ASME MFC-10M–2000
(Revision of ASME MFC-10M-1994)

METHOD FOR ESTABLISHING INSTALLATION EFFECTS ON FLOWMETERS

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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A N A M E R I C A N N A T I O N A L S T A N D A R D

METHOD FOR ESTABLISHING INSTALLATION EFFECTS ON FLOWMETERS

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The next edition of this Standard is scheduled for publication in 2006. There will be no addenda issued to this edition.

ASME will issue written replies to inquiries concerning interpretations of technical aspects of this Standard.

The American Society of Mechanical Engineers
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FOREWORD

This Standard was prepared by Subcommittee 15 of the ASME Committee on Measurement of Fluid Flow in Closed Conduits. The Committee is indebted to the many engineers who contributed to this work.

The need for a document that describes how to determine the effects of installation conditions on the performance of a flowmeter has been recognized for some time. This Standard was prepared in response to that need. It presents a procedure for establishing the performance of a flowmeter under reference conditions as well as a method for determining the changes in perfomance caused when a disturbing element is installed upstream or downstream of the flowmeter.

This Edition of ASME MFC-10M was approved by letter ballot by both the ASME MFC Standards Committee and Subcommittee 15 on June 28, 2000.

This Standard was approved as an American National Standard on October 23, 2000.

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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 plans or drawings which are necessary to explain the question; however, they should not contain proprietary names or information.

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CONTENTS

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METHOD FOR ESTABLISHING INSTALLATION EFFECTS ON FLOWMETERS

INTRODUCTION

Under certain circumstances, flowmeter coefficient shifts and calibration errors caused by installation effects (pipe flow phenomena), i.e., flow pattern, pulsations, etc., can be significant. These changes can be most severe when a flowmeter is moved from an installation in which there are long lengths of straight pipe upstream and downstream of the meter, to an installation where the meter is mounted close to a disturbing pipeline element such as an elbow, valve, or pump. Because different types of flowmeters can be affected differently by the same flow pattern, it becomes important to know the flow pattern sensitivity of a given flowmeter in order to properly use it. This pattern sensitivity is established by first determining the performance of a meter in a reference installation and then determining the variations in the meter's performance caused by other installation conditions.

When preparing programs to test for installation effects, it should be realized that the purpose of the tests is to uncover effects that change the metering performance. These effects may be stated as a function of the flow profile at the meter, the pertinent parameters such as Reynolds number, relative roughness, etc., and the type of disturbing element, the flow condition entering it, and the distance separating it from the meter.

When analyzing installation effects, the changes in the metering performance of a flowmeter are obtained by evaluating the signature (e.g., flow coefficient versus Reynolds number), bias, and precision of a meter when it is flow calibrated in reference and nonreference piping.

1 SCOPE

This Standard establishes methods for determining the influence of installation conditions or flow patterns on the performance of flowmeters in closed conduits (i.e., pipe, ducts, etc.).

This Standard also addresses

(a) means and terminology for defining a reference condition for flow calibration of a particular flowmeter; and

(b) guidelines for extrapolation and interpolation of installation effects to untested piping conditions.

This Standard does not supersede or otherwise replace qualification tests or installation tests that are specified by other standards such as ISO 9951.

2 REFERENCES AND RELATED DOCUMENTS

ASME B46.1-1985, Surface Texture (Surface Roughness, Waviness, and Lay)

Fluid Meters, Their Theory and Application. 1971. 6th ed.

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

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

ASME PTC 11, Testing of Fans

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

Bendat, J. S. and Piersol, A. G. *Random Data: Analysis and Measurement Procedures*. 2nd ed. New York: John Wiley & Sons, Inc. 1981.

Bogue, D. C. and A. B. Metzner. *Velocity Profiles in Turbulent Pipe Flow.* I & EC Fundamentals, 2 (2). 1963.

Coles, D. E., *The Turbulent Boundary Layer In A Compressible Fluid*. The Rand Corporation: Report R-403-PR. 1962.

Hinze, J. O. *Turbulence.* New York: McGraw Hill Book Co. 1977. 2nd ed.

ISO 3966 Measurement of Fluid Flow in Closed Conduits — Velocity Area Method Using Pitot-Static Tubes

ISO 7066-1 Assessment of Uncertainty in the Calibration and Use of Flow Measurement Devices — Part 1: Linear Calibration Relationships

ISO 7066-2 Assessment of Uncertainty in the Calibration and Use of Flow Measurement Devices — Part 2: Non-Linear Calibration Relationships
ISO 7194 Measurement of Fluid Flow in Closed Conduits — Velocity Area Methods of Flow Measurement in Swirling or Asymmetric Flow Conditions by Means of Current-Meters or Pitot-Static Tubes
ISO 9951 Measurement of Gas Flow in Closed Conduits — Turbine Meters
Publisher: International Organization for Standardization (ISO), 1 rue de Varembé, Case Postale 56, CH-1211, Genève, Switzerland/Suisse

Pao, R. H. F. *Fluid Mechanics*. Ch. 7. New York: John Wiley & Sons, Inc. 1961.

Schlichting, H. *Boundary-Layer Theory*. Ch. XX. New York: McGraw Hill Book Co. 1968.

Taylor, B. N. and C. E. Kuyatt. NIST Technical Note 1297, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*. United States Department of Commerce.

Tennekes, H. and J. L. Lumley. *A First Course In Turbulence*. Cambridge: The MIT Press. 1972.

3 DEFINITIONS

The following definitions are given for terms used in some special sense or whose meaning seems useful to emphasize. A more comprehensive list of definitions and symbols applicable to the measurement of fluid flow in closed conduits can be found in ASME MFC-1M and ASME MFC-2M.

bias limit (B): the estimate of the upper limit of the true bias error, β (see ASME MFC-2M for further details on this subject).

fully developed axial flow profile: an axial velocity distribution that does not change with axial position along a pipe of constant cross-section.

identical: differing by less than the uncertainty interval for the measurements. It is assumed that every reasonable effort is made to eliminate significant bias and precision errors.

*precision (*also known as *random error):* the closeness of agreement between the results obtained at the same installation by applying the experimental procedure several times under prescribed conditions. The smaller the random part of the experimental errors which affect the results, the more precise the procedure (see ASME MFC-2M).

precision index: an estimate of the standard deviation of repeated measurements of the same thing, e.g., meter output at constant flowing conditions. It is given by:

$$\text{precision index} = S = \sqrt{\frac{\sum_{i=1}^{N} (X_i - \overline{X})^2}{N-1}}$$

where
N = number of measurements made
$\overline{X}$ = average of individual measurements X_i (see ASME MFC-2M)

single flowmeter: any meter of a specified design by a specified manufacturer in a specified line size, model number, etc. Two flowmeters of identical mechanical design and, where applicable, using identical signal processing algorithms are a single flowmeter.

uncertainty interval (U): an estimate of the error band, centered about the measurement, within which the true value must fall with a stated probability. The uncertainty interval is given by:

$$U = ku_c = 2\sqrt{u_A^2 + u_B^2}$$

where
u_A = determined with statistical methods
u_B = determined with methods other than statistical
u_C = the combined uncertainty
k = the coverage factor taken to be 2 for 95% confidence
U = the expanded uncertainty at 95% confidence (See NIST Technical Note 1297)

In the preceding equation, $u^2{}_A$ and $u^2{}_B$ are the root sum square of type A and type B uncertainties, respectively.

4 GENERAL GUIDELINES

The following guidelines should be adhered to in establishing installation effects on flowmeters.

(a) Care must be taken to achieve a proper and repeatable alignment between the meter and the adjacent piping at both inlet and outlet of the meter. Alignment of the meter per appropriate standards such as ASME MFC-12M or AGA9, etc., or according to manufacturers recommendations is recommended.

(b) The flow condition should be one of a conduit running full and steady with a homogeneous, single phase fluid. Flow is considered steady if, within the

measurement uncertainty, it is constant in time aside from variations related to turbulence generated within the piping.

(c) The tests outlined in this Standard should cover the pertinent range of fluid flow rates, Reynolds numbers, etc., of the meter to be evaluated.

NOTE: This requirement can be satisfied by stating the range of pertinent nondimensionalized parameters over which the data were obtained (see Section 7).

(d) To avoid missing periodic spatial flow variations, measurements should be made at pipe lengths that are not integer multiples of each other.

(e) All calibrations should be performed at the same flow conditions or as close as practical to the same conditions when comparing different test runs. When reducing data, corrections can be made via an independent parameter such as Reynolds number when it can be shown that the overall effects of the different fluid conditions (temperature, pressure, etc.) and/or the fluid properties (density, viscosity, etc.) on the tested flowmeter size and type are known and have been accounted for.

(f) All raw calibration data should be recorded and retained.

5 STANDARD REFERENCE CONDITIONS

5.1 Description

The process of establishing installation effects involves the comparison of the performance to that obtained in a standard reference condition. This document allows for two standard reference conditions. One is based on having specific, well-defined flow patterns in the test installation (Basic Reference Condition), and the other is based on the constancy of flowmeter performance along the pipe (Working Reference Condition).

5.1.1 Basic Reference Condition. The Basic Reference Condition exists when the fluid velocity pattern at the flowmeter is identical to that which would exist if the meter were installed in a conduit running full and steady with unlimited lengths of straight upstream and downstream pipe. Such a flow pattern is characterized by zero time-averaged radial and azimuthal fluid velocity components and an axisymmetric axial velocity profile that is independent of axial position. These components can be considered to be zero if their average values are zero to within the measurement uncertainty or if they are negligible to within 0.01% of the average flow velocity. The exact axial velocity profile depends on the inner wall roughness of the pipe (see ASME B46.1-1985) and the Reynolds number of the flow.

The above flow pattern which defines the Basic Reference Condition is often described as one which is steady, free from swirl, and having a fully-developed axial velocity profile.

5.1.2 Working Reference Condition. From a practical standpoint, the achievement and/or verification of Basic Reference Conditions may be limited by the test flow facility and/or instrumentation. When such limitations exist, a working reference should be established. The method for establishing the existence of this reference condition is markedly different from that for the Basic Reference Condition. Here flowmeter performance rather than a specific flow pattern is used as the criterion. Specifically, the Working Reference Condition is achieved when the flowmeter performance is independent of orientation and axial location of the flowmeter along the pipe.

NOTE: Ideally, the flowmeter performance achieved under the Working Reference Condition will not differ from that which would be observed if the flowmeter were installed in a Basic Reference Condition. This is so even though the flow patterns present in the working reference condition may in some cases differ from those in the Basic Reference Condition. The explanation for this lies in the fact that different flowmeters have different sensitivities to flow patterns. As a consequence of this differing sensitivity, the lengths of straight upstream and downstream piping required to achieve the Working Reference Condition will depend on the type of flowmeter being tested, as well as the test installation. A flowmeter that is fairly insensitive to flow pattern will require only short straight lengths of adjacent piping.

5.2 Experimental Methods for Establishing Standard Reference Conditions

There are two ways to establish reference conditions in this Standard. They are described in the following subparagraphs. The first of these is more fundamental while the second is more practical and perhaps easier to accomplish in most circumstances.

5.2.1 Establishing a Basic Reference Condition. For a given flow facility, minimum straight lengths of pipe upstream and downstream of the meter are to be determined such that for an installation change beyond those minimum lengths of pipe, the time-averaged radial and azimuthal fluid velocity components are zero and the axial velocity profile remains unchanged. By comparing this unchanging axial, velocity profile with those in the literature (see works by Schlicting, Pao, Coles, Hines, Tennekes, Bogue, and *Fluid*

Meters, in Section 2), the effective inner pipe wall roughness can be determined. On the other hand, if the pipe roughness is already known, the existence of a fully-developed axial velocity profile can be established directly by comparing the measured profile with those in the literature.

Measurements of the local fluid velocity can be carried out using standard techniques such as pitot tubes, hot wire or hot film anemometers, laser Doppler velocimeters, etc. (See, for example, ISO 3966, ISO 7194, ASME PTC 11, and similar references.)

A Basic Reference Condition can be established by following the steps outlined below. If necessary, a limited test program is permitted, provided that all of the limitations are documented.

Step 1. Using calibration procedures, establish that the velocity measurement instrumentation is operating properly and quantify its uncertainty.

Step 2. Install the velocity measurement probe in the pipe with any convenient upstream straight pipe length, but with at least four pipe diameter lengths of straight pipe downstream of the probe.

Step 3. If instrumentation allows, measure at a nominal flow rate the radial and azimuthal velocity components at ten or more locations in the cross-sectional plane. If the time-averaged values at any given location are not equal to zero within the measurement uncertainty, then Basic Reference Conditions do not exist. In this case, proceed to Step 6.

Step 4. If the time-averaged radial and azimuthal velocity components are zero (see 5.1.1), measure the axial velocity at ten or more appropriately spaced positions along a diameter. Repeat this for several flow rates, preferably ten or more, spaced over the flow rate range of the meter to be tested.

Step 5. Repeat the same procedure as outlined in Step 4 in at least one additional orientation 45 deg or more from the first. Additional profile measurements, each at new angular orientations that are up to 90 deg from a previously used orientation, are desirable.

Step 6. Install the velocity probe with at least five additional pipe diameters of upstream straight piping and with the same downstream piping.

Step 7. Repeat Steps 3 through 5.

Step 8. Repeat Steps 6 and 7 until an upstream length can be established beyond which the time-averaged radial and azimuthal velocity measurements are zero and the axial velocity profile remains unchanged. These conditions can be considered satisfied if the measurement data obtained agrees with the desired outcome within a 95% confidence interval as defined in NIST 1297. The location nearest to the disturbance at which the above condition is satisfied can be considered the shortest reference piping for the Basic Reference Condition.

Step 9. Compare the form of the fully-developed axial velocity profile established in Step 8 with that in the literature to determine the effective roughness of the pipe.

NOTE: If pipe roughness is already known (see ASME B46.1-1985), an alternative procedure for establishing that the axial velocity profile is independent of axial position, i.e., fully developed, is to compare the measured profile with that cited in the literature, rather than with that measured with a different length of straight piping.

Step 10. The shortest reference downstream piping length for a given downstream piping disturbance can be established in a similar manner, but, in this case, the upstream reference piping should remain unchanged.

Step 11. If the shortest reference downstream piping length established in Step 10 is greater than the length used in Step 2, then Steps 2 through 11 must be repeated using a length equal to or greater than the shortest reference downstream length.

5.2.2 Establishing a Working Reference Condition. A piping configuration is considered a Working Reference Condition for a given flowmeter if the flowmetering performance of the flowmeter (the output of the meter, its precision, and its variation with flow rate and Reynolds number, etc.), when installed and calibrated with the piping, does not change (beyond the uncertainty of the calibration or a specified meter uncertainty) when the meter orientation is altered or when more straight pipe (five diameters or 20% of the existing straight pipe, whichever is greater) is added upstream and/or downstream of the flowmeter.

The working reference condition can be established using the steps outlined below. If necessary, a limited test program is permitted, provided that all of the limitations are documented.

Step 1. By physical inspection, establish that the flowmeter is of proper specification and condition.

Step 2. Install the flowmeter in the test loop with any convenient upstream straight pipe length, but with at least four pipe diameter lengths of straight pipe downstream of the meter. If the manufacturer of the flowmeter specifies minimum upstream and downstream lengths, then these are the minimum lengths to be used in this and subsequent steps.

Step 3. Make a full calibration of the flowmeter in this location. A full calibration is one that includes calibrations at several flow rates, preferably eight or more, spaced over the flow rate range of the meter.

Step 4. Repeat the full calibration in at least one additional orientation 45 deg or more from the first, provided this change is within the scope of the manufacturer's specifications. Note that instead of rotating the flowmeter, it is permissible to rotate only the disturbing elements for this test. Additional calibrations, each at new angular orientations that are up to 90 deg from previously used orientations, may be desirable. A sufficient number of these calibrations should be performed to ensure that the uncertainty of the flowmeter can be reliably stated.

Step 5. Install the flowmeter with at least five additional pipe diameters of longer upstream piping and with the same downstream pipe.

Step 6. Repeat the full calibration in the same orientations as in Step 4.

Step 7. Repeat Steps 5 and 6 until an upstream length can be established beyond which the flowmeter's signature, bias, and precision are independent of location and orientation. This condition can be considered satisfied if the calibration data obtained at this and other downstream locations agree within a 95% confidence interval as defined in NIST 1297. The location nearest to the disturbance at which the above condition is satisfied can be considered the shortest reference piping for the flowmeter.

Step 8. The shortest reference downstream piping for a flowmeter and for a given downstream piping disturbance can be established in a similar manner but, in this case, the upstream reference piping should remain unchanged.

Step 9. If the shortest reference downstream piping length established in Step 8 is greater than the length used in Step 2, then Steps 2 through 9 must be redone using a length equal to or greater than the shortest reference downstream length.

NOTE: When the available space at a test flow facility or field site is inadequate for the establishment of a standard reference condition, then the facility or site alone cannot be used to determine installation effects (see Section 6.3). However, a meter can be calibrated in-situ for a given installation in that facility, but its calibration curve is valid only for that facility or for a geometrically scaled installation in which pertinent fluid dynamic parameters are the same.

6 METHOD FOR ESTABLISHING INSTALLATION EFFECTS ON FLOWMETERS

6.1 Nonreference Conditions

Nonreference conditions are those that do not satisfy the definitions for the Basic or Working Reference Conditions given in Section 5. These nonreference conditions may be generated by upstream and/or downstream piping geometry such as single or multiple elbows, by upstream equipment such as a partially opened gate valve, pumps, etc., or by the entrance or exit of a pipe. The flow disturbance must be defined and recorded. This includes the piping upstream of the disturbance, any flow conditioner that is used, upstream fittings, and the orientation of system components.

6.2 Method of Establishing the Effects of Nonreference Conditions for a Single Flowmeter in a Given Facility

The effect of these nonreference flow conditions on the performance of flowmeters can be evaluated by first establishing the flowmeter performance under reference conditions, and then testing the meter in nonreference conditions and comparing the results. This will identify deviations that occur between reference and nonreference conditions. The calibration tests should be conducted over approximately the same nondimensionalized parameter range (such as Reynolds number range) using the same fluid, instrumentation, and flowmeter as used in the reference condition calibrations. Enough data should be taken to statistically establish the uncertainty and the precision of the flowmeter. See Section 8 regarding interpolation and extrapolation of results to untested fluids or conditions.

6.3 Method of Establishing the Effects of Nonreference Conditions for a Single Flowmeter Using Different Facilities

The effect of nonreference flow conditions on the performance of flowmeters may be evaluated by first establishing the flowmeter performance under reference conditions in one facility and then comparing the results to the meter performance obtained in-situ at a different facility with a nonreference installation. The calibration tests should be conducted over approximately the same nondimensionalized parameter range (such as Reynolds number range) using the same meter as used in the reference condition calibrations.

Results of installation effects established using the method in this section may be extended to flowmeters of identical mechanical design and, where applicable, using identical signal processing algorithms.

Calibrations of the flowmeter in two different facilities may influence the uncertainty of evaluating the effect of nonreference conditions. This uncertainty may be established through statistical evaluation of the test results.

7 DOCUMENTATION OF RESULTS AND TEST CONDITIONS

Installation effects of a flowmeter can be obtained by comparing the signature curves, bias, and precision errors of a meter when it is flow calibrated in reference and nonreference piping conditions. These should be calculated and reported in accordance with ASME MFC-2M. The difference between results obtained in reference and nonreference installations can be expressed as percentages. Beyond this, other statistically-based data reduction methods can be performed in accordance with methods available in the literature. When such methods are used, the results and literature sources should be reported.

NOTE: See Section 2, Bendat and Piersol, for a number of different methods for data reduction and validation.

In reporting results, it is essential to fully document all relevant piping configurations (i.e., type of disturbance, geometry, pipe dimensions, inner pipe surface roughness, etc.). Test conditions such as fluid composition and properties together with pertinent thermodynamic variables such as temperature, pressure, etc., relevant to establishing both reference conditions and installation effects must also be documented.

8 INTERPOLATION AND EXTRAPOLATION

Interpolation of results can be made in certain cases provided that the installations geometrically scale and the pertinent nondimensional fluid dynamic parameters fall within the range of those tested. Extrapolation of results above or below the range of pertinent nondimensionalized parameters for which test data exists is not recommended.

The notion that disturbances can geometrically scale, is an optimistic one. The dynamics of fluid flow through, and around, objects may or may not scale to the quality needed for an extrapolation of flow meter performance. It may be possible to optimize installation-effects test programs using partial-factorial, experimental design methods, but caution is needed when extrapolating data to smaller or larger flow meters of the same type. The interaction between a flow meter and a disturbance may not scale.

NOTE: It may be feasible to predict installation effects satisfactorily if the flow at the intended installation is sufficiently understood and if the meter performance relative to this flow is known. This prediction can be based upon limited calibrations of the meter in flows similar to, but not identical to, that of the intended installation location. Interpolation — and possibly, extrapolation — techniques can be used for such predictions.