ASME MFC-22–2007

Measurement of Liquid by Turbine Flowmeters

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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Three Park Avenue • New York, NY 10016

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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.

ASME issues written replies to inquiries concerning interpretations of technical aspects of this document. Periodically certain actions of the ASME MFC Committee may be published as Cases. Cases and interpretations are published on the ASME Web site under the Committee Pages at http://cstools.asme.org as they are issued.

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

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FOREWORD

Turbine flowmeters cover a family of devices with varying designs that depend on rotating blades for the measurement of fluid velocity. This Standard is for liquid turbine meters and is not intended for gas turbine meters. The primary purpose of the liquid turbine flowmeter is to measure flowing volume. The flowing volume can be recalculated as volume at a specific set of conditions or as mass flow with the proper addition of additional measurements that can include temperature, pressure, and analytical devices.

The liquid flow turbine meters can be used for process monitoring, control, and custody transfer applications.

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

Following approval by the Standards Committee and the ASME Board, this Standard was approved as an American National Standard on June 8, 2007, with the designation ASME MFC-22–2007.

ASME MFC COMMITTEE
Measurement of Fluid Flow in Closed Conduits

(The following is the roster of the Committee at the time of approval of this Standard.)

CORRESPONDENCE WITH THE MFC COMMITTEE

General. ASME Standards are developed and maintained with the intent to represent the consensus of concerned interests. As such, users of this Standard may interact with the Committee by requesting interpretations, proposing revisions, and attending committee meetings. Correspondence should be addressed to:

Secretary, MFC Standards Committee
The American Society of Mechanical Engineers
Three Park Avenue
New York, NY 10016-5990

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.

Requests for Cases shall provide a Statement of Need and Background Information. The request should identify the standard, the paragraph, figure or table number(s), and be written as a Question and Reply in the same format as existing Cases. Requests for Cases should also indicate the applicable edition(s) of the standard to which the proposed Case applies.

Interpretations. Upon request, the MFC Committee will render an interpretation of any requirement of the Standard. Interpretations can only be rendered in response to a written request sent to the Secretary of the MFC Standards Committee.

The request for interpretation should be clear and unambiguous. It is further recommended that the inquirer submit his/her request in the following format:

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.

ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME Committee or Subcommittee. ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

Attending Committee Meetings. The MFC Committee regularly holds meetings, which are open to the public. Persons wishing to attend any meeting should contact the Secretary of the MFC Standards Committee.

MEASUREMENT OF LIQUID BY TURBINE FLOWMETERS

1 SCOPE

This Standard describes the criteria for the application of a turbine flowmeter with a rotating blade for the measurement of liquid flows through closed conduit running full.

The standard discusses the following:

(a) considerations regarding the liquids to be measured

(b) turbine flowmeter system

(c) installation requirements

(d) design specifications

(e) the maintenance, operation, and performance

(f) measurement uncertainties

This Standard does not address the details of the installation of accessory equipment used to measure pressure, temperature, and/or density for the accurate determination of mass or base volumes, or those accessories used to automatically compute mass or base volumes.

2 REFERENCES

The following is a list of publications referenced in this Standard. Unless otherwise specified, the latest edition shall apply.

ANSI/NCSL Z540.2-1997 (R2002), U.S. Guide to Expression of Uncertainty in Measurement

Publisher: NCSL International, 2995 Wilderness Place, Suite 107, Boulder, CO 80301-5404

ASME MFC-1M, Glossary of Terms Used in the Measurement of Fluid Flows 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 Guide to the expression of uncertainty in measurement

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

NIST Technical Note 1297 (TN 1297), Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results

Publisher: United States Department of Commerce, Technology Administration, National Institute of Standards and Technology (NIST), 100 Bureau Drive, Gaithersburg, MD 20899; http://physics.nist.gov/Pubs/guidelines/TN1297/tn1297s.pdf

3 DEFINITIONS AND SYMBOLS

Much of the vocabulary and many of the symbols used in this Standard are defined in ASME MFC-1M. Others that are unique in the field under consideration, or with special technical meanings are given in para. 3.1. Where a term has been adequately defined in the main text, reference is made to the appropriate paragraph.

3.1 Definitions

base flow rate: flow rate converted from flowing conditions to base conditions of pressure and temperature, generally expressed in units of base volume per unit time (e.g., gpm, m^3/h, etc.).

base pressure: a specified reference pressure to which a fluid volume at flowing conditions is reduced for the purpose of billing and transfer accounting. It is generally taken as 14.73 psia (101.560 kPa) by the gas industry in the U.S.

base temperature: a specified reference temperature to which a fluid volume at flowing conditions is reduced for the purpose of billing and transfer accounting. It is generally taken as 60°F (15.56°C) by the gas industry in the U.S.

base volume: volume of the fluid at base pressure and temperature.

flowing pressure: static pressure of the fluid at the flowing condition.

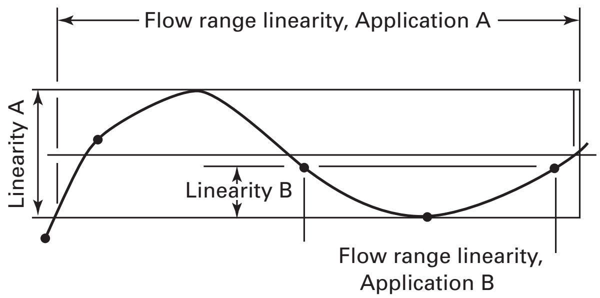
flowing temperature: the temperature of the fluid at the flowing condition.

linearity: linearity refers to the constancy of K factor over a specified range, defined by either the pipe Reynolds number or the flow rate. A typical liquid turbine meter performance curve is shown in Fig. 1. The linear range of the turbine meter is usually specified by a band defined by maximum and minimum K factors, within which the K factor for the meter is assumed to be K_{mean}. The upper and lower limits of this range can be specified by the manufacturer as a function of maximum and minimum Reynolds number ranges, a flow rate range of a specified fluid, or other meter design limitations such as pressure, temperature, or installation effects.

pipe Reynolds number: expressed by the equation

$$Re_p = \frac{v_p D}{\upsilon} = \frac{\rho v_p D}{\mu} \quad (1)$$

Fig. 1 Typical Meter Performance Curve



where

D = diameter of the inlet pipe that is of the same nominal size as the meter
v_p = average fluid velocity in the inlet pipe
μ = dynamic viscosity of the fluid
ρ = density of the fluid

rangeability or 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 and/or accuracy.

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

reproducibility: the closeness of agreement between results obtained when the conditions of measurement differ; for example, with respect to different test apparatus, operators, facilities, time intervals, etc.

Reynolds number: a dimensionless parameter expressing the ratio between inertia and viscous forces.

turbine meter: a flow measuring device with a rotor that responds to the velocity of flowing fluid in closed conduit. The flowing fluid causes the rotor to move with a tangential velocity that is directly linearly proportional to the volumetric flow rate.

3.2 Symbols

See Table 1.

4 PRINCIPLE OF MEASUREMENT

4.1 Measuring Mechanism

The measuring mechanism consists of the rotor, rotor shafting, bearings, and the necessary supporting structure (Figs. 2 and 3). The flowing fluid passing through the blades of the rotor, which are at an angle to the direction of the flow, imparts a tangential force on the blades. This tangential force causes the rotation of the rotor that is directly linearly proportional to the axial flow rate through the meter. For ideal fluids and frictionless rotor, the rate of rotation is linearly proportional to the axial flow velocity and the constant of proportionality is a function of the blade angle.

4.2 Output and Readout Device

4.2.1 The rate of revolution of the rotor is normally determined from the blade passing frequency or by other means that relates to the rate of rotation.

4.2.2 Turbine meter output may be mechanical, electrical, electromechanical, optical, analog, and digital. The readout devices may be of any form suitable for the application.

4.2.3 For electrical pulse output meters, the output includes the pulse detector system and all electrical connections necessary to transmit the indicated rotor revolutions outside the body for uncorrected volume registration.

5 SELECTION OF METER AND ACCESSORY EQUIPMENT FOR FLOW RATE DETERMINATION

For proper selection and operation of the meter, the following information may be necessary:

(a) fluid properties of the flowing stream including viscosity, vapor pressure, toxicity, corrosiveness, lubrication properties, specific gravity, etc.

(b) flow rate range and operational conditions including unidirectional or bidirectional flows and continuous or intermittent flows

(c) performance characteristics that are required for the application including linearity over a specified flow range, repeatability at any flow rate, and improved linearity over a flow range

(d) the flange rating, area classification, materials, and dimensions of the equipment used

(e) available space for the meter installation and proving facility, if required for the application

(f) operating pressure ranges, acceptable pressure losses through the meter installation, and necessary consideration to avoid vaporization of the fluid while passing through the meter

(g) operating temperature range and the applicability of the automatic temperature compensation

(h) effects of corrosive fluids and contaminants on the meter

(i) amount and size of the suspended solids in the flowing stream including filtering equipment for the metering section

(j) types of readout and printout devices, or desired output system to be used for signal preamplification and output units of the measurement as required

(k) for multiple meter-run installations and how a meter is taken in or out of service during operation of the entire system

Fig. 2 Schematic of Liquid Turbine Meter (Upstream-Downstream Stator)

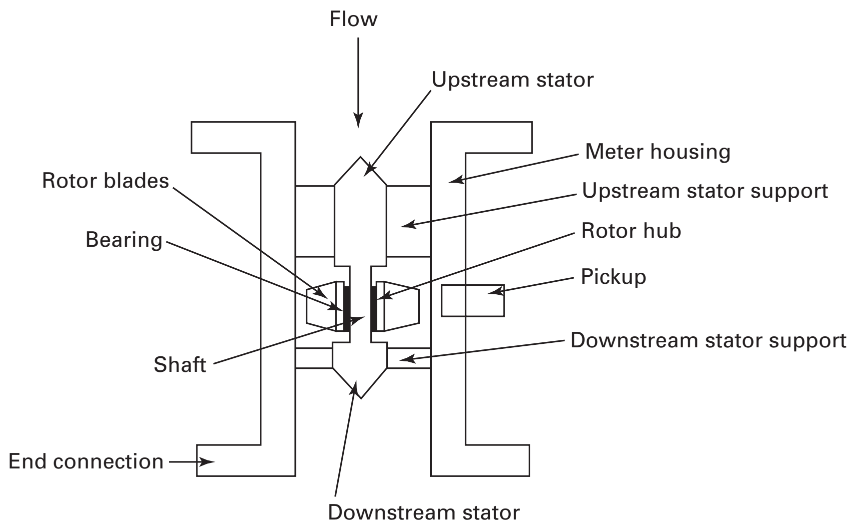


Table 1 Symbols

Symbol	Quantity	Dimensions [Note (1)]	SI Units	U.S. Customary Units
G	Specific gravity	Dimensionless	. . .	. . .
K	Calibration factor (pulses/unit volume)	L^{-3}	pulses/m^3	pulses/ft^3
P_a	Static pressure, absolute	$ML^{-1}T^{-2}$	Pa abs	lbf/ft^2 abs
P_g	Static pressure, gauge	$ML^{-1}T^{-2}$	Pa gage	lbf/ft^2 gage
ΔP	Meter pressure loss	$ML^{-1}T^{-2}$	Pa	lbf/ft^2
q	Volume flow rate	L^3T^{-1}	m^3/s	ft^3/hr
V	Liquid volume passed	L^3	m^3	ft^3
M	Liquid mass passed	M	kg	lb$_m$
ρ	Mass density	ML^{-3}	kg/m^3	lb$_m$/ft^3
f	Frequency linearly related to rotational speed	T^{-1}	s^{-1}	sec^{-1}
P_e	Equilibrium pressure	$ML^{-1}T^{-2}$	Pa	lbf/ft^2
V_p	Average fluid velocity	LT^{-1}	m/s	ft/sec

GENERAL NOTE:
- b = subscript for base conditions of temperature, pressure, and fluid composition
- f = subscript for flowing conditions of temperature, pressure, and fluid composition
- p = subscript for inlet pipe
- eff = subscript for effective degrees

NOTE:
(1) Fundamental dimensions: M = mass; L = length; T = time.

Fig. 3 Schematic of Liquid Turbine Meter (Cantilever Stator)

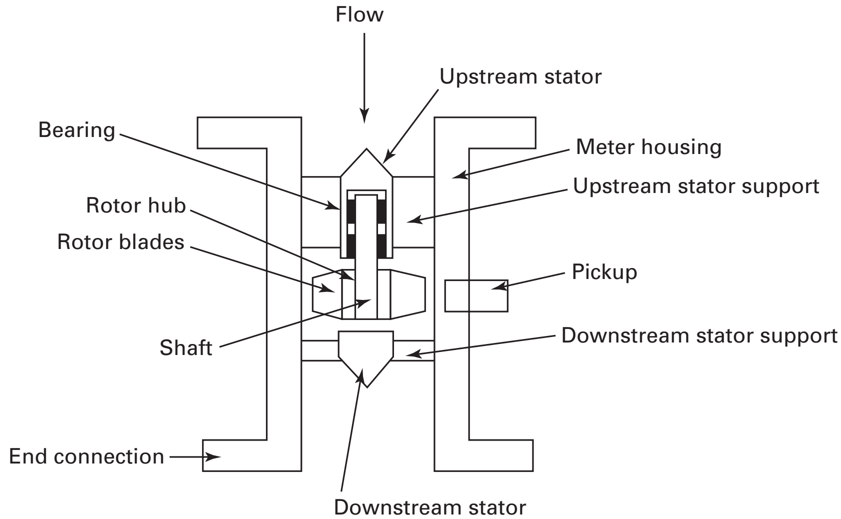
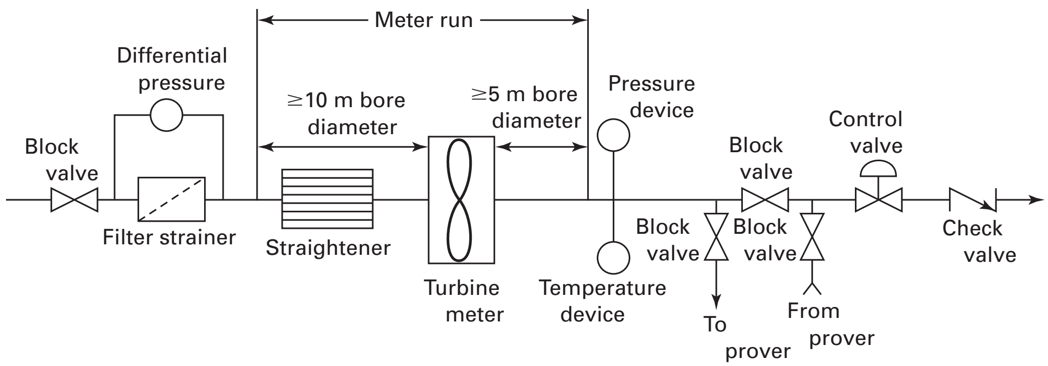


Fig. 4 Typical Turbine Meter System



(l) method by which each meter can be proved over the normal operating flow range of the meter

(m) the method of meter proving and proving interval

(n) method of factoring or adjusting meter registration or output

(o) accessory equipment needed for batching operations based on the output of the meter

(p) valves in the meter installations require special consideration as their performance can affect the measurement accuracy

(q) the flow and pressure control valve in the mainstream meter run should not result in shocks and surges

(r) valves, particularly those between the meter and the prover, require leak-proof shutoff (e.g., double block-and-bleed valves)

(s) maintenance methods, costs, and spare parts needed

(t) requirements and suitability for security sealing

(u) power supply requirements for continuous or intermittent meter readout

(v) fidelity and security of pulse data transmission systems

6 INSTALLATION

Details for the installation of turbine meters are provided in paras. 6.1 through 6.4. Figure 4 is a typical schematic diagram of a unidirectional turbine meter system.

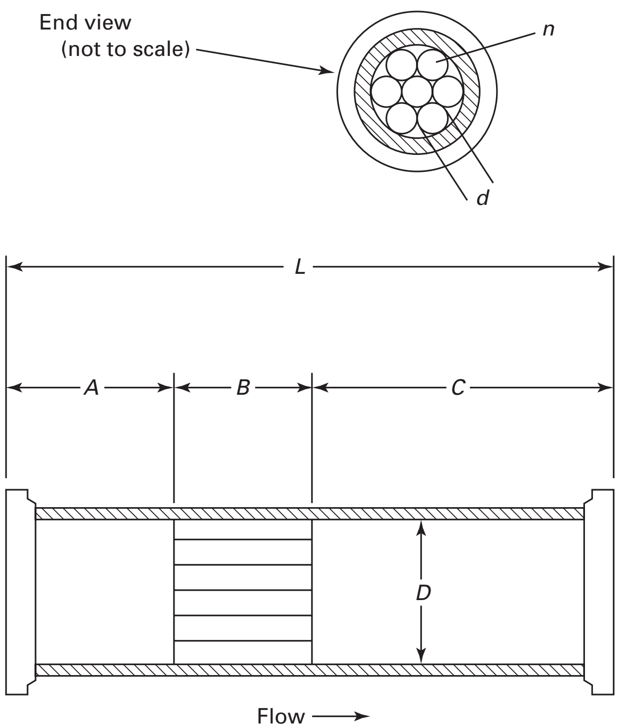
6.1 Flow Conditioning

The meter performance is affected by swirling and asymmetric flow profiles. Flow conditioning remediates these adverse conditions. Figure 5 is a typical installation of an upstream flow conditioner.

6.2 Valves

6.2.1 The valves in a turbine meter installation require special consideration since their performance

Fig. 5 Typical Installation of an Upstream Flow Conditioner



A = upstream plenum (2-3*D*)
B = length of straightener (2-3*D*)
C = length of upstream plenum (≥ 5*D*)
D = nominal diameter
d = nominal diameter of individual tubes ($B/d \geq 10$)
L = face-to-face length of flow conditioner section
n = number of individual tubes or vanes (≥ 4)

can affect measurement accuracy. The flow- or pressure-control valves on the mainstream meter run should be capable of rapid, smooth opening and closing to prevent shocks and surges. Other valves, particularly those between the meter or meters and the prover (e.g., stream diversion valves, drains, and vents) require leak-proof shutoff, which may be provided by a double block-and-bleed valve or an effective method of verifying shutoff integrity.

6.2.2 If a bypass is permitted around a meter or a battery of meters, it should be provided with a blind or a positive shutoff, double block-and-bleed valve with telltale bleed. The bypass should be sealed with a tamperproof seal if the meter or battery of meters is used for fiscal measurement.

6.2.3 All valves, especially spring-loaded or self-closing valves, should be designed so that they will not admit air when they are subjected to vacuum conditions.

6.2.4 Valves for intermittent flow control should be fast acting and shock-free to minimize the adverse effects of starting and stopping liquid movement.

6.3 Piping

6.3.1 Turbine meters are normally installed in a horizontal orientation. The manufacturer should be consulted if space limitations dictate a different orientation for the meter.

6.3.2 Where the flow range is over the limit of any one meter or the prover for the system, a bank of meters may be installed in parallel. Each meter in the bank of meters should operate within its minimum and maximum flow rates. A means should be provided to balance flow through each meter. Generally, balance of flow rate can be accomplished by using a flow control valve installed downstream of each meter run.

6.3.3 Meters should be installed so that they will not be subjected to undue stress, strain, or vibration. Provision should be made to minimize meter distortion caused by piping expansion and contraction.

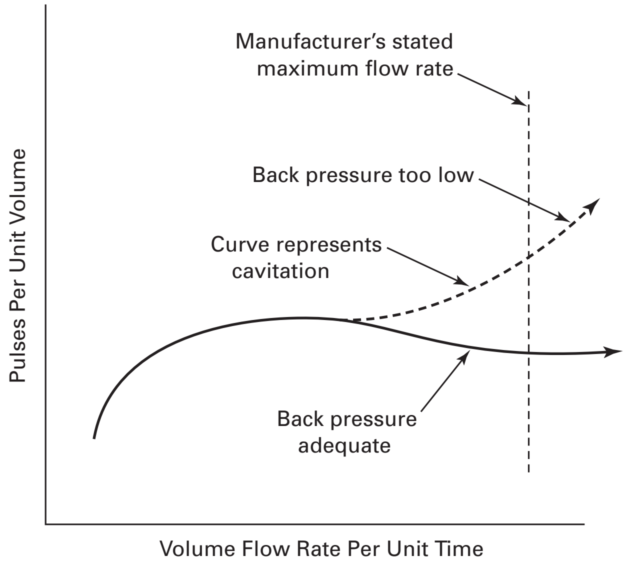
6.3.4 Measurement systems should be installed so that they will have a maximum, dependable operating life. This requires that, in certain services, protective devices be installed to remove liquid abrasives or other entrained particles that could impair meter performance characteristics or cause premature wear. If strainers, filters, sediment traps, settling tanks, water separators, a combination of these items, or any other suitable devices are required, they should be sized and installed to prevent flash vaporization of the liquid before it passes through the meter. Protective devices may be installed singly or in an interchangeable battery, depending on the importance of continuous service. In services where the liquid is clean or the installed meter does not require or warrant protection, omission of protective devices may be acceptable. Monitoring devices should be installed to determine when the protective device needs to be cleaned.

6.3.5 Measurement systems should be installed and operated so that they provide satisfactory performance within the viscosity, pressure, temperature, and flow ranges that will be encountered.

6.3.6 Meters should be adequately protected from pressure pulsations and excessive surges and from excessive pressure caused by thermal expansion of the liquid. This kind of protection may require the installation of surge tanks, expansion chambers, pressure-limiting valves, pressure relief valves, and/or other protective devices. When pressure relief valves or pressure-limiting valves are located between the meter and the prover, a means of detecting spills from the valves should be provided.

6.3.7 Conditions that contribute to flashing and/or cavitation of the liquid stream as it passes through the meter should be avoided through suitable system design and operation of the meter within the flow range

Fig. 6 Typical Performance Curve of Turbine Meter Showing Effect of Back Pressure



specified by the manufacturer. A typical liquid turbine meter performance curve illustrating the effect of back pressure is shown in Fig. 6. This deterioration of meter performance can be avoided by maintaining sufficient pressure within the meter. This may be accomplished by placing a back-pressure valve downstream of the meter to maintain pressure on the meter and the prover above the vapor pressure of the liquid. In some operations, the normal system pressure may be sufficient to prevent flashing and/or cavitation without the use of a back-pressure valve. Since the meter outlet pressure requirement is dependent upon the fluid conditions and the meter selection, the meter manufacturer should be consulted for recommendations on the minimum acceptable operating pressures for specific applications.

6.3.8 In the absence of a manufacturer's recommendation, the numerical value of the minimum pressure at the outlet of the meter may be calculated with the following expression, which has been commonly used. The calculated pressure has proven to be adequate in most applications and it may be conservative for some situations.

$$P_b = 2 \cdot \Delta p + 1.25 \cdot p_e \qquad (2)$$

where

P_b = minimum back pressure, pounds per square inch gauge (psig)

p_e = equilibrium vapor pressure of the liquid at the operating temperature, pounds per square inch absolute (psia) (gauge pressure plus atmospheric pressure)

Δp = pressure drop through the meter at the maximum operating flow rate for the liquid being measured, pounds per square inch (psi)

6.3.9 For higher vapor pressure liquids or liquids with vapor pressures of more than 1 000 kPa or about 150 psi at the flowing conditions, it may be possible to reduce the coefficient of 1.25 in eq. (2) to some other practical and operable margin. A back pressure greater than 350 kPa or about 50 psi above the vapor pressure of the liquid for the flowing conditions is normally adequate for proper operation of the liquid turbine meter. In either case, the recommendations of the meter manufacturer should be considered. During proving operations, additional back pressure may be required to prevent vaporization in the prover.

6.3.10 When a flow-limiting device or a restricting orifice is required, it should be installed downstream of the meter run. A restricting orifice plate, installed downstream of the meter provides additional back pressure in the event of a sudden increase in flow rate due to an upset condition (generally, an increase in upstream pressure); thereby preventing the meter from operating under high flow rates that may damage the meter. An alarm may be desirable to signal a flow rate that has exceeded the design limits. Flow-limiting or other pressure-reducing devices installed upstream of the meter should be designed and located to satisfy flow-conditioning and meter pressure requirements.

6.3.11 Each meter should be installed such that neither air nor vapor can pass through it. If necessary, air and vapor elimination equipment should be installed upstream of the meter. The equipment should be installed as close to the meter as is consistent with good practice, but it must not be so close that it generates a swirl or a distorted velocity profile at the entry to the meter. Any vapor released from the line should be vented in a safe manner.

6.3.12 Meters and piping should be installed so that accidental drainage or vaporization of liquid is avoided. The piping should have no unvented high points or pockets where air or vapor could accumulate and be carried through the meter by the added turbulence that results from an increased flow rate. The installation should prevent air from being introduced into the system through leaky valves, piping, glands of pump shafts, separators, connecting lines, and so forth.

6.3.13 The recommended location for prover connections is downstream of the meter run. If it is necessary to locate prover connections upstream of the meter run, it should be demonstrated that meter performance is not different between proving and normal operation.

6.3.14 Lines from the meter to the prover should be installed to minimize the possibility of air or vapor being trapped. Manual bleed valves should be installed at high points so that air can be drawn off before proving. The distance between the meter and its prover should be minimized. The diameter of the connecting lines should be large enough to prevent a significant decrease in flow rate during proving. Flow rate control valves may be required downstream of each meter, particularly in multimeter installations, to keep the proving flow rate equal to the normal operating rate for each meter.

6.3.15 Piping should be designed to prevent the loss or gain of liquid between the meter and the prover during proving.

6.3.16 Special consideration should be given to the location of each meter, its accessory equipment, and the piping manifold so that mixing of dissimilar liquids is minimized.

6.3.17 Most turbine meters will register flow in both directions, but seldom with identical meter factors. If flow must be restricted to a single direction because of meter design, flow in the opposite direction should be prevented. Reverse flow can be measured by a unidirectional turbine meter by directing the flow through the meter always in the same direction by installing valves and piping for reverse flows.

6.3.18 A thermometer, or a thermowell that permits the use of a temperature-measuring device, should be installed in or near the inlet or outlet of a meter run so that metered stream temperatures can be determined. The device should not be installed upstream of the meter between the meter and the flow-conditioning sections or at a downstream location closer than the manufacturer's recommended position. If temperature compensators are used, a suitable means of checking the operation of the compensators is required.

6.3.19 To determine meter operating pressure, a gauge, recorder, or transmitter of suitable range and accuracy should be installed near the inlet or outlet of each meter.

6.4 Electrical

Turbine meters usually include a variety of electrical or electronic accessories. The electrical systems should be designed and installed to meet the manufacturer's recommendations and the applicable hazardous area classifications and to minimize the possibility of mechanical damage to the components. Since turbine meters usually provide electrical signals at a relatively low power level, care must be taken to avoid signal and noise interference from nearby electrical equipment.

7 METER PERFORMANCE

Meter performance is defined by the reflection of the meter's output to the actual flow rate including linearity, repeatability, and reproducibility.

7.1 Meter Factor

Meter factors are determined by proving the meter under conditions of flow rate, viscosity, temperature, density, and pressure similar to that of actual operating conditions. The meter performance curve can be developed from a set of proving results.

7.2 Causes in Variations in Meter Factor

7.2.1 Many factors can change the performance of a turbine meter. Some factors, such as the entrance of foreign matter into the meter, can be remedied only by eliminating the cause. Other factors, such as the buildup of deposits in the meter, depend on the characteristics of the liquid being measured; these factors must be overcome by properly designing and operating the meter system.

7.2.2 The variables that have the greatest effect on the meter factor are flow rate, viscosity, temperature, deposits, or foreign matter. If a meter is proved and operated on liquids with inherently identical properties, and operating conditions such as flow rate remain similar, the highest level or accuracy can be anticipated. If there are changes in one or more of the liquid properties or in the operating conditions between the proving and the operating cycles, a change in meter factor may result and a new meter factor must be determined.

7.3 Variations in Flow Rate

At the low end of the range of flow rates, the meter factor curve may become less linear than it is at the medium and higher rates (see Fig. 1, Applications A and B). If a plot of meter factor versus flow rate has been developed for a particular liquid and other variables are constant, a meter factor may be selected from the plot for flow rates within the meter's working range; however, for greatest accuracy, the meter should be reproved at the new operating flow rate.

If the metering installation is monitored and flow rate is computed by an electronic flow computer, a multipoint meter performance curve as a function of the rotational speed of the rotor can be developed and used to determine the flow rate. A multipoint meter calibration curve can improve the measurement accuracy relative to using a mean or fixed *K*-factor value for the meter (Fig. 1). Many commercially available flow computers for turbine meters offer optional capability of the flow computer to update the meter performance curve with the latest data when the meter is calibrated. Using fitted curve and/or updating meter performance curve with most recent data can noticeably improve the measurement of accuracy and linearity of the meter.

7.4 Variations in Viscosity

7.4.1 Turbine meters are sensitive to variations in viscosity. Since the viscosity of liquid hydrocarbons changes with temperature, the response of a turbine meter depends on both viscosity and temperature. The viscosity of light hydrocarbons such as gasolines essentially remains the same over wide temperature changes, and the meter factor remains relatively stable. In heavier, more viscous hydrocarbons such as crude oils, the change in meter factor can be significant because of the viscosity changes associated with relatively small temperature changes. It is advisable to reprove the meter frequently when the viscosity of the fluid is known to vary under normal operating conditions.

7.4.2 Some commercially available liquid turbine meters with helical or specially designed blade shapes have negligible influence on meter performance curve over a wide range of density and viscosity of the flowing fluid. The manufacturer should be consulted for the viscosity range over which the meter may not require performance verification or recalibration. Rotors with straight or slightly curved blades are influenced more by the fluid viscosity than that of specially designed rotor blades.

7.4.3 Most commercially available flow computers can be programmed to store meter performance curves as a function of viscosity of the given fluid. The input received manually or from an online viscosity measuring device can improve the measurement accuracy of the meter.

7.5 Variations in Density

7.5.1 A change in the density of the metered liquid can result in significant differences in the meter factor in the lower flow ranges, thereby requiring the meter to be proved.

7.5.2 For liquids with a relative density of approximately 0.7 or less, consideration must be given to raising the value of the meter's minimum flow rate to maintain linearity. The amount of increase in lower flow rates will vary depending on meter size and type. To establish the minimum flow rate, several provings should be made at different rates until a meter factor that yields an acceptable linearity and repeatability can be determined.

7.6 Variation in Temperature

In addition to affecting changes in viscosity, significant variations in the temperature of the liquid can also affect meter performance by causing changes in the physical dimensions of the meter and in the apparent volume measured by the meter as a result of thermal expansion or contraction of the liquid. For greatest accuracy, the meter should be proved in the range of normal operating conditions.

7.7 Variations in Pressure

7.7.1 The effect of normal pressure variations in the flow line on liquid turbine meters is insignificant for most incompressible liquids. If the pressure change is significantly high to affect the meter dimension and/or fluid properties like density and/or viscosity due to the change in line pressure, the meter performance should be verified and the meter calibrated, if required. For liquids that have noticeable influence on density and/or viscosity due to relatively small variations in pressure (e.g., liquefied ethylene), the meter should be recalibrated if pressure change is enough to affect the meter performance beyond the acceptable or allowable limits of measurement. If the pressure of the liquid when it is metered varies from the pressure that existed during proving, the relative volume of the liquid will change as a result of its compressibility. The physical dimensions of the meter will also change as a result of the expansion or contraction of its housing under pressure. The potential for measurement error increases in proportion to the difference between the proving and operating conditions. For greatest accuracy, the meter should be proved at the operating conditions.

7.7.2 Volumetric corrections for the pressure effects on liquids with vapor pressures above atmospheric pressure are referenced to the equilibrium vapor pressure of the liquid at the standard temperature (e.g., 60°F, 15°C, or 20°C) rather than to atmospheric pressure, which is the typical reference for liquids with vapor pressures below atmospheric pressure for the measurement temperature. Both the volume of the liquid in the prover and the registered metered volume are corrected from the measurement pressure to the equivalent volumes at the equilibrium vapor pressure at the standard temperature, 60°F, 15°C, or 20°C.

7.7.3 This is a two-step calculation that involves correcting both measurement volumes to the equivalent volumes at equilibrium vapor pressure at measurement temperature. The volumes are then corrected to the equivalent volumes at the equilibrium vapor pressure at the standard temperature, 60°F, 15°C, or 20°C.

8 OPERATION AND MAINTENANCE

8.1 Conditions That Affect Operation

8.1.1 The overall accuracy of measurement by turbine meter depends on the condition of the meter and its accessories, the temperature and pressure corrections, the proving system, the frequency of proving, and the variations, if any, between operating and proving conditions. A meter factor obtained for one set of conditions will not necessarily apply to a changed set of conditions.

8.1.2 Turbine meters should be operated within the specified flow range and operating conditions that produce the desired linearity of registration. They should be operated with the equipment recommended by the manufacturer and only with liquids whose properties were considered in the design of the installation.

8.1.3 If a bidirectional turbine meter is used to measure flow in both directions, meter factors should be obtained for each direction of flow. The meter factors can be determined by a prover that has the proper piping manifold, the required protective equipment, and the flow conditioning located both upstream and downstream of the meter.

Failure to remove foreign matter upstream of a turbine meter and its flow-conditioning system may result in meter damage or mismeasurement. Precautions should be taken to prevent accumulation of foreign material (e.g., vegetation, fibrous materials, hydrates, and ice) in the turbine meter run.

8.2 Precautions for Operating Newly Installed Meters

When a new meter installation is placed in service, particularly on newly installed lines, foreign matter can be carried to the metering mechanism during the initial passage of liquid. Protection should be provided from malfunction or damage caused by foreign matter, such as slag, debris, welding spatter, thread cuttings, and pipe compound. The following are suggested means for protecting the meter from foreign matter:

(a) Temporarily replace the meter with a spool.

(b) Put a temporary bypass around the meter.

(c) Remove the metering element.

(d) Install a protective device upstream of the meter.

8.3 Operating Meter Systems

Definite procedures both for operating metering systems and for calculating measured quantities should be furnished to personnel at meter stations. The following is a list of items that these procedures should include that can be used for reference and assistance in developing these operating guidelines:

(a) a standard procedure for meter proving

(b) instructions for operating standby or spare meters

(c) minimum and maximum meter flow rates and other operating conditions, such as pressure and temperature

(d) instructions for applying pressure and temperature correction factors

(e) a procedure for recording and reporting corrected meter volumes and other observed data

(f) a procedure for estimating the volume passed, in the event of meter failure or mismeasurement

(g) instructions in the use of control methods and the action to be taken when the meter factor exceeds the established acceptable limits

(h) instructions regarding who should witness meter provings and repairs

(i) instructions for reporting breaks in any security seal

(j) instructions in the use of all forms and tables necessary to record the data that support proving reports and meter tickets

(k) instructions for routine maintenance

(l) instructions for taking samples

(m) details of the general policy regarding the frequency of meter proving and reproving when changes in flow rate or other variables affect meter accuracy

(n) procedures for operations that are not included in this list but that may be important in an individual installation

8.4 Meter Proving

8.4.1 Each turbine meter installation for accounting measurement should contain a permanent prover, connections for a permanent prover, connections for a portable prover, master meter, or some other method of determining the meter's *K*-factor and *K*-factor repeatability on a regular basis. The selection of proving methods should be acceptable to all parties involved.

8.4.2 The optimum frequency of proving depends on so many operating conditions that it is unwise to establish a fixed time or throughput interval for all conditions. In clean liquid service at substantially uniform rates and temperatures, meter factors have negligible change in meter performance curve, hence necessitating less frequent meter proving. More frequent proving is required with liquids that contain abrasive materials, in liquefied petroleum (LP) gas service where meter wear may be significant, or in any service where flow rates and/or viscosities vary substantially. Likewise, frequent changes in the type of product necessitate more frequent provings. In seasons of rapid ambient temperature change, meter factors vary accordingly, and proving should be more frequent. Studying the meter factor control chart or other historical performance data that include information on liquid temperature and flow rate will aid determination of the optimum frequency of proving.

8.4.3 Provings should be frequent (every tender or everyday) when a meter is initially installed. After frequent proving has shown that meter factor values for any given liquid are being reproduced within narrow limits, the frequency of proving can be reduced if the factors are under control and the overall repeatability of measurement is satisfactory to the parties involved.

8.4.4 A meter should always be proved after maintenance. If the maintenance has shifted the meter factor values, the period of relatively frequent proving should be repeated to set up a new database by which meter performance can be monitored. When the values have stabilized, the frequency of proving can again be reduced.

8.5 Meter Maintenance

8.5.1 For maintenance purposes, a distinction should be made between parts of the system (e.g., pressure gauges and mercury thermometers) that can be checked by operating personnel and more complex components that may require the services of technical personnel. Turbine meters and associated equipment can normally be expected to perform well for long periods. Indiscriminate adjustment of the more complex parts and disassembly of equipment are neither necessary nor recommended. The manufacturer's standard maintenance instructions should be followed.

8.5.2 Meters stored for a long period should be kept under cover and should have protection to minimize corrosion.

8.5.3 Establishing a definite schedule for meter maintenance is difficult, in terms of both time and throughput, because of the many different sizes, services, and liquids measured. Scheduling repair or inspection of a turbine meter can best be accomplished by monitoring the meter factor history for each product or grade of crude oil. Small random changes in meter factor will naturally occur in normal operation, but if the value of these changes exceeds the established deviation limits, the cause of the change should be investigated, and any necessary maintenance should be provided. Using deviation limits to determine acceptable normal variation strikes a balance between looking for trouble that does not exist and not looking for trouble that does exist.

9 MEASUREMENT UNCERTAINTY

9.1 Flow Rate Uncertainty

9.1.1 The uncertainty of a flow rate measurement can be estimated using the procedures in NIST/TN 1297 or ANSI/NCSL Z540.2-1997. The uncertainty analysis is performed by determining the parameters of importance that affect the flow rate measurement. This can be determined from the equation relating the output of the flow meter to the flow rate. In the case of a turbine, the relevant equation is given by

$$q = \frac{f}{K} \tag{3}$$

where

f = frequency that is linearly related to the rotational speed of the turbine

K = ratio between the flow rate and frequency as determined by calibration of the meter

q = volume flow rate

9.1.2 The sensitivity of the flow rate to variations in these parameters can be determined using variational analysis that when applied to the above equation yields

$$\delta q = \frac{\partial q}{\partial f}\,\delta f + \frac{\partial q}{\partial K}\,\delta K \tag{4}$$

This equation is read as follows: The variation in the flow rate, q, is equal to the partial derivative of q with respect to f times the variation in f plus the partial derivative of q with respect to K times the variation in K. The values of the partial derivatives are called "sensitivity coefficients" and are given by

$$\frac{\partial q}{\partial f} = \frac{1}{K} \tag{5}$$

$$\frac{\partial q}{\partial K} = \frac{f}{K^2} \tag{6}$$

Substituting these results in eq. (4), we obtain

$$\delta q = \frac{1}{K}\,\delta f - \frac{f}{K^2}\,\delta K \tag{7}$$

9.1.3 This result can be expressed as a percentage by dividing both sides of the equation by q and multiplying by 100%. Performing this operation yields

$$\frac{1}{q}\,\delta q \times 100\% = \frac{1}{q}\frac{1}{K}\,\delta f \times 100\% - \frac{1}{q}\frac{f}{K^2}\,\delta K \times 100\% \tag{8}$$

where the product operation in the equation is shown with the symbol "δ." If we substitute for q from eq. (3), eq. (8) becomes

$$\frac{1}{q}\,\delta q \times 100\% = \frac{1}{f}\,\delta f \times 100\% - \frac{1}{K}\,\delta K \times 100\% \tag{9}$$

This equation can be read as follows: At the flow rate q, the percent variation in the flow rate is equal to the percent variation in the turbine's blade frequency evaluated at the flow rate q minus the percent variation in the turbine's meter factor or K factor also evaluated at the flow rate q. In considering random variations of frequency both during use and during meter calibration, as well as a normal distribution for the K factor uncertainty that is determined during factory calibration, the "δ" quantities are to be considered as having either a "+" or a "−." Since the frequency and the meter factor are independent, the relative variance of q is the sum of the squares of the relative variances of frequency and K factor.

The uncertainty analysis in this document will utilize the uncertainty coefficients given in eqs. (5) and (6) and will express the flow rate uncertainty using eq. (A-3) given in NIST/TN 1297. NIST/TN eq. (A-3) is copied as eq. (10) in this document. Thus, the combined standard flow rate uncertainty, $u_c(q)$, is obtained by substituting eqs. (5) and (6) into eq. (10) and is given by

$$u_c^2(y) = \sum_{i=1}^{N}\left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i) + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j}u(x_i, x_j) \quad (10)$$

$$u_c^2(q) = \frac{1}{K^2}u^2(f) + \frac{f^2}{K^4}u^2(K) + 2\frac{f}{K^3}u(f,K) \quad (11)$$

where

$u(f)$ = standard uncertainty associated with the frequency, f
$u(K)$ = standard uncertainty associated with the meter factor, K
$u(f, K)$ = estimated covariance associated with f and K

9.1.4 The expanded uncertainty, U_p, is then given in NIST/TN 1297 as

$$U_p = k_p u_c(q) \quad (12)$$

where
k_p = a coverage factor, associated with the coverage factor, p. For 95% confidence, $k_p = 2$.
p = a confidence interval for flowmeters; unless stated otherwise, $p = 95$, which stands for 95% confidence

9.1.5 As addressed above, for the purpose of this discussion, it is assumed that the estimated covariance associated with f and K for the turbine meter used in this example is zero so that eqs. (10) and (11) become

$$u_c^2(q) = \frac{1}{K^2}u^2(f) + \frac{f^2}{K^4}u^2(K) \quad (13)$$

If there are two contributions to the frequency uncertainty, as will be the case in the example that follows, this equation is

$$u_c^2(q) = \frac{1}{K^2}u_1^2(f) + \frac{1}{K^2}u_2^2(f) + \frac{f^2}{K^4}u^2(K) \quad (14)$$

The additonal term is consistent with eq. (A-3), of NIST/TN 1297 (see also ANSI/NCSL Z540.2-1997).

9.1.6 From eqs. (13) and (14), it is clear that frequency uncertainty contributions to $u_c^2(q)$ are given by terms of the form $\frac{1}{K^2}u^2(f)$ and the contribution from the meter factor has the form $\frac{f^2}{K^4}u^2(K)$. It is important to use a consistent set of units when evaluating these terms.

9.1.7 Now, according to NIST/TN 1297 (see also ANSI/NCSL Z540.2-1997), when reporting a measurement result and its uncertainty, the following information shall be included in the report itself or by reference to a published document: a list of all components of standard uncertainty, together with their degrees of freedom where appropriate, and the resulting value of u_c.

The components should be identified according to the method used to estimate their numerical values as follows:

(a) those which are evaluated by statistical methods
(b) those which are evaluated by other means
(c) a detailed description of how each component of standard uncertainty was evaluated
(d) a description of how the coverage factor, k, was chosen when k is not taken as equal to 2.

9.1.8 In section B of NIST/TN 1297, the four-step procedure for calculating k_p is defined as follows:

Step 1: Obtain y and $u_c(y)$ as indicated in NIST/TN 1297.

Step 2: Estimate the effective degrees of freedom, v_{eff}, of $u_c(y)$ from the Welch-Satterthwaite formula:

$$v_{eff} = \frac{u_c^4(y)}{\sum_{i=1}^{N}\frac{c_i^4 u^4(x_i)}{v_i}} \quad (15)$$

where $c_i \equiv \partial f/\partial x_i$, all of the $u(x_i)$ are mutually statistically independent, v_i is the degrees of freedom of $u(x_i)$, and

$$v_{eff} \leq \sum_{i=1}^{N} v_i \quad (16)$$

The degrees of freedom of a standard uncertainty, $u(x_i)$, obtained from a Type A evaluation is determined by appropriate statistical methods. In the common case discussed in subsection A.4 of NIST/TN 1297 where $x_i = \overline{X}_i$ and $u(x_i) = s(\overline{X}_i)$, the degrees of freedom of $u(x_i)$ is $v_i = n - 1$. If m parameters are estimated by fitting a curve to n data points by the method of least squares, the degrees of freedom of the standard uncertainty of each parameter is $n - m$.

The degrees of freedom to associate with a standard uncertainty $u(x_i)$ obtained from a Type B evaluation is more problematic. However, it is common practice to carry out such evaluations in a manner that ensures that an underestimation is avoided. For example, when lower and upper limits, a_- and a_+, are set as in the case discussed in subsection A.5 of NIST/TN 1297, they are usually chosen in such a way that the probability of the quantity in question lying outside these limits is in fact extremely small. Under the assumption that this practice is followed, the degrees of freedom of $u(x_i)$ may be taken to be $v_i \rightarrow \infty$.

NOTE: See section 2 of the ISO Guide to the expression of uncertainty in measurement for a possible way to estimate v_i when this assumption is not justified.

Table 2 Results of the Uncertainty Example

Variable	Uncertainty	Confidence Interval, %	Standard Uncertainty [Note (1)]	Type
Frequency measurement	0.2 Hz	95	0.1 Hz	B
Frequency variation at constant flow rate	< 0.1 Hz	95	< 0.05 Hz	B
Meter factor	4.5 pulses/ft^3	95	2.3 pulses/ft^3	B

NOTE:
(1) According to section 4.3 of NIST/TN 1297, the quoted uncertainty at 95% confidence is to be divided by 1.960 in order to convert it to a standard uncertainty.

Step 3: Obtain the t factor, $t_p(\upsilon_{eff})$, for the required level of confidence, p, from a table of values of $t_p(\upsilon)$ from the Student t-distribution, such as Table B.1 of NIST/TN 1297. If υ_{eff} is not an integer, which will usually be the case, either interpolate or truncate υ_{eff} to the next lower integer.

Step 4: Take $k_p = t_p(\upsilon_{eff})$ and calculate $U_p = k_p u_c(y)$

EXAMPLE: Suppose that a 2-in. turbine meter has an output frequency at a constant flow rate that is measured with an instrument having an uncertainty to 95% confidence that is stated by the instrument manufacturer to be ±0.01% ±1 count of the least significant digit. Suppose that the measured frequency is 1013.7 Hz. Then the uncertainty in this frequency is ±0.2 Hz to 95% confidence. Suppose also that the flowmeter's factor as given by the manufacturer is K = 2996.0 pulses/ft^3 ± 0.15% to 95% confidence over the 10 to 1 flow rate range from 450 ACFH to 4500 ACFH, where ACFH is the actual cubic feet per hour. The uncertainty in the meter factor is then ±4.5 pulses/ft^3 to 95% confidence. Finally, suppose that the manufacturer of the flowmeter further states that any variation in the turbine frequency is less than ±0.01% to 95% confidence when the flow rate is constant. The calculated flow rate is then given by

$$q = f/K = 1013.7/2996.0 = 0.33835 \text{ ft}^3/\text{sec} = 1218.1 \text{ ACFH} \quad (17)$$

Step 5: Standard uncertainties calculated for the above flowing conditions and uncertainty specifications are specified in Table 2.

For the standard uncertainties of Table 2 and substituting values of the flowing conditions defined by the Example in Step 4, eq. (14) yields the following:

$$u_c^2(q) = \frac{1}{(2996.0)^2}(0.1)^2 + \frac{1}{(2996.0)^2}(0.05)^2 + \frac{(1013.7)^2}{(2996.0)^4}(2.3)^2 \quad (18)$$

or

$$u_c^2(q) = 1.11408 \times 10^{-9} + 2.7852 \times 10^{-10} + 6.74695 \times 10^{-8} \quad (19)$$

so that

$$u_c^2(q) = 6.88621 \times 10^{-8} \quad (20)$$

and

$$u_c(q) = 0.00026242 \text{ ft}^3/\text{sec} \quad (21)$$

Equivalently,

$$u_c(q) = 0.94 \text{ ACFH} \quad (22)$$

The next step in the uncertainty analysis is to calculate υ_{eff}. Because we are dealing with manufacturer specifications for all components of uncertainty, we assume that the number of degrees of freedom in each case is infinite. That is, each of the υ_i in eq. (15) is equal to infinity. The result is then

$$\upsilon_{eff} = \infty \quad (23)$$

From Table B.1 of NIST/TN 1297 (see also ANSI/NCSL Z540.2-1997), it follows then that

$$k_p = t_p\ \upsilon_{eff} = 1.960 \quad (24)$$

and the expanded uncertainty in the flow rate at the 95% confidence level is given by

$$U_p = k_p\ u_c(q) = 1.8 \text{ ACFH} \quad (25)$$

The flow rate can then be expressed as q = 1218.1 ± 1.8 ACFH to 95% confidence.

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