
Measurement of Gas by Multipath Ultrasonic Meters

Transmission Measurement Committee



AGA Report No. 9

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FOREWORD

This report is published as a recommended practice and is not issued as a standard. It has been written in the form of a performance-based specification. Multipath ultrasonic meters should meet or exceed the accuracy, functional and testing requirements specified in this report and users should follow the applicable installation recommendations.

AGA Engineering Technical Note M-96-2-3, *Ultrasonic Flow Measurement for Natural Gas Applications*, is included in Appendix C, as a source of background information on ultrasonic gas metering. Contents of this technical note were based on the information available when the note was written in March 1996. Therefore, in case of any conflict between the information in the main report and the technical note (Appendix C) the content in the main report prevails.

Research test results and flow-meter calibration data have indicated that multipath ultrasonic flow meters can accurately measure gas flow rate when installed with upstream piping lengths sufficient to produce fully developed turbulent flow-velocity profiles. Various combinations of upstream fittings, valves and lengths of straight pipe can produce profile disturbances at the meter inlet that may result in flow-rate measurement errors. The amount of meter error will depend on the magnitude of the inlet velocity profile distortion produced by the upstream piping configuration and the meter's ability to compensate for this distortion. Other effects that may also result in flow-rate measurement errors for a given installation include levels of pulsation, range of operating pressures and ambient temperature conditions.

A flow calibration of each meter may be necessary to meet the accuracy requirements specified in this report. Flow-calibration guidelines are provided for occasions when a flow calibration is requested by the user to verify the meter's accuracy or to apply a calibration factor to minimize the measurement uncertainty (see Appendix A).

Unlike most traditional gas meters, multipath ultrasonic meters inherently have an embedded microprocessor system. Therefore, this report includes, by reference, a standardized set of international testing specifications applicable to electronic gas meters. These tests, summarized in Appendix B, are used to demonstrate the acceptable performance of the multipath ultrasonic meter's electronic system design under different influences and disturbances.

This report offers general criteria for the measurement of gas by multipath ultrasonic meters. It is the cumulative result of years of experience of many individuals and organizations acquainted with measuring gas flow rate. Changes to this report may become necessary from time to time. When any revisions are deemed advisable, recommendations should be forwarded to: **Operations and Engineering Section, American Gas Association, 400 North Capitol Street, NW, 4th Floor, Washington, DC 20001, U.S.A.** A form is included for that purpose at the end of this report.

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AGA's Transmission Measurement Committee members represent a broad base of experience in natural gas measurement technologies. Through its committee structure, AGA provides the mechanism by which these committee members' experiences and technical expertise are used collectively to prepare industry guidelines, recommendations and reports.

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1 Introduction

1.1 Scope

This report was developed for multipath ultrasonic transit-time flow meters, typically 6" and larger in diameter, used for the measurement of natural gas. Multipath ultrasonic meters have at least two independent pairs of measuring transducers (acoustic paths). Typical applications include measuring the flow of large volumes of gas through production facilities, transmission pipelines, storage facilities, distribution systems and large end-use customer meter sets.

1.2 Principle of Measurement

Multipath ultrasonic meters are inferential meters that derive the gas flow rate by measuring the transit times of high-frequency sound pulses. Transit times are measured for sound pulses traveling diagonally across the pipe, downstream with the gas flow and upstream against the gas flow. The difference in these transit times is related to the average gas flow velocity along the acoustic paths. Numerical calculation techniques are then used to compute the average axial gas flow velocity and the gas volume flow rate at line conditions through the meter.

The accuracy of an ultrasonic gas meter depends on several factors, such as

- precise geometry of the meter body and ultrasonic transducer locations
- the integration technique inherent in the design of the meter
- the quality of the flow profile, levels of pulsation that exist in the flowing gas stream and gas uniformity
- the accuracy of the transit-time measurements

The accuracy of the transit-time measurement depends on

- the electronic clock stability
- consistent detection of sound pulse wave reference positions
- proper compensation for signal delays of electronic components and transducers

2 Terminology

For the purposes of this report, the following definitions apply:

auditor	Representative of the operator or other interested party that audits operation of multipath ultrasonic meter.
designer	Company that designs and constructs metering facilities and purchases multipath ultrasonic meters.
inspector	Representative of the designer who visits the manufacturer's facilities for quality assurance purposes.
manufacturer	Company that designs, manufactures, sells and delivers multipath ultrasonic meters.
operator	Company that operates multipath ultrasonic meters and performs normal maintenance.
SPU	Signal Processing Unit, the portion of the multipath ultrasonic meter that is made up of the electronic microprocessor system.
UM	Multipath ultrasonic meter for measuring gas flow rates.

3 Operating Conditions

3.1 Gas Quality

The meter shall, as a minimum requirement, operate with any of the “normal range” natural gas composition mixtures specified in AGA Report No. 8. This includes relative densities between 0.554 (pure methane) and 0.87.

The manufacturer should be consulted if any of the following are expected: 1) acoustic wave attenuating carbon dioxide levels are above 10%, 2) operation near the critical density of the natural gas mixture, or 3) total sulfur level exceeds 20 grains per 100 cubic feet (320 PPM approx.), including mercaptans, H₂S and elemental sulfur compounds.

Deposits due to normal gas pipeline conditions (e.g., condensates or traces of oil mixed with mill-scale, dirt or sand) may affect the meter’s accuracy by reducing the meter’s cross-sectional area. Deposits may also attenuate or obstruct the ultrasonic sound waves emitted from and received by the ultrasonic transducers, and in some designs reflected by the internal wall of the meter.

3.2 Pressures

Ultrasonic transducers used in UMs require a minimum gas density (a function of pressure) to ensure acoustic coupling of the sound pulses to and from the gas. Therefore, the designer shall specify the expected minimum operating pressure as well as the maximum operating pressure.

3.3 Temperatures, Gas and Ambient

The UM should operate over a flowing gas temperature range of -13° to 131° F (-25° to 55° C). The designer shall specify the expected operating gas temperature range.

The operating ambient air temperature range should be at a minimum -13° to 131° F (-25° to 55° C). This ambient temperature range applies to the meter body with and without gas flow, field-mounted electronics, ultrasonic transducers, cabling, etc.

The manufacturer shall state the flowing gas and ambient air temperature specifications for the multipath ultrasonic meter, if they differ from the above.

3.4 Gas Flow Considerations

The flow-rate limits that can be measured by a UM are determined by the actual velocity of the flowing gas. The designer should determine the expected gas flow rates and verify that these values are within the q_{min} , q_t and q_{max} specified by the manufacturer (see Section 5.1 for definitions). The accuracy requirements for operation within q_{min} , q_t and q_{max} are stated in Sections 5.2, 5.2.1 and 5.2.2 of this report. The designer is cautioned to examine carefully the maximum velocity for noise and piping safety (erosion, thermowell vibrations, etc.) concerns.

UMs have the inherent capability of measuring flow in either direction with equal accuracy; i.e., they are bi-directional. The designer should specify if bi-directional measurement is required so that the manufacturer can properly configure the SPU parameters.

3.5 Upstream Piping and Flow Profiles

Upstream piping configurations may adversely affect the gas velocity profile entering a UM to such an extent that measurement error occurs. The magnitude of the error, if any, will be a function of the meter’s ability to correctly compensate for such conditions. Research work on meter installation effects is ongoing, and the designer should consult the manufacturer and review the latest meter test results to

evaluate how the accuracy of a UM may be affected by a particular piping installation configuration. Further recommendations are provided in Section 7.2.2 of this report.

4 Meter Requirements

4.1 Codes and Regulations

The meter body and all other parts, including the pressure-containing structures and external electronic components, shall be designed and constructed of materials suitable for the service conditions for which the meter is rated, and in accordance with any codes and regulations applicable to each specific meter installation, as specified by the designer.

Unless otherwise specified by the designer, the meter shall be suitable for operation in a facility subject to the U.S. Department of Transportation's (DOT) regulations in 49 C.F.R. Part 192, *Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards*.

4.2 Meter Body

4.2.1 Maximum Operating Pressure

Meters should be manufactured to meet one of the common pipeline flange classes — ANSI Class 300, 600, 900, etc. The maximum design operating pressure of the meter should be the lowest of the maximum design operating pressure of the following: meter body, flanges, transducer connections, transducer assemblies.

The required maximum operating pressure shall be determined using the applicable codes for the jurisdiction in which the meter will be operated and for the specified environmental temperature range. The designer should provide the manufacturer with information on all applicable codes for the installation site and any other requirements specific to the operator.

4.2.2 Corrosion Resistance

All wetted parts of the meter shall be manufactured of materials compatible with natural gas and related fluids.

All external parts of the meter should be made of a noncorrosive material or sealed with a corrosion-resistant coating suitable for use in atmospheres typically found in the natural gas industry, and/or as specified by the designer.

4.2.3 Meter Body Lengths and Bores

The manufacturers should publish their standard overall face-to-face length of the meter body with flanges, for each ANSI flange class and diameter. The designer, as an option, may specify a different length to match existing piping requirements.

The UM bore and the adjacent upstream pipe along with flanges should have the same inside diameter to within 1% of each other. For bi-directional applications, both ends of the meter should be considered “upstream.”

4.2.4 Ultrasonic Transducer Ports

Because natural gas may contain some impurities (e.g., light oils or condensates), transducer ports should be designed in a way that reduces the possibility of liquids or solids accumulating in the transducer ports.

If specified by the designer and available from the manufacturer, the meter should be equipped with valves and necessary additional devices, mounted on the transducer ports in order to make it possible to replace the ultrasonic transducers without depressurizing the meter run. In that case, a bleed valve may be required in addition to the isolation valve to ensure that no pressure exists behind a transducer before releasing the extraction mechanism.

4.2.5 Pressure Tap

At least one pressure tap shall be provided for measuring the static pressure in the meter. Each pressure-tap hole should be between 1/8" and 3/8" nominal in diameter and cylindrical over a length at least 2.5 times the diameter of the tapping, measured from the inner wall of the meter body. The tap hole edges at the internal wall of the meter body should be free of burrs and wire edges, and have minimum rounding. For a meter body with a wall thickness less than 5/16", the hole should be 1/8" nominal in diameter.

Female pipe threads should be provided at each pressure tap for a 1/4" NPT or 1/2" NPT isolation valve. Turning radius clearance should be provided to allow a valve body to be screwed directly into the pressure tap. Pressure taps can be located at the top, left side, and/or right side of the meter body. Additional taps may provide the designer with flexibility in locating pressure transducers for maintenance access and proper drainage of gauge line condensates back into the meter body.

4.2.6 Miscellaneous

The meter should be designed in such a way that the body will not roll when resting on a smooth surface with a slope of up to 10%. This is to prevent damage to the protruding transducers and SPU when the UM is temporarily set on the ground during installation or maintenance work.

The meter should be designed to permit easy and safe handling of the meter during transportation and installation. Hoisting eyes or clearance for lifting straps should be provided.

4.2.7 Meter Body Markings

A nameplate containing the following information should be affixed to the meter body.

- the manufacturer, model number, serial number and month and year manufactured
- meter size, flange class and total weight
- internal diameter
- maximum and minimum storage temperatures
- body design code and material, and flange design code and material
- maximum operating pressure and temperature range
- maximum and minimum actual (at flowing conditions) volumetric flow rate per hour
- direction of positive or forward flow
- (optional) purchase order number, shop order number and/or user tag number

Each transducer port should be permanently marked with a unique designation for easy reference. If markings are stamped on the meter body, low-stress stamps that produce a rounded bottom impression should be used.

4.3 Ultrasonic Transducers

4.3.1 Specifications

The manufacturers should state the general specifications of their ultrasonic transducers, such as critical dimensions, maximum allowable operating pressure, operating pressure range, operating temperature range and gas composition limitations.

The manufacturer should specify the minimum operating pressure based on the ultrasonic transducer model, UM size and expected operating conditions. This minimum pressure should be marked or tagged on the UM to alert the operator's field personnel that the meter may not register flow at reduced pipeline pressures.

4.3.2 Rate of Pressure Change

Sudden depressurization of an ultrasonic transducer can cause damage if a trapped volume of gas expands inside the transducer. If necessary, clear instructions should be provided by the manufacturer for depressurization and pressurization of the meter and transducers during installation, start-up, maintenance and operation.

4.3.3 Exchange

It shall be possible to replace or relocate transducers without a significant change in meter performance. This means that after an exchange of transducers and a possible change of SPU software constants directed by the manufacturer, the resulting shift in the meter's performance shall not be outside the limits of the performance requirements specified in Sections 5.2, 5.2.1 and 5.2.2. The manufacturer should specify procedures to be used when transducers have to be exchanged, and possible mechanical, electrical or other measurements and adjustments have to be made.

4.3.4 Transducer Tests

Each transducer or pair of transducers should be tested by the manufacturer and the results documented as part of the UM's quality assurance program. Each transducer should be marked or tagged with a permanent serial number and be provided with the general transducer data listed in Section 4.3.1. If the SPU requires specific transducer characterization parameters, each transducer or transducer pair should also be provided with test documentation that contains the specific calibration test data, calibration method used and characterization parameter(s).

4.4 Electronics

4.4.1 General Requirements

The UM's electronics system, including power supplies, microcomputer, signal processing components and ultrasonic transducer excitation circuits, may be housed in one or more enclosures mounted on or next to the meter and is referred to as a Signal Processing Unit (SPU).

Optionally, a remote unit containing the power supplies and the operator interface could be installed in a nonhazardous area and connected to the SPU by multi-conductor cable.

The SPU should operate over its entire specified environmental conditions within the meter performance requirements specified in Sections 5.2, 5.2.1 and 5.2.2. It should also be possible to replace the entire SPU or change any field replacement module without a significant change in meter performance. "Significant change" is explained in Section 4.3.3.

The system should contain a watch-dog-timer function to ensure automatic restart of the SPU in the event of a program fault or lock-up.

The meter should operate from a power supply of nominal 120V AC or 240V AC at 50 or 60 Hz or from nominal 12V DC or 24V DC power supply/battery systems, as specified by the designer.

4.4.2 Output Signal Specifications

The SPU should be equipped with at least one of the following outputs.

- serial data interface; e.g., RS-232, RS-485 or equivalent
- frequency, representing flow rate at line conditions

The meter may also be equipped with an analog (4-20mA, DC) output for flow rate at line conditions.

Flow-rate signal should be scaleable up to 120% of the meter's maximum flow rate, $q_{\max}$.

A low-flow cutoff function should be provided that sets the flow-rate output to zero when the indicated flow rate is below a minimum value (not applicable to serial data output).

Two separate flow-rate outputs and a directional state output or serial data values should be provided for bi-directional applications to facilitate the separate accumulation of volumes by the associated flow computer(s) and directional state output signal.

All outputs should be isolated from ground and have the necessary voltage protection to meet the electronics design testing requirements of Appendix B.

4.4.3 Electrical Safety Design Requirements

The design of the UM, including the SPU, should be analyzed, tested and certified by an applicable laboratory, and then each meter should be labeled as approved for operation in a National Electric Code Class I, Division 2, Group D, Hazardous Area, at a minimum. Intrinsically safe designs and explosion-proof enclosure designs are generally certified and labeled for Division 1 locations. The designer may specify the more severe Division 1 location requirement to achieve a more conservative installation design.

Cable jackets, rubber, plastic and other exposed parts should be resistant to ultraviolet light, flames, oil and grease.

4.5 Computer Programs

4.5.1 Firmware

Computer codes responsible for the control and operation of the meter should be stored in a nonvolatile memory. All flow-calculation constants and the operator-entered parameters should also be stored in nonvolatile memory.

For auditing purposes, it should be possible to verify all flow-calculation constants and parameters while the meter is in operation.

The manufacturer should maintain a record of all firmware revisions, including revision serial number, date of revision, applicable meter models, circuit board revisions and a description of changes to the firmware.

The firmware revision number, revision date, serial number and/or checksum should be available to the auditor by visual inspection of the firmware chip, display or digital communications port.

The manufacturer may offer firmware upgrades from time to time to improve the performance of the meter or add additional features. The manufacturer shall notify the operator if the firmware revision will affect the accuracy of a flow-calibrated meter.

4.5.2 Configuration and Maintenance Software

The meter should be supplied with a capability for local or remote configuring of the SPU and for monitoring the operation of the meter. As a minimum, the software should be able to display and record the following measurements: flow rate at line conditions, mean velocity, average speed of sound, speed of sound along each acoustic path and ultrasonic acoustic signal quality received by each transducer. As an option, the manufacturer can provide these software functions as part of the meter's embedded software.

4.5.3 Inspection and Auditing Functions

It should be possible for the auditor or the inspector to view and print the flow-measurement configuration parameters used by the SPU; e.g., calibration constants, meter dimensions, time averaging period and sampling rate.

Provisions should be made to prevent an accidental or undetectable alteration of those parameters that affects the performance of the meter. Suitable provisions include a sealable switch or jumper, a permanent programmable read-only memory chip or a password in the SPU.

(Optional) It should be possible for the auditor to verify that all algorithms, constants and configuration parameters being used, in any specific meter, are producing the same or better performance as when the meter design was originally flow-tested or when the specific meter was last flow-calibrated and any calibration factors were changed. The auditor may have to rely on the manufacturer for portions of this verification because of the proprietary nature of some UM algorithms.

4.5.4 Alarms

The following alarm-status outputs should be provided in the form of fail-safe, dry, relay contacts or voltage-free solid-state switches isolated from ground.

- output invalid: when the indicated flow rate at line conditions is invalid
- (optional) trouble: when any of several monitored parameters fall outside of normal operation for a significant period of time
- (optional) partial failure: when one or more of the multiple ultrasonic path results is not usable

4.5.5 Diagnostic Measurements

The manufacturer should provide the following and other diagnostic measurements via a serial data interface; e.g., RS-232, RS-485 or equivalent.

- average axial flow velocity through the meter
- flow velocity for each acoustic path (or equivalent for evaluation of the flowing velocity profile)
- speed of sound along each acoustic path
- average speed of sound
- velocity sampling interval
- averaging time interval
- percentage of accepted pulses for each acoustic path
- status and measurement quality indicators
- alarm and failure indicators

4.5.6 Engineering Units

The following units should be used for the various values associated with the UM.

<u>Parameter</u>	<u>U.S. Units</u>	<u>SI Units</u>
density	lb/cf	kg/m ³
energy	Btu	J
mass	lb	kg
pipe diameter	in	mm
pressure	psi or lbf/in ²	bar or Pa
temperature	°F	°C
velocity	ft/s	m/s
viscosity, absolute dynamic	lb/(ft·sec)	cP or Pa·s
volume	cf	m ³
actual (at flowing conditions) volume flow rate	acf/h	am ³ /h

4.6 Documentation

Other sections of this report require documentation on accuracy, installation effects, electronics, ultrasonic transducers and zero-flow verification. The manufacturer should also provide all necessary data, certificates and documentation for a correct configuration, set-up and use of the particular meter so that it operates correctly. This includes an operator's manual, pressure test certificates, material certificates, measurement report on all geometrical parameters of the spool piece and certificates specifying the zero-flow verification parameters used. Quality-assurance documentation should be available for the inspector or the designer upon request.

The manufacturer should provide the following set of documents, at a minimum. All documentation should be dated.

- a. a description of the meter, giving the technical characteristics and the principle of its operation
- b. a perspective drawing or photograph of the meter
- c. a nomenclature of parts with a description of constituent materials of such parts
- d. an assembly drawing with identification of the component parts listed in the nomenclature
- e. a dimensioned drawing
- f. a drawing showing the location of verification marks and seals
- g. a dimensioned drawing of metrologically important components
- h. a drawing of the data plate or face plate and of the arrangements for inscriptions
- i. a drawing of any auxiliary devices
- j. instructions for installation, operation, periodic maintenance and trouble-shooting
- k. maintenance documentation, including third-party drawings for any field-repairable components
- l. a description of the electronic SPU and its arrangement, and a general description of its operation
- m. a description of the available output signals and any adjustment mechanisms

- n. a list of electronic interfaces and user wiring termination points with their essential characteristics
- o. a description of software functions and SPU configuration parameters, including their default value and operating instructions
- p. documentation that the design and construction comply with applicable safety codes and regulations
- q. documentation that the meter's performance meets the requirements of Section 5, "Performance Requirements"
- r. documentation that the meter's design successfully passed the tests in Appendix B, "Electronics Design Testing"
- s. upstream and downstream piping configurations in minimum length that will not create an additional flow-rate measurement error of more than $\pm 0.3\%$
- t. maximum allowable flow-profile disturbance, which will not create an additional flow-rate measurement error of more than $\pm 0.3\%$
- u. a field verification test procedure as described in Section 8
- v. a list of the documents submitted

4.6.1 After Receipt of Order

The manufacturer should furnish specific meter outline drawings, including overall flange face-to-face dimensions, inside diameter, maintenance space clearances, conduit connection points and estimated weight.

The manufacturer should provide a recommended list of spare parts.

The manufacturer should also furnish meter-specific electrical drawings that show customer wiring termination points and associated electrical schematics for all circuit components back to the first isolating component; e.g., optical isolator, relay, operational amplifier, etc. This will allow the designer to properly design the interfacing electronic circuits.

4.6.2 Before Shipment

Prior to shipment of the meter, the manufacturer should make the following available for the inspector's review: metallurgy reports, weld inspection reports, pressure test reports and final dimensional measurements as required in Section 6.2.

5 Performance Requirements

This section specifies a set of minimum measurement performance requirements that UMs must meet. If a meter is not flow-calibrated, the manufacturer shall provide sufficient test data confirming that each meter shall meet these performance requirements. The designer may also specify that a meter be flow-calibrated per Section 6.4. If a meter is flow-calibrated, then it shall meet the same minimum measurement performance requirements before the application of any calibration-factor adjustment. The amount of calibration-factor adjustment, therefore, should be within the error limits stated in the performance requirements. This is to ensure that a major flaw in the meter is not masked by a large calibration-factor adjustment. Calibration-factor adjustments are made to minimize a meter's measurement bias error. The designer is referred to Appendix A and Section 6.4.1 for an explanation of

the methods and benefits of flow-calibrating a meter and for calibration-factor adjustment. The designer should also follow carefully the installation recommendations of Section 7, as any installation effects will add to the overall measurement uncertainty.

For each meter design and size, the manufacturer shall specify flow-rate limits for $q_{\min}$, q_t and $q_{\max}$ as defined in Section 5.1. Each UM, whether flow-calibrated or not, shall perform within the more accurate measurement range for gas flow rates from q_t to $q_{\max}$ and within the less accurate range for gas flow rates less than q_t but greater than or equal to $q_{\min}$, as defined in Sections 5.2, 5.2.1 and 5.2.2.

5.1 Definitions

Deviation	The difference between the actual volume flow rate (e.g., flow rates in engineering units of acf/h) measured by the meter under test and the actual volume flow rate measured by a reference meter. Corrections shall be made for the differences in flowing gas pressure, temperature and compressibility between the two meters. The deviation is also measured as a difference between the mass flow rate through the meter under test and the mass flow rate through the reference meter. Typically, three or more test runs are averaged to establish the deviation at each nominal flow rate. These test runs can be used to determine the repeatability as defined below.
Error	The observed deviation of a meter calculated as: Percent Error = [(Test Meter Reading – Reference Meter Reading) ÷ (Reference Meter Reading)] x 100.
Maximum Error	The allowable error limit within the specified operational range of the meter, as shown in Figure 1 and Sections 5.2.1 and 5.2.2.
Maximum Peak-to-Peak Error	The largest allowable difference between the upper-most error point and the lower-most error point as shown in Figure 1 and Section 5.2. This applies to all error values in the flow-rate range between q_t and $q_{\max}$.
$q_{\max}$	The <i>maximum</i> gas flow rate through the UM that can be measured within the error limits, as shown in Sections 5.2.1 and 5.2.2 for large and small meters, respectively.
q_t	The <i>transition</i> gas flow rate below which the expanded error limit is applicable, and where $q_t \leq 0.1q_{\max}$. See Figure 1 and Sections 5.2.1 and 5.2.2.
$q_{\min}$	The <i>minimum</i> gas flow rate through the UM that can be measured within the expanded error limits, as shown in Figure 1 and Sections 5.2.1 and 5.2.2.
q_i	The actual measured gas flow rate passing through a UM under a specific set of test conditions.

Reference Meter A meter or measurement device of proven flow measurement accuracy.

Repeatability The closeness of agreement among a number of consecutive measurements of the output of the test meter for the same reference flow rate under the same operating conditions, approaching from the same direction, for full-scale traverses. The repeatability shall correspond to the 95% confidence interval of the deviation based on the assumption of a normal distribution. See Section 5.2.

Resolution The smallest step by which the change of the flow velocity is indicated by the meter. See Section 5.2.

Velocity Sampling Interval The time interval between two succeeding gas velocity measurements by the full set of transducers or acoustic paths. Typically, between 0.05 and 0.5 seconds, depending on meter size. See Section 5.2.

Zero-Flow Reading The maximum allowable flow-velocity reading when the gas is at rest; i.e., both the axial and the non-axial velocity components are essentially zero. See Section 5.2.

5.2 General

The general flow-measurement performance of *all* UMs shall meet the following requirements, prior to making any calibration-factor adjustment.

Repeatability:	$\pm 0.2\%$ for $q_t \leq q_i \leq q_{\max}$ $\pm 0.4\%$ for $q_{\min} \leq q_i < q_t$
Resolution:	0.003 ft/s (0.001 m/s)
Velocity Sampling Interval:	≤ 1 second
Maximum Peak-to-Peak Error:	0.7% for $q_t \leq q_i \leq q_{\max}$ (See Figure 1)
Zero-Flow Reading:	< 0.040 ft/s (12 mm/s) for each acoustic path

5.2.1 Large Meter Accuracy

UMs of 12" (nominal) diameter size and larger shall meet the following flow-measurement accuracy requirements, prior to making any calibration-factor adjustment.

Maximum Error:	$\pm 0.7\%$ for $q_t \leq q_i \leq q_{\max}$ (See Figure 1) $\pm 1.4\%$ for $q_{\min} \leq q_i < q_t$
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5.2.2 Small Meter Accuracy

UMs less than 12" (nominal) diameter shall meet the following flow-measurement accuracy requirements, prior to making any calibration-factor adjustment. Note that the requirements for the smaller meters have been relaxed slightly because of the difficulty in measuring acoustic transit times in turbulent gas flow when the path lengths are shorter.

Maximum Error:	$\pm 1.0\%$ for $q_t \leq q_i \leq q_{\max}$
(See Figure 1)	$\pm 1.4\%$ for $q_{\min} \leq q_i < q_t$

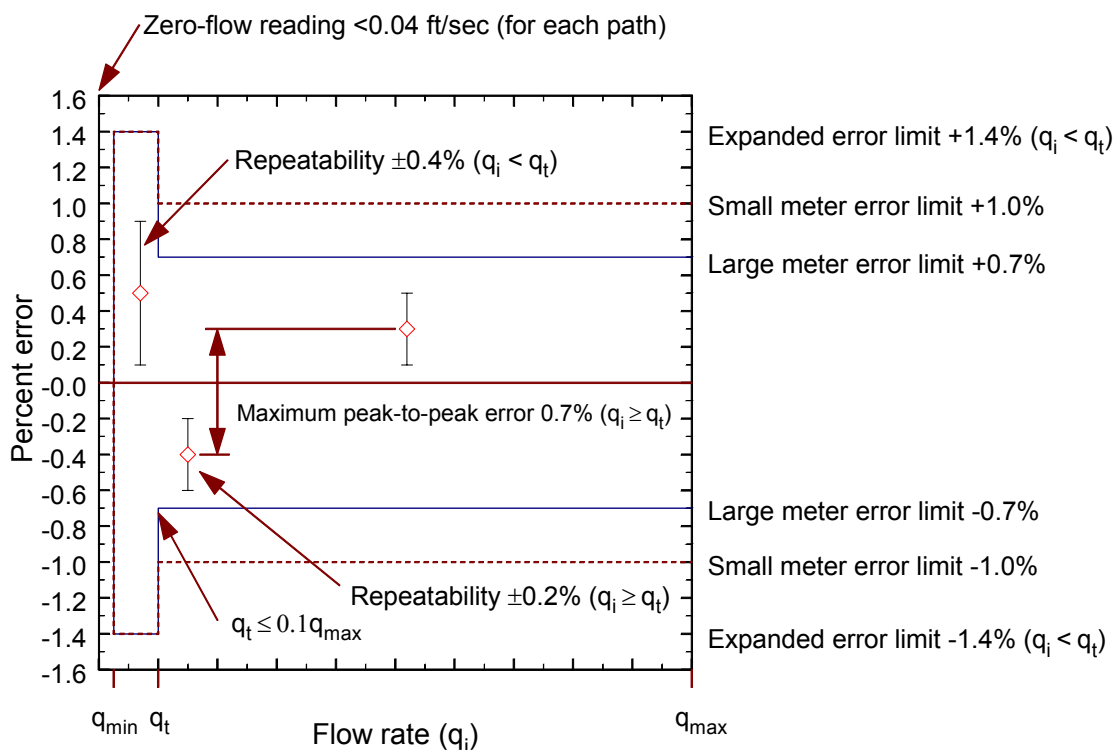


Figure 1

Performance Specification Summary

5.3 Pressure, Temperature and Gas Composition Influences

The UM shall meet the above flow-measurement accuracy requirements over the full operating pressure, temperature and gas composition ranges without the need for manual adjustment, unless otherwise stated by the manufacturer. If the UM requires a manual input to characterize the flowing gas conditions (e.g., gas density and viscosity), the manufacturer shall state the sensitivity of these parameters so that the operator can determine the need to change these parameters as operating conditions change.

6 Individual Meter Testing Requirements

Prior to the shipment of each UM to the designer or the operator, the manufacturer shall perform the following tests and checks on each meter. The results of all tests and checks performed on each meter shall be documented in a report (see Section 6.4.2) prepared by the manufacturer and submitted to the designer or the operator.

6.1 Leakage Tests

Every UM, complete with transducers and transducer isolation valves (if used), shall be leak-tested by the manufacturer after final assembly and prior to shipment to the designer or flow-calibration facility. The test medium should be an inert gas, such as nitrogen. The leak test pressure shall be a minimum of 200 psig, maintained for a minimum of 15 minutes, with no leaks detectable with a noncorrosive liquid solution or an ultrasonic leak detector as described in ASTM E 1002 - 93. This leak test does not preclude the requirements to perform a hydrostatic qualification test.

6.2 Dimensional Measurements

The manufacturer shall measure and document the average internal diameter of the meter, the length of each acoustic path between transducer faces and the axial (meter body axis) distance between transducer pairs.

The average internal diameter should be calculated from a total of 12 inside diameter measurements or the equivalent determined by a coordinate measuring machine. Four internal diameter measurements (one in the vertical plane, another in the horizontal plane and two in planes approximately 45° from the vertical plane) shall be made at three meter cross-sections: 1) near the set of upstream ultrasonic transducers, 2) near the set of downstream transducers and 3) half way between the two transducer sets.

If the acoustic path lengths or the axial distances between ultrasonic transducer pairs cannot be directly measured, then the unknown distances shall be calculated using right-angle trigonometry and distances that can be measured directly. Where the measurement of angles is difficult and the result is imprecise, such measurements shall not be used to calculate the required distances.

The meter body temperature shall be measured at the time these dimensional measurements are made. The measured lengths shall be corrected to an equivalent length at a meter body temperature of 68° F (20° C) by applying the applicable coefficient of thermal expansion for the meter body material. The individual corrected lengths shall then be averaged and reported to the nearest 0.0001" (0.01 mm).

All instruments used to perform these measurements shall have valid calibrations traceable to national standards; e.g., NIST in U.S.A.

These measurements and calculations shall be documented on a certificate, along with the name of the meter manufacturer, meter model, meter serial number, meter body temperature at the time dimensional measurements were made, date, name of the individual who made the measurements and name of the inspector if present.

6.3 Zero-Flow Verification Test (Zero Test)

To verify the transit-time measurement system of each meter, the manufacturer shall perform a Zero-Flow Verification Test. The manufacturer shall document and follow a detailed test procedure that includes the following elements, at a minimum.

- After blind flanges are attached to the ends of the meter body, the meter shall be purged of all air and pressurized with a pure test gas or gas mixture. The selection of the test gas shall be the

responsibility of the manufacturer. However, the acoustic properties of the test gas must be well-known and documented.

- The gas pressure and temperature shall be allowed to stabilize at the outset of the test. The gas velocities for each acoustic path shall be recorded for at least 30 seconds. The mean gas velocity and standard deviation for each acoustic path shall then be calculated.
- Adjustments to the meter shall be made as necessary to bring the meter performance into compliance with the manufacturer's specifications and the specifications stated in this report.

If the measured speed-of-sound values are compared with theoretical values, the theoretically determined value shall be computed using a complete compositional analysis of the test gas, precise measurements of the test gas pressure and temperature and the equation of state used in AGA Report No. 8, "Detail Characterization Method."

As part of the test procedure, the manufacturer shall document the ultrasonic transducer serial numbers and their relative locations in the meter body. The manufacturer shall also document all parameters used by the meter; e.g., transducer/electronic transit-time delays, incremental timing corrections, and all acoustic path lengths, angles, diameters and other parameters used in the calculation of the gas velocity for each acoustic path. The manufacturer should note if the constants are dependent on specific transducer pairs.

The manufacturer may also implement a zero-flow offset factor, in engineering units of positive or negative feet per second or meters per second. This zero-flow offset factor would be applied to the meter's flow-rate output. Use of this factor is intended to improve the accuracy of the low gas velocity measurements, while not significantly affecting the accuracy of the higher velocity measurements. This zero-flow offset factor, if used, shall be documented by the manufacturer.

6.4 Flow-Calibration Test

If specified by the designer, the UM should be flow-calibrated. If a flow calibration is performed, the following nominal test flow rates are recommended, at a minimum: q_{min} , $0.10 q_{max}$, $0.25 q_{max}$, $0.40 q_{max}$, $0.70 q_{max}$, and q_{max} . The designer may also specify additional flow calibration tests at other flow rates. (See the example in Appendix A, where additional tests at $0.15 q_{max}$ and/or $0.20 q_{max}$ could be useful).

Flow-calibration tests should be performed at a gas pressure, temperature and density near the expected average operating conditions as specified by the designer. Tests at any other specific pressure, temperature and gas density range may be performed, if necessary. The designer may also require that specific piping configurations and/or flow conditioners be used during flow calibration, understanding that differences in upstream piping configurations may influence meter performance.

It is recognized that it may not be possible to test large UMs up to their maximum capacity because of the limitations of currently available test facilities. In such cases, the designer may specify a lower flow rate instead of q_{max} . The manufacturer should state on all applicable documents if a reduced q_{max} was used during flow-calibration tests.

The upstream flange and piping internal diameters should match and be aligned with the meter under test as specified in Section 7.2.3, "Protrusions".

All test measurements performed by a flow-calibration facility should be traceable with current calibration certificates to the applicable national standards; e.g., in the United States, traceable to NIST. Any property or thermophysical values (e.g., density, compressibility, speed of sound, critical flow factor, etc.) used during flow calibration shall be computed from AGA Report No. 8, "Detailed Characterization Method Equation of State".

The designer and the operator are encouraged to release test results to the gas industry, including flow-measurement accuracy data before and after calibration factors are applied. This will enable the

manufacturers to demonstrate UM performance and will facilitate research evaluation of current UM technology. The Gas Research Institute currently has a program to compile UM calibration data.

6.4.1 Calibration Factors Adjustment

If a meter is flow-calibrated, the calibration factors should normally be applied to eliminate any indicated meter bias error. Some suggested methods of applying calibration factors are:

- a) Using flow-weighted mean error (FWME) over the meter's expected flow range (the calculation of FWME is shown in Appendix A)
- b) Using a more sophisticated error correction scheme (e.g., a multi-point or polynomial algorithm, a piecewise linear interpolation method, etc.) over the meter's range of flow rates.

For bi-directional flow calibrations, a second set of calibration factors may be used for reverse flow.

If an offset factor was established during the zero-flow validation tests, it may be revised based on the results of the flow calibration to optimize the meter's overall accuracy performance. The manufacturer shall document such a change in this factor and alert the operator that the zero-flow output may have some intentional bias in order to improve accuracy at $q_{\min}$.

6.4.2 Test Reports

The results of each test required in Section 6, shall be documented in a written report supplied to the designer or the operator by the manufacturer. For each meter, the report shall include, at a minimum:

- a. the name and address of the manufacturer
- b. the name and address of the test facility
- c. the model and serial number
- d. the SPU firmware revision number
- e. the date(s) of the test
- f. the name and title of the person(s) who conducted the tests
- g. a written description of the test procedures
- h. the upstream and downstream piping configurations
- i. a diagnostic report of the software configuration parameters
- j. all test data, including flow rates, pressures, temperatures, gas composition and the measurement uncertainty of the test facility
- k. a description of any variations or deviations from the required test conditions

At least one copy of the complete report shall be sent to the designer or the operator and one copy retained in the manufacturer's files. The manufacturer shall ensure that the complete report is available to the operator on request, for a period of 10 years after shipment of any meter.

6.5 Quality Assurance

The manufacturer shall establish and follow a written comprehensive quality-assurance program for the assembly and testing of the meter and its electronic system (e.g., ISO 9000, API Specification Q1, etc.). This quality-assurance program should be available to the inspector.