + D \cdot F_L \qquad \text{(A-1)}$$

where

A_{eff} = the effective area of the electrode leads through which the magnetic field (B) passes, m^2

D = the inner diameter of the flowtube, m

dB/dt = the rate of change in time of the magnetic field, Tesla/s

F_L = the effective Lorentz Force per unit charge, N/coulomb

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

$$F_L = C \cdot B_o \cdot V \qquad \text{(A-2)}$$

where

B_o = magnetic field at the center of the flowtube, Tesla

C = a dimensionless parameter that depends on the specific design of the flowtube, and to a limited extent on the velocity profile

V = flow velocity (average axial liquid velocity over the cross-section), m/s

Assuming the transformer term (emf_t) can be made sufficiently small (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

$$emf_F = emf_v = C \cdot D \cdot B_o \cdot V \qquad \text{(A-3)}$$

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 primary. This emf_c, similar to that generated in a battery, appears on the sensing electrodes together with emf_v. The magnitude of emf_c can be comparable to emf_v.

In order to reduce the effect of this undesired emf_c, an alternating electromagnetic field is used. This has a twofold advantage. First, it inherently reduces the magnitude of emf_c by periodically reversing electrochemical processes. Second, since emf_c varies slowly in time relative to the period of the alternating electromagnetic field, a measurement technique can be used to separate emf_c from emf_v. This technique takes advantage of the fact that a reversal in the direction of the electromagnetic field results in a reversal (change of sign) of emf_v, but has no effect on the sign of emf_c.

A-2.2 Transformer Electromotive Force, emf_t

Unfortunately, alternating the electromagnetic field to reduce the effect of emf_c can introduce an unwanted electromotive force (see section A-1) that is proportional to the rate of change of the magnetic flux through the loop defined by the electrical leads connecting the secondary to the electrodes in the primary device (i.e., $emf_t = A_{eff} \cdot dB/dt$). 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. 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
ITEMS OF POTENTIAL INTEREST TO USERS

B-1 GENERAL

The manufacturer should be prepared to respond to the user's hardware, performance, and application questions on items such as the following.

NOTE: Many of the items listed are included in specification sheets and operating manuals.

B-2 FLOWMETER PRIMARY

B-2.1 Variables

(a) nominal sizes that are available
(b) actual inside diameter for a given nominal line size
(c) temperature, pressure, and vacuum ratings
(d) materials that are available for wetted parts
(1) lining material
(2) electrode material
(e) materials of construction of all nonwetted parts
(1) pressure boundary
(2) flange material
(3) housing material

B-2.2 Operating Limits

(a) uncertainty statement
(1) maximum and minimum velocities for which the accuracy or uncertainty statement applies
(2) confidence level of uncertainty statement
(b) process liquid
(1) pressure limits
(2) temperature limits
(3) corrosive liquid limitations
(c) ambient conditions
(1) temperature limits
(2) humidity limits
(3) corrosive atmosphere limitations
(d) hazardous area and intrinsic safety code classification
(e) enclosure rating

B-2.3 Calibration

(a) method of determining meter factor
(1) direct calibration (gravimetric or volumetric)
(2) indirect calibration (master or transfer meter)
(b) flowmeter primary and flowmeter secondary calibration
(1) system calibration using matched flowmeter primary and flowmeter secondary electronics
(2) flowmeter primary calibration using "master," or laboratory, flowmeter secondary electronics
(3) effect on system uncertainty statement if master electronics are used

B-2.4 Effects on Performance of

(a) variations in process liquid
(1) conductivity and/or fluctuations in conductivity
(2) temperature and/or temperature fluctuations
(3) pressure and/or pressure fluctuations
(4) density
(5) viscosity
(6) pulsation of flow rate
(7) multiphase flow
(8) erosion by slurries, contamination, etc.
(9) build-up, liner, and/or electrode coating
(b) installation
(1) upstream and downstream piping configurations
(2) end connections, pipe I.D. mismatch, etc.
(3) alignment of meter in pipeline
(4) stress due to installation
(5) vibration
(6) power supply voltage and frequency
(c) ambient conditions
(1) ambient temperature variation
(2) electromagnetic interference (EMI)
(d) upset conditions
(1) flow rate beyond range
(2) process liquid does not fill pipe
(3) flowmeter primary is powered with no liquid in the meter

B-2.5 Installation Requirements

(a) upstream and downstream piping necessary to maintain performance specifications
(b) effect on uncertainty when the recommended straight pipe is not available
(c) location of power supply
(d) process connection (mating flanges, threaded ends, welding neck, etc.)
(e) liner entrance protectors
(f) mounting requirements — unit weight, dimensions, and mounting brackets
(1) clearance for maintenance
(2) stress limitations due to piping

(3) orientation requirements
(g) mounting, vibration, and shock limitations
(h) provisions for heat tracing (if necessary)
(i) provisions for thermal insulation (if necessary)
(j) appropriate signal and power cable
(k) requirements for special bolts
(l) torque recommendations for flanged meters and wafer meters

B-2.6 Hydraulic Considerations

(a) allowable pressure loss in terms of flow rate for the application
(b) line size to provide appropriate range on velocities
(c) sensitivity of meter to noise when measuring slurries or pulp stock
(d) recommendations for minimizing the effects of pipeline noise

B-2.7 Maintenance Considerations

(a) cleaning supplies and procedures for all wetted parts
(b) special tools, test instruments, or alignment gauges

B-3 FLOWMETER SECONDARY

(a) available outputs — analog and digital
(b) supply voltage and frequency limits
(c) ambient temperature limits
(d) humidity limits
(e) electrical code classification and approvals
(f) enclosure rating
(g) cabling requirements and limitations
(h) distance limitation for remote-mounted flowmeter secondary; considerations regarding process liquid conductivity
(i) external devices required to change span of meter
(j) displays
(k) alarms
(l) totalizers
(m) additional outputs

NONMANDATORY APPENDIX C
LINER MATERIAL GUIDELINES

Table C-1 Liner Material Guidelines

Material Classification	Liner Material	Typical Temperature Range	Notes
Elastomers	Hard rubber	0°C to 90°C (32°F to 195°F)	(1), (2)
Elastomers	Natural rubber	−20°C to 70°C (−4°F to 160°F)	(1), (2)
Elastomers	Synthetic rubber	−20°C to 70°C (−4°F to 160°F)	(1), (3)
Elastomers	Neoprene	0°C to 100°C (32°F to 212°F)	(1), (2)
Elastomers	Polyurethane	−50°C to 50°C (−58°F to 125°F)	(1), (3)
Fluorinated hydrocarbons	PTFE (Teflon®)	−50°C to 180°C (−58°F to 360°F)	(4), (5)
Fluorinated hydrocarbons	PFA (Neoflon®)	50°C to 180°C (−58°F to 360°F)	(4), (5)
Fluorinated hydrocarbons	ETFE (Tefzel®)	−40°C to 120°C (−40°F to 250°F)	(4), (5)
Fluorinated plastics	Polyamide	0°C to 65°C (32°F to 150°F)	(6)
Fluorinated plastics	Chlorinated polyester	0°C to 120°C (32°F to 250°F)	(6)
Ceramics	Aluminum oxide	−65°C to 180°C (−85°F to 360°F)	(7), (8), (9)
Others	Vitreous enamel	0°C to 150°C (32°F to 300°F)	(9), (10)
Others	Epoxy	−60°C to 110°C (−75°F to 230°F)	(3), (8), (11)

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 fluid, and/or cause injury to personnel. Be extremely careful with highly corrosive, reactive, or dangerous process fluids such as strong acids and bases.

NOTES:

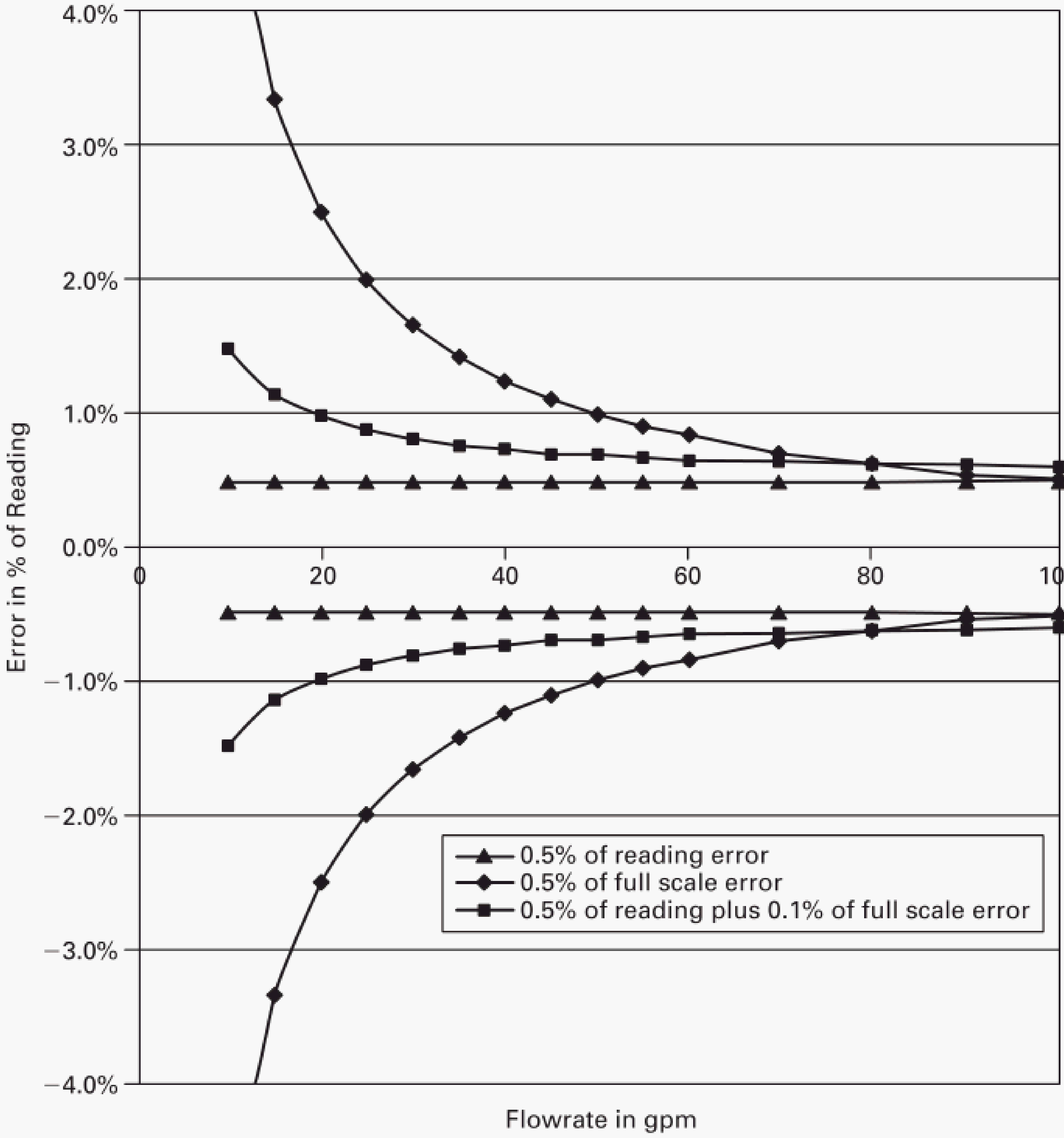
(1) Water, wastewater, alcohols, metallic salt solutions, acids and bases.
(2) Possible attack by high concentrations of free halogens, aromatic and halogenated hydrocarbons, and high concentrations of oxidizing chemicals.
(3) Impact and abrasion resistant.
(4) Water, wastewater, most alcohols, metallic salt solutions, acids and bases.
(5) Possible collapse under subatmospheric or vacuum conditions.
(6) Water, wastewater, some alcohols, some metallic salt solutions, some acids and bases.
(7) Water, wastewater, alcohols, many acids and bases, caustic and metallic salt solutions.
(8) Vacuum resistant and abrasion resistant.
(9) Thermal shock may cause cracking.
(10) Water, wastewater, alcohols, acids and bases, caustic and metallic salt solutions.
(11) Water, wastewater, some alcohols, metallic salt solutions, acids and bases.

NONMANDATORY APPENDIX D
ACCURACY SPECIFICATIONS FOR ELECTROMAGNETIC FLOWMETERS

Manufacturers state the accuracy specification for electromagnetic flowmeters in different ways. The specification can be stated as a percentage of reading, as a percentage of full scale, or as some combination of the two. Figure D-1 shows sample accuracy specifications and how the specification affects the allowable error.

These examples are shown in tabular form in Nonmandatory Appendix E.

Fig. D-1 Percent Error Examples



NONMANDATORY APPENDIX E
CALCULATION EXAMPLES

Tables E-1 through E-3 show the "true" flow rate and the expected error bands around the "true" flow rate. A few sample accuracy statements are shown.

Table E-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 FS	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 E-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 FS	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 E-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 FS	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 F
ADDITIONAL REFERENCES

The following publications are not referenced in this Standard, however, they are included as useful resources. All references are to the latest published edition of these standards.

ASME MFC-2M, Measurement Uncertainty for Fluid Flow in Closed Conduits

ASME MFC-9M, Measurement of Liquid Flow in Closed Conduits by Weighing Method

ASME MFC-10M, Method for Establishing Installation Effects on Flowmeters

ASME PTC 19.5, Electromagnetic Flow Meters (Section 11)

Publisher: The American Society of Mechanical Engineers (ASME), Three Park Avenue, New York, NY 10016-5990; Order Department: 22 Law Drive, P.O. Box 2300, Fairfield, NJ 07007-2300

Flow Measurement Engineering Handbook, Third Edition, Miller, R. W., 1989

Publisher: The McGraw Hill Companies, P.O. Box 182604, Columbus, OH 43272

ISO 6817, Measurement of Conductive Liquid Flow Rate in Closed Conduits — Method Using Electromagnetic Flowmeters

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

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