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BSI Standards Publication

Measurement of fluid flow in closed conduits — Ultrasonic meters for gas

Part 1: Meters for custody transfer and allocation measurement

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National foreword

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Measurement of fluid flow in closed conduits — Ultrasonic meters for gas —

Part 1: Meters for custody transfer and allocation measurement

Mesurage du débit des fluides dans les conduites fermées — Compteurs à ultrasons pour gaz —

Partie 1: Compteurs pour transactions commerciales et allocations

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CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 5, *Velocity and mass methods*.

This second edition cancels and replaces the first edition (ISO 17089-1:2010), which has been technically revised. The main changes compared to the previous edition are as follows:

— Clause 3 has been revised;

— Formulae have been corrected throughout the document;

— editorial and terminological changes throughout the document;

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Introduction

Ultrasonic meters (USMs) for gas flow measurement have penetrated the market for meters rapidly since 2000 and have become one of the prime flowmeter concepts for operational use as well as custody transfer and allocation measurement. Next to the high repeatability and high accuracy, ultrasonic technology has inherent features like: negligible pressure loss; high rangeability; and the capability to handle pulsating flows.

USMs can deliver extended diagnostic information through which it may be possible to demonstrate the functionality of an USM. Also, the measured speed of sound of the USM may be compared with the speed of sound calculated from pressure, temperature, and gas composition, to check the mutual consistency of the four instruments involved. Due to the extended diagnostic capabilities, this document advocates the addition and use of automated diagnostics instead of labour-intensive quality checks.

This document focuses on meters for custody transfer and allocation measurement (class 1 and class 2 meters). Meters for industrial gas applications, such as utilities and process, as well as flare gas and vent measurement, is the subject of ISO 17089-2.

Typical performance factors of the classification scheme are:

Class	Typical applications	Required accuracy class	Reference
1	Custody transfer	class 0.5 or class 1.0	This document
2	Allocation	class 1.5	This document
3	Utilities and process		ISO 17089-2
4	Flare gas and vent gas		ISO 17089-2

Typical configurations for class 1 and class 2 meters are multi-path meters with chords at different radial positions.

Typical configurations for class 3 and class 4 meters are single-path meters, meters with only diametrical paths, insertion type meters, household type, stack or chimney type, and flare type meters.

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Measurement of fluid flow in closed conduits — Ultrasonic meters for gas —

Part 1: Meters for custody transfer and allocation measurement

1 Scope

This document specifies requirements and recommendations for ultrasonic gas flowmeters (USMs), which utilize the transit time of acoustic signals to measure the flow of single phase homogenous gases in closed conduits.

This document applies to transit time ultrasonic gas flowmeters used for custody transfer and allocation metering, such as full-bore, reduced-area, high-pressure, and low-pressure meters or any combination of these. There are no limits on the minimum or maximum sizes of the meter. This document can be applied to the measurement of almost any type of gas, such as air, natural gas, and ethane.

Included are flow measurement performance requirements for meters of two accuracy classes suitable for applications such as custody transfer and allocation measurement.

This document specifies construction, performance, calibration, diagnostics for meter verification, and output characteristics of ultrasonic meters for gas flow measurement and deals with installation conditions.

NOTE It is possible that national or other regulations apply which can be more stringent than those in this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4006, *Measurement of fluid flow in closed conduits — Vocabulary and symbols*

ISO 5168, *Measurement of fluid flow — Procedures for the evaluation of uncertainties*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4006 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

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3.1.1 Quantities

3.1.1.1
volume flow rate

$$q_V = \frac{\mathrm{d}V}{\mathrm{d}t}$$

where

V is volume

t is time

3.1.1.2
pressure
p
absolute gas pressure in a meter under flowing conditions to which the indicated volume of gas is related

3.1.1.3
average velocity
v
volume flow rate divided by the cross-sectional area

3.1.2 Meter design

3.1.2.1
meter body
pressure-containing structure of the meter

3.1.2.2
acoustic path
path travelled by an acoustic signal between a pair of ultrasonic transducers

3.1.2.3
axial path
path travelled by an acoustic signal entirely in the direction of the main pipe axis

Note 1 to entry: An axial path can be both on or parallel to the centre-line or long axis of the pipe, see Figure 1.

Figure 1 — Axial path

3.1.2.4
diametrical path
acoustic path whereby the acoustic signal travels through the centre-line or long axis of the pipe

Note 1 to entry: See Figure 2 for a representation.

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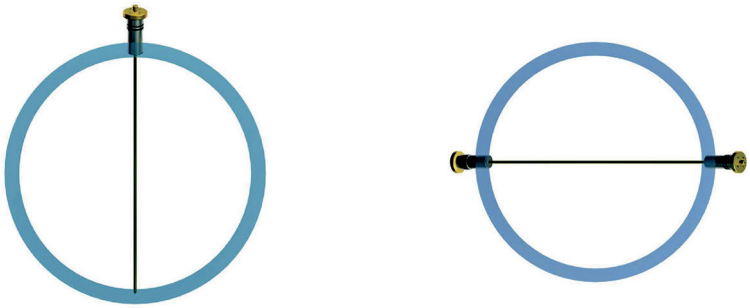

Figure 2 — Diametrical paths

3.1.2.5
chordal path
acoustic path whereby the acoustic signal travels parallel to the diametrical path

Note 1 to entry: See Figure 3 for a representation.

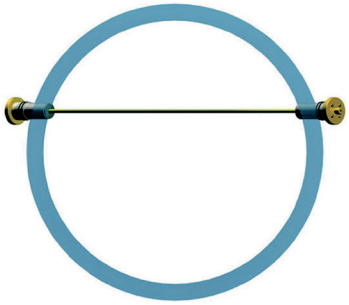

Figure 3 — Chordal paths

3.1.3 Thermodynamic conditions

3.1.3.1
metering conditions
conditions, at the point of measurement, of the fluid whose volume is to be measured

Note 1 to entry: Metering conditions include gas composition, gas temperature, and gas pressure.

[SOURCE: ISO 9951:1993, 3.1.6, modified — the term fluid is used instead of gas.]

3.1.3.2
base conditions
conditions to which the measured volume of the fluid is converted

Note 1 to entry: Base conditions include base temperature and base pressure.

[SOURCE: ISO 9951:1993, 3.1.7, modified — the term fluid is used instead of gas.]

3.1.4 Statistics

3.1.4.1
measurement error
the error of measurement is the measured quantity value minus a reference quantity value

[SOURCE: ISO/IEC Guide 99:2007, 2.16]

EXAMPLE Measured quantity value of meter under test minus quantity value of reference meter.

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3.1.4.2
calibration curve
set of measurmement errors, at a number of different flow rates, with respect to a known reference quantity meter

3.1.4.3
maximum permissible error
extreme value of measurement error, with respect to a known reference quantity value, permitted by specifications or regulations for a given operational range of the meter

[SOURCE: ISO/IEC Guide 99:2007, 4.26, modified — the term measurement has been removed from the definition, thus the current term can be abbribivated by MPE.]

3.1.4.4
maximum peak-to-peak error
maximum difference between any two error values

3.1.4.5
repeatability
closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement

Note 1 to entry: The repeatability shall be calculated in absolute terms for the meter error as the type A uncertainty in a single measurement (U_{AS}) according to ISO 5168. The coverage factor k_{95} shall be derived from the Student's distribution for a 95,45 % confidence level depending on the number of measurements taken. See ISO 5168:2005, Table C.1.

$$r_p = U_{AS} = k_{95}\sqrt{\frac{\sum_{i=1}^{n}\left(E_i - \bar{E}\right)^2}{(n-1)}}$$

Typical values of the coverage factor k_{95} are:

Measurements taken	3	5	7	10	100	∞
Coverage factor k_{95}	4,53	2,87	2,52	2,32	2,02	2,00

3.1.4.6
reproducibility
closeness of the agreement between the results of measurements of the same measurand carried out under changed conditions of measurement

3.1.4.7
resolution
smallest difference between indications of a meter that can be meaningfully distinguished

[SOURCE: ISO 11631:1998, 3.28, modified — the term meter has been replaced by flowmeter.]

3.1.4.8
zero flow reading
flow-velocity reading when the gas is assumed to be at rest, i.e. both the axial and non-axial velocity components are essentially zero

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3.1.4.9
linearization
way of reducing the non-linearity and offset of the ultrasonic meter readingby applying corrections in the software

Note 1 to entry: The linearization can be applied to meter electronics or in a flow computer connected to the USM. The correction can be, for example, piece-wise linearization or polynomial linearization.

3.2 Symbols and subscripts

The symbols and subscripts used in this document are given in Tables 1 and 2. Examples of uses of the volume flow rate symbol are given in Table 3.

Table 1 — Symbols

Quantity	Symbol	Dimensions[a]	SI unit
Cross-sectional area	A	L^2	m^2
Speed of sound in fluid	c	LT^{-1}	m/s
Outside pipe diameter	D	L	m
Inside diameter of the meter body	d	L	m
Modulus of elasticity; Young modulus meter body	E	$ML^{-1}T^{-2}$	MPa
Modulus of elasticity; Young modulus tranducer	E_t	$ML^{-1}T^{-2}$	MPa
Indicated flow error	E_i	—	1
Weighting factor (live inputs)	f_i	—	1
Integers (1, 2, 3, ...)	i, j, n	—	1
Impulse factor	I	L^{-3}	m^{-3}
Calibration factor	K	—	1
Body style factor	K_s	—	1
Body end correction factor	K_E	—	1
Velocity distribution correction factor	k_h	—	1
Flange stiffening factor	K_f	—	1
Minimum distance to a specified upstream flow disturbance	l_{min}	L	m
Typical averaging length in the ultrasonic flow meter	L_{AV}	L	m
Noise amplitude	L_p	—	dB
Path length	l_p	L	m
Attenuation factor	N_d	—	1
Valve-weighting factor	N_v	—	1
Absolute pressure	p	$ML^{-1}T^{-2}$	Pa
Pressure difference	Δp	$ML^{-1}T^{-2}$	Pa
Emitted acoustic pressure	p_n	$ML^{-1}T^{-2}$	Pa
Signal strength of the USM	P_s	$ML^{-1}T^{-2}$	Pa
Volume flow rate	q_V	L^3T^{-1}	m^3/s
Outside pipe radius	R	L	m
Inside pipe radius	r	L	m
Reynolds number	Re	—	1
Repeatability	r_p	—	1
Repeatability during calibration	r_{cal}	—	1
Absolute temperature of the gas	T	Θ	K

[a] M ≡ mass; L ≡ length; T ≡ time; Θ ≡ temperature.

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Table 1 *(continued)*

Quantity	Symbol	Dimensions[a]	SI unit
Temperature difference	ΔT	Θ	K
Time	t	T	s
Standard deviation of the instantaneous turbulent scatter	u^*	—	1
standard deviation of the required turbulent scatter after averaging	u_d	—	1
Velocity	v	LT^{-1}	m/s
Average velocity	$\bar{v}$	LT^{-1}	m/s
Velocity of the acoustic path i	v_i	LT^{-1}	m/s
Volume	V	L^3	m^3
Weighting factor (fixed value)	w_I	—	1
Compressibility	Z	—	1
Coefficient of thermal expansion	α	Θ^{-1}	K^{-1}
Error at a flow rate $q_{V,i}$	Δ_i	—	%
Pipe wall thickness	δ	L	M
Dynamic viscosity	η	$L^{-1}MT^{-1}$	Pa·s
Wavelength of ultrasonic oscillation	λ	L	M
Poisson ratio	μ	—	1
Density of fluid	ρ	ML^{-3}	kg/m^3
Sensing point for pressure measurement	p_m	—	—
Path angle	ϕ	—	rad

[a] M ≡ mass; L ≡ length; T ≡ time; Θ ≡ temperature.

Table 2 — Subscripts

Subscript	Meaning
cal	calibration
min	minimum
max	maximum
op	operational
t	transition

Table 3 — Examples of flow rate symbols

Symbol	Meaning
$q_{V,\,max,\,20}$	Designed maximum flow rate, designed for maximum gas speed of 20 m/s
$q_{V,\,max,\,x}$	Designed maximum flow rate, designed for maximum gas speed of x m/s
$q_{V,\,max,\,op}$	Operational maximum flow rate; defined only when smaller than designed maximum
$q_{V,\,max,\,cal}$	Highest flow rate calibrated; defined only when smaller than operational maximum
$q_{V,\,min}$	Designed minimum flow rate
$q_{V,\,t}$	Transition flow rate for defining accuracy requirements

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3.3 Abbrevations

CMC	calibration and measurement capability
ES	electronics system
FAT	factory acceptance test
FC	flow conditioner
FWME	flow-weighted mean error
M&R	metering and regulating stations
MPE	Maximum permissible error
MSOS	measured speed of sound
SAT	Site Acceptance Test
S/N	signal-to-noise ratio
SOS	speed of sound
TSOS	theoretical speed of sound
USM	ultrasonic flow meter
USMP	USM package, including meter tubes, flow conditioner, and thermowell
USM(P)	USM and USMP

4 Principles of measurement

4.1 Basic formulae

USMs are based on the measurement of the propagation time of acoustic signals in a flowing medium.

Figure 4 shows the basic system setup. On both sides of the pipe, at positions A and B, are mounted transducers capable of transmitting and receiving ultrasonic sound signals. These transducers transmit sound signals within such a short interval that the speed of sound (SOS) is identical for both measurements and their transit times are measured. With zero flow, the transit time from A to B, t_{AB}, is equal to the transit time from B to A, t_{BA}. However, if there is flow, the transit time of the sound signal from A to B decreases and the one from B to A increases, according to (ignoring second order effects, such as path curvature):

$$t_{AB} = \frac{l_p}{(c + v\cos\phi)} \tag{1}$$

and

$$t_{BA} = \frac{l_p}{(c - v\cos\phi)} \tag{2}$$

where

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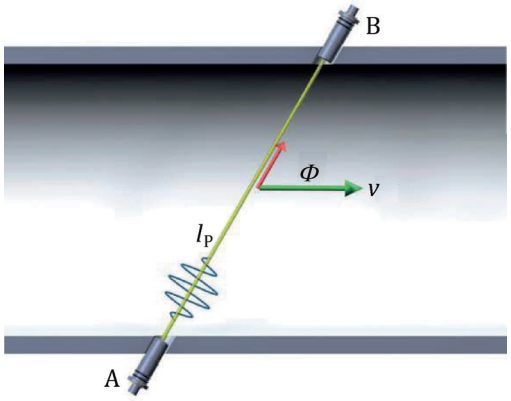
l_p is the path length;

c is the SOS;

v is the average velocity;

ϕ is the path angle;

t_{AB}, t_{BA} are transit times of the acoustic signal.



Key

A, B positions

l_P path length

v average velocity

Φ path angle

Figure 4 — Basic system set-up

Formula (3) for the measured gas velocity can be derived by subtracting Formula (2) from Formula (1):

$$v_i = \frac{l_p}{2\cos\phi}\left(\frac{1}{t_{AB}} - \frac{1}{t_{BA}}\right) \tag{3}$$

Note that the term for the SOS in the gas has been eliminated in Formula (3). This means that the measurement of the gas velocity is independent of the properties of the gas, e.g. pressure, temperature, and gas composition.

In a similar way, the SOS can be derived by adding Formulas (1) and (2) and rearranging:

$$c = \frac{l_p}{2}\left(\frac{1}{t_{AB}} + \frac{1}{t_{BA}}\right) \tag{4}$$

In multi-path meters, the individual path velocity measurements are combined by a mathematical function to yield an estimate of the average velocity:

$$v = f\left(v_1 \ldots v_n\right) \tag{5}$$

where n is the total number of paths. Due to variations in path configuration and different proprietary approaches to solving Formula (7), even for a given number of paths, the exact form of $f(v_1 \ldots v_n)$ can differ.

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To obtain the volume flow rate, q_V, multiply the estimate of the average velocity, v, by the cross-sectional area of the measurement section, A, as follows:

$$q_V = A \cdot v \tag{6}$$

4.2 Factors affecting the performance

The performance of a USM is dependent on a number of intrinsic and extrinsic factors. Intrinsic factors (i.e. those related to the meter and its calibration prior to delivery) include:

— the geometry of the meter body and ultrasonic transducer locations and the uncertainty with which these are known (including the temperature and pressure coefficient);

— the accuracy and quality of the transducers and electronic components used in the transit time measurement circuitry (e.g. the electronic clock stability);

— the techniques utilized for transit time detection and computation of average velocity (the latter of which determines the sensitivity of the meter to variations in the flow velocity distribution);

— adjustments (including proper compensation for signal delays in electronic components and transducers).

Extrinsic factors, i.e. those related to the flow and environmental conditions of the application, include:

a) the flow velocity profile including swirl and skewness;

b) change of wall roughness due to corrosion, solid and liquid contamination over time;

c) the temperature distribution;

d) flow pulsations;

e) noise, both acoustic and electromagnetic;

f) temporary or permanent buildup resulting in a reduction of the meter body cross sectional area.

4.3 Description of generic types

4.3.1 General

This generic description of USMs for gases recognizes the scope for variation within commercial designs and the potential for new developments. For the purpose of description, USMs are considered to consist of several components, namely:

a) transducers;

b) a meter body with acoustic path configuration;

c) electronics;

d) a data-processing and presentation unit.

4.3.2 Transducers

Transducers are supplied in various forms. Typically, they comprise a piezoelectric element with electrode connections and a supporting mechanical structure with which the process connection is made. The transducers for custody transfer and allocation measurement are installed in a wetted (in direct contact with the fluid) mounting arrangement. Typical arrangements are shown in Figure 5. The process connections for wetted transducers may be welded, flanged, threaded or may be more mechanically complex, e.g. to allow the removal of transducers from a pressurized line. The active

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element is usually separated from the fluid by an acoustic coupling element housing. The transducers are orientated such that the active element transmits ultrasonic signals at an angle to the meter body axis in the direction of a second transducer or reflection point in the meter body interior.

For specific applications, special transducers can be required. These can differ from the norm in terms of frequency, construction materials and mechanical arrangement. Transducer specification and mounting should be given careful consideration for extreme or difficult application conditions such as:

a) high and low temperature;

b) high and low pressure;

c) high gas velocities;

d) high acoustic attenuation;

e) close proximity to high pressure drop throttle valve (potential of in-pipe ultrasonic noise);

f) rapid or cyclic temperature or pressure changes;

g) corrosive or erosive gas (sour gas);

h) gas with traces of moisture or dirt.

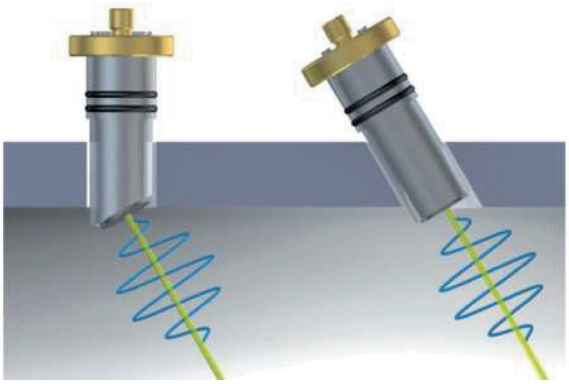

Figure 5 — Typical transducer arrangements

4.3.3 Meter body and acoustic path configurations

4.3.3.1 General

USMs are available in a variety of path configurations. The numbers of measurement paths are generally chosen based on a requirement with respect to variations in velocity distribution and required accuracy.

As well as variations in the radial position of the measurement paths in the cross-section, the path configuration can be varied in orientation to the pipe axis. By utilizing reflection of the ultrasonic signal from the interior of the meter body or from a fabricated reflector, the path can traverse the cross-section several times.

4.3.3.2 Basic acoustic paths types

Common acoustic path types are illustrated in Figure 6.

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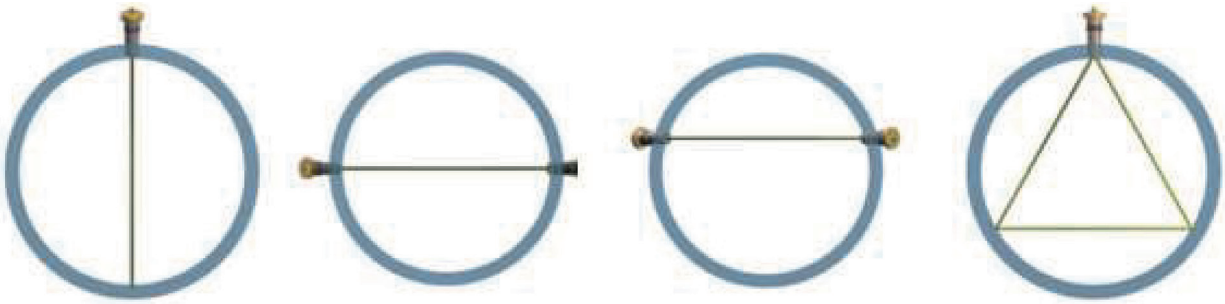
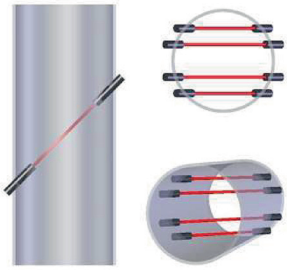


a) b) c) d)

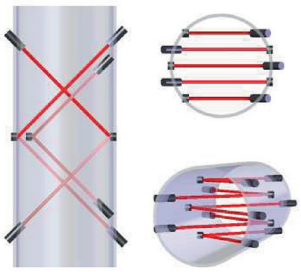
Figure 6 — Basic acoustic path types for multi-path meters

4.3.3.3 Commonly used multi-path cross-sectional configurations

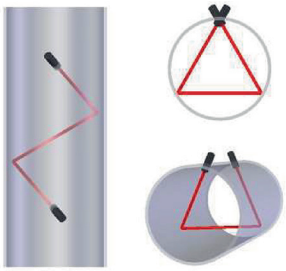
The cross-sectional configuration dictates what information about the axial velocity distribution is available for the computation of the average axial velocity. Selections of commonly encountered cross-sectional configurations are shown in Figure 7.



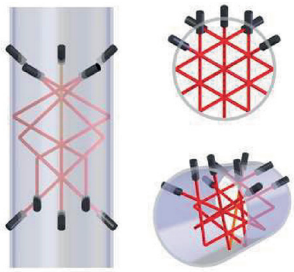
a) Multi-path parallel chord



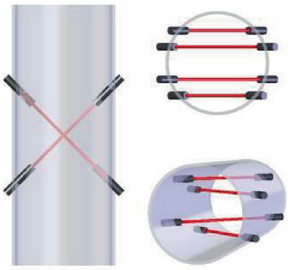
b) Multi-path parallel chord reflective



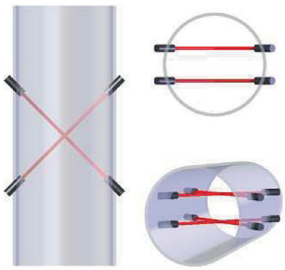
c) Single path mid-radius reflective



d) Multi-path mid-radius and diametric



e) Multi-path parallel crossed chord



f) Multi-path in plane crossed chord

Figure 7 — Selections of commonly encountered cross-sectional configurations

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4.3.4 Average velocity calculation

Meters with paths of equal radial displacement [e.g. Figure 7 c) and f)] essentially make the same measurement with respect to velocity distribution if the flow is axisymmetric, regardless of the number of paths employed. In such cases, the average velocity, v, is determined by a simple arithmetic mean. In fully developed flow, a theoretical correction factor, k_h, can be introduced to account for the known variation in velocity profile. This, however, applies only to fully developed flow, not to disturbed flows.

$$v = k_h \frac{\sum_{i=1}^{n} v_i}{n} \tag{7}$$

where

n is the total number of paths;

v_i is the flow velocity measured on path i.

The k_h factor is a function of the Reynolds number, pipe roughness, and radial displacement. In practice, it can be input as a single constant or may be calculated on the basis of static parameters or measured variables.

In the case of meters with paths at off-diameter positions [e.g. Figure 7 e) and d)], the velocity is measured at different radial positions. Several methods can be used when combining the velocities to obtain the average pipe velocity. These can be classified as follows.

Summation with constant weighting:

$$v = \sum_{i=1}^{n} w_i v_i \tag{8}$$

where the radial displacements of the paths and the constants, w_1 to w_n, are determined on the basis of documented numerical integration methods.

Or summation with variable weighting:

$$v = \sum_{i=1}^{n} f_i v_i \tag{9}$$

where the radial displacements of the paths are fixed at design and the variables, f_1 to f_n, may be determined from input parameters or measured variables (e.g. velocities).

In any of the given configurations, a multiplying or calibration factor, K (either constant or variable), may be applied after summation to correct for deviations due to manufacturing tolerances and incomplete assumptions, i.e.

$$q_V = K \cdot A \cdot v \tag{10}$$

The rules and tolerances for implementing corrections and linearization by calibration factor K are given in 5.8 and 6.3.3.

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4.4 Contributions to the uncertainty in measurement

The total volume flow, q_V, measured by a USM can be calculated using Formula (11):

$$q_V = A \cdot K \sum_{i=1}^{n} f_i \frac{l_i}{2\cos\phi_i} \left(\frac{1}{t_{\mathrm{AB},i}} - \frac{1}{t_{\mathrm{BA},i}} \right) \tag{11}$$

Considering this equation, the total uncertainty depends upon the individual uncertainties of all factors involved. Four sources can be distinguished:

a) the uncertainty in the calibration factor, K, which is a function of both the calibration uncertainty and the correction method applied. K is a function of q_V;

b) the uncertainties in the measurements of the transducers and in the geometry of the meter body;

c) the uncertainty in the live input weighting factor or flow profile correction factor, f;

d) the uncertainty in the transit time and transit time difference measurement.

After calibration and adjustment, the errors in indicated flow rate, q_V, caused by l, ϕ, A, and f are compensated for by multiplying the right-hand side by a calibration factor, K. The only remaining uncertainty at the calibration site is that of the calibration factor, K.

NOTE Transferring the meter to the field, there is an additional uncertainty due to the specific operating conditions and installation conditions in the field, which differ from those at the calibration site.

4.5 Reynolds number

The flow profile is a function of the Reynolds number. The Reynolds number is calculated from the known inside diameter of the body, d, the measured average velocity, v, density, ρ, and the dynamic viscosity, η.

$$Re = \frac{v \cdot d \cdot \rho}{\eta} \tag{12}$$

The instant average velocity and the density, for which pressure is the dominant factor, are the main contributors in changes of the Reynolds number for a specific gas.

The impact of changes in the Reynolds number on the calibration factor of a single path depends on the path configuration of the USM. For Reynolds numbers greater than 10 000, the impact ranges from approximately 1 % per decade for a diametrical path to less than 0,3 % per decade for a chordal path at a half-radius position. For high Reynolds numbers for instance at high pressures and/or high flow velocity, the change of the flow profile becomes insignificiant and the calibration factor will become a constant number.

The path configurations of most ultrasonic multi-path meters are designed to reduce the impact to a negligible amount per decade.

Nevertheless the calibration factor may change with respect to Reynolds number changes due to the working pressure especially for flow rates below $q_{V,t}$. The manufacturer shall specify the applicable pressure range and whether during calibration, as well as during operation, the actual values for the density and the viscosity shall be entered in the ES of the USM. See also 5.8.3.

4.6 USM classification

To aid the user in making a meter selection based on the demanded accuracy, a USM can be classified by application. This process involves dividing the meters available into classes of performance as outlined in Table 4. Only classes 1 and 2 are suitable for custody transfer and allocation duties. Other classes deal with other measurement applications and are covered by ISO 17089-2.

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Table 4 — USM classification

Class	Typical applications	Required accuracy class
1	Custody transfer	class 0.5 or class 1.0
2	Allocation	class 1.5 or better

The two classes are intended to represent typical measurement specifications commonly applied in industry. Depending on the importance of measurement with respect to regulatory or custody transfer demands, the total uncertainty budget for the system differs.

5 Meter characteristics

5.1 Operating conditions

5.1.1 Flow rates and gas velocities

The maximum flow rate and the minimum flow rate shall be specified by the manufacturer for the gas densities for which the meter operates within the specifications of the meter performance defined in 5.8. The maximum flow rate, in cubic metres per hour, of the meter depends on the maximum gas velocity the meter is designed for.

The flow range for bidirectional applications is: $-q_{V,\,\max} < q_V < -q_{V,\,\min}$ and $q_{V,\,\min} < q_V < q_{V,\,\max}$.

5.1.2 Pressure

Ultrasonic transducers used in USMs require a minimum gas density to ensure acoustic coupling of the sound signals to and from the gas where pressure is the predominant factor of gas density. Therefore, the gas composition and the minimum operating pressure as well as the maximum operating pressure shall be specified.

5.1.3 Temperature

The manufacturer or supplier shall specify the operating and ambient temperature ranges for the equipment being offered, inclusive of meter body, field-mounted electronics, and its associated peripherals and cabling as well as ultrasonic transducers.

5.1.4 Gas quality

The meter shall operate within the relevant accuracy limits for all gases for which the meter is intended to be used.

The presence of some components in the gas can impact on the performance of a meter. In particular, high levels of carbon dioxide and hydrogen in a gas mixture can influence and even inhibit the operation of a USM owing to their acoustic absorption properties.

Deposits which may be present in a process (e.g. condensates, glycol, amines, inhibitors, water or traces of oil mixed with mill scale, dirt or sand) may affect the accuracy of the meter by reducing its cross-sectional area, by reducing the effective acoustic path length and by obstructing the emitted and received ultrasonic signals.

The manufacturer should be consulted if any of the following are expected:

a) when the acoustic-signal-attenuating carbon dioxide levels are above 3 % molar fraction or the occurrence of carbon dioxide in large meters (>12″);

b) when the hydrogen levels are above 10 % molar fraction;

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c) when the operation is near the critical density of the natural gas mixture (crossing a phase boundary causing retrograde condensation resulting in 2 phase flow);

d) when the total sulfur level, from materials such as hydrogen sulfide, mercaptans (thiols), and elemental sulfur, exceeds 320 µmol/mol (which is corrosive and may require resistant materials or additional wall thickness allowance);

e) deposits.

5.2 Meter body, materials, and construction

5.2.1 Materials

The meter body and the internal mechanism shall be manufactured from materials suited to the service conditions and resistant to attack by the fluid which the meter is to handle. Exterior surfaces of the meter shall be protected as necessary against corrosion. Internal surfaces of the meter shall be designed to resist changes to the internal cross-sectional area and the wall roughness to the extent required so that meter accuracy is not endangered.

5.2.2 Meter body

The meter body and all other parts comprising the fluid-containing structure of the meter shall be constructed of sound materials and designed to handle the pressures and temperatures for which they are rated.

5.2.3 Connections

The inlet and outlet connections of the meter shall conform to recognized standards, e.g. ANSI (class 300, 600, 900, etc.), DIN, and JIS.

5.2.4 Dimensions

5.2.4.1 General

The flanges of the USM shall both have the same inside diameter to within 1 % of each other. An USM with an inside diameter equal to the flange diameter shall be indicated as “full bore”. An USM of inside diameter smaller than the flange diameter shall be indicated as “reduced bore”. Any measurement of the bore of the meter should be within 0,5 % of the average over the length of the meter or, in the case of reduced bore meters, the measurement zone.

5.2.4.2 Geometrical parameters of the measuring section

The manufacturer shall measure and document:

a) the average inside diameter representative for the measuring section of the meter;

b) the length of each acoustic path between transducer faces;

c) the inclination angle of each acoustic path or the axial (meter body axis) distance between transducer pairs;

d) the uncertainty of measurements a) to c);

e) the meter body material;

f) the meter body coefficients for pressure and temperature expansion.

The meter body temperature shall be measured and documented at the time these measurements are made. The individual lengths shall be reported to the smallest practicable uncertainty. All instruments

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used to perform these measurements shall have valid calibrations traceable to internationally recognized standards.

5.2.5 Ultrasonic transducer ports

Since the measured gas may contain some impurities (e.g. light oils or condensates), transducer ports shall be designed to reduce the possibility of liquids or solids accumulating in the transducer ports. The USM transducer ports may also be equipped with devices to allow safe draining of any accumulated fluids (e.g. double block and bleed).

The USM may be equipped with valves or 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 shall be required in addition to the isolation valve to ensure that no excess pressure exists behind a transducer before releasing the extraction mechanism.

Note the conditions for exchange of components (5.6).

5.2.6 Pressure tappings

At least one metering-pressure tapping, drilled perpendicular in the top ±85°, shall be provided on the meter body or on the piping adjacent to the meter for the full bore flow meter to enable direct measurement of the static pressure under metering conditions.

For a reduced bore flow meter, the metering pressure tapping shall be provided on the meter body in the reduced bore section.

The connection of the pressure tapping shall be marked "p_m" to be used at both the installation and calibration. If more than one "p_m" tapping is provided, the difference in pressure readings shall not exceed 100 Pa at maximum flow rate at ambient conditions.

Meters have the option of utilising tappings in the pipework adjacent to the meter providing the difference in pressure readings does not exceed 100 Pa at maximum flow rate at ambient conditions.

Depending of the end user piping standards the pressure connection shall be either a screwed or flanged type design.

A meter may be equipped with other pressure tappings in addition to the p_m tapping. These may serve to determine the pressure drop over a part of the meter or for other purposes. The other pressure tapping shall be marked "p".

The centre-line of the tapping shall meet the pipe centre-line and be at an angle of 90° to it. At the point of breakthrough, the hole shall be circular. The edges shall be flush with the internal surface of the pipe wall and as sharp as possible. To ensure the elimination of all burrs or wire edges at the inner edge, rounding is permitted, but shall be kept as small as possible and, where it can be measured, its radius shall be less than one-tenth of the pressure tapping diameter. No irregularity shall appear inside the connecting hole, on the edges of the hole drilled in the pipe wall, or on the pipe wall close to the pressure tapping. Conformity of the pressure tappings with the requirements specified may be judged by visual inspection. The diameter of the pressure tapping shall have a minimum bore diameter of 3 mm and a maximum bore of 12 mm. The pressure tapping shall be circular and cylindrical over a length of at least $2{,}5d_1$, where d_1 is the inside diameter of the tapping hole, measured from the inner wall of the pipeline. The centre-line of the pressure tapping may be located in any axial plane of the pipeline.

The installation of a pressure tapping in close proximity to a transducer port should be avoided.

5.2.7 Anti-roll provision

The meter shall be designed so that the meter body does 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 electronic system (ES) when the USM is temporarily set on the ground during installation or maintenance work.

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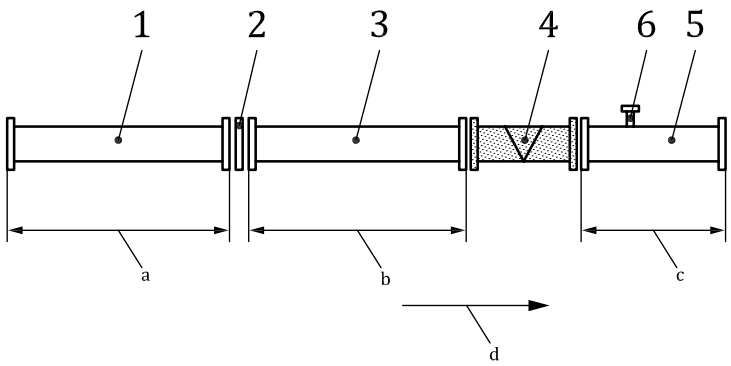
The meter shall be designed to permit easy and safe handling during transportation and installation; however, the anti-roll provision alone is not sufficient during transportation. Hoisting eyes or clearance for lifting straps shall be provided.

5.2.8 Flow conditioner

A flow conditioner irremovably attached to the meter is deemed to be part of the meter.

A USM package is formed when the flow conditioner is positioned at a distance less than L_{min}. The package consists of the flow conditioner, inlet spool and the meter. In a bidirectional setup, a thermowell is also part of the USMP. Calibration shall always be done with the whole measurement package or a simulated package consisting of a upstream pipe and the same make and model flow conditioner (all of the same exact dimensions, inner wall conditions and type) may be considered.



Key

1 upstream spool
2 flow conditioner
3 inlet spool
4 ultrasonic flowmeter (USM)
5 outlet spool
6 temperatur sensor (TS)
[a] ≥2*D* (preferably 3*D*).
[b] ≥*XD* (Specified by the manufacturer).
[c] TS 2*D* to 5*D* (Outlet spool 3*D* to ≥6*D*).
[d] Flow primary direction (Forward).

Figure 8 — Typical drawing of USMP

For the USMP and the simulated USMP, it shall be guaranteed that all components are mounted in correct direction and orientation as in the field situation. For this purpose the direction and orientation should be permanently marked on these components.

Any other flow conditioner upstream of a USMP is regarded as part of the “installation” or of the “calibration facility”.

5.2.9 Markings

Nameplates shall include the following:

a) manufacturer, model number, serial number, and month and year of manufacture;

b) meter size, flange class, and total mass;

c) meter body design code and material, flange design code and material;

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d) maximum and minimum operating pressure, and operating temperature range;

e) the nominal maximum and minimum actual volume flow rate per hour over the calibrated range;

f) direction of positive or forward flow;

Nameplates may include the following:

g) purchase order number or shop order number;

h) legal metrology approval identification;

i) transition actual volume flow rate per hour.

Each transducer port shall be permanently marked with a unique designation for easy reference.

5.2.10 Corrosion protection

Immediately after production, the inner surface of the meter, spool pieces, and flow conditioners should be protected from corrosion.

5.3 Transducers

5.3.1 Specification

The acoustic frequency shall be specified.

5.3.2 Rate of pressure change

Rapid depressurization of a USM may cause damage to the transducer or the coating on the inner wall, resulting in a change of the characteristics of the meter. It shall therefore be ensured that the meter runs are depressurized as slowly as possible and, in the absence of information from the manufacturer, a rate of no greater than 0,5 MPa/min is recommended.

5.3.3 Transducer characterization

If the flowmeter electronics system (ES) requires specific transducer characterization parameters, documentation of all parameters which are unique to each transducer, or transducer pair, shall be provided.

5.3.4 Path configuration

In a multi-path arrangement, the number of chords, their positioning and the integration technique used affects the measurement uncertainty as well as its sensitivity to changes in the flow profile. The number of transducer pairs, the number of reflections per path and the attachment method into the conduit (protruding, retracted flush or wall-mounted) shall be specified.

5.3.5 Marking

Each transducer shall be permanently marked with a unique serial number.

5.3.6 Cable

If the USM is sensitive to the characteristics of the individual transducer cable, then the cable shall be treated as an integral part of the meter and it shall be marked with a warning indicating the characteristic not to be changed, e.g. length.

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5.3.7 Robustness

The wetted part of the transducer shall be manufactured of materials suited for the service conditions and resistant to attack by the fluid which the meter is exposed to.

5.4 Electronics

5.4.1 General requirements

The ES of a USM usually include power supply, microcomputer, signal processing components, and ultrasonic transducer excitation circuits.

It shall be verified that the ES operates over its specified range of environmental conditions without a significant change in meter performance. The ES operating the transducers shall be capable of withstanding electromagnetic discharge as specified in 7.5. Intrinsically safe designs and explosion-proof enclosure designs shall comply with national requirements.

The ES shall contain a self-monitoring function to ensure automatic restart in the event of a program lock-up.

5.4.2 Display

The meter shall have the capability for local and/or remote display.

5.4.3 Power supply

The manufacturer shall specify the necessary power supply, the tolerance on the voltage variation, and the power consumption. The reaction of the USM to power interruptions and voltage drops shall be specified.

5.4.4 Signal detection method

The signal detection method shall be designed to ensure reliable time measurement; this implies accurate detection of start and stop triggers, use of a precision clock, and resistance to systematic errors like “peak-switching”, etc.

5.4.5 Sampling or pulsating flow

The meter shall cope with non-steady flow. For that purpose, acoustic signals may be fired at a non-constant rate. The manufacturer shall specify the maximum flow fluctuation frequency.

5.4.6 Signal-to-noise ratio

The USM shall indicate the S/N ratio per transducer or per acoustic path.

5.4.7 Alarm signal

The meter shall trigger an alarm when the performance of the meter deteriorates due to for low S/N or signal acceptance rate for example.

5.4.8 Processing of data

The processing section shall, in addition to determining the volume flow rate from the measured transit times, be capable of rejecting invalid measurements. The indicated volume flow rate may be the result of one or more individual velocity determinations. The percentage of valid measurements to performed measurements may be indicated for every acoustic path by the USM.

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5.4.9 Output

The meter shall be equipped with at least one of the following outputs:

a) serial data interface; e.g. RS-232, RS-485, or fieldbus;

b) a frequency output representing flow rate at metering conditions;

c) a digital status output.

The time-integrated values of outputs a) and b) shall match better than 0,02 % in every arbitrary interval of 100 s for flow rates above $q_{V,\,\mathrm{min}}$.

The meter may be equipped with the following outputs:

a) additional frequency outputs;

b) additional status outputs;

c) additional data interfaces (e.g. Ethernet, read-only serial port);

d) analogue (4 mA to 20 mA) outputs.

Flow rate outputs shall function up to 120 % of the maximum flow rate, $q_{V,\mathrm{max,cal}}$, of the meter. A low flow cut-off function may be provided that sets the flow rate output to zero when the indicated flow rate is below a minimum value.

NOTE Setting the output to zero at low flow can cause problems if the USM output is used to control valve settings.

Two separate flow rate outputs or serial data values may be provided for bidirectional applications to facilitate the separate accumulation of volumes by the associated flow computer(s).

All outputs shall be isolated from ground and have the necessary voltage protection to meet the electrical testing requirements.

For control purposes, output signal(s) of the measured flow shall be updated at a frequency of not less than 1 Hz.

5.4.10 Cable jackets and insulation

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

5.4.11 Marking

Each electronic assembly shall be permanently marked with a unique version number for easy reference. A list of electronic assemblies, including version number, shall be kept up to date by the manufacturer as part of version management.

5.5 Software

5.5.1 Firmware

Computer codes responsible for the control and operation of the meter shall be stored innon-volatile memory. All flow calculation constants and operator-entered parameters shall also be stored in non-volatile memory.

It shall be possible to verify all constants and parameters while the meter is in operation. A firmware check-sum and event log shall be provided to validate that no unauthorized changes have been made to the firmware.

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5.5.2 MODBUS communication data specification

The USM shall provide a defined data structure (see Annex F) for serial communication to simplify the data communication to a communication system (e.g. flow computer or data acquisition system).

The data communication protocol is based on the publicly available specifications of the "Modbus Organization, Inc."[83].

5.5.3 Discontinuity

When exposed to a continuous increase or decrease of flow, the firmware shall be designed to avoid a step change in the calculated output flow rate.

5.5.4 Marking and version management

The manufacturer shall maintain a record of all firmware revisions including the revision serial number, date of revision, applicable meter models and circuit board revisions, and description of changes to firmware performed by them or by their representative.

The firmware revision number, revision date, serial number, and checksum shall be available for 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 user if the firmware revision affects the accuracy of a flow-calibrated meter.

5.5.5 Monitoring and recording of measuring and diagnostic data

The meter shall have the capability to monitor and record as a minimum the following data:

a) actual volume flow rate;

b) totalizers;

c) average velocity;

d) average SOS;

e) individual path velocity;

f) individual path SOS;

g) percentage of accepted signals for each acoustic path;

h) S/N ratio or equivalent (gain control);

i) status and measurement quality indicators;

j) alarm and failure indicator.

5.5.6 Correction functions and parameters

Both at operation and calibration, correct parameter settings for Reynolds correction, body expansion correction and calibration curve correction should be used. This is valid either when these parameters are inside the USM or inside the flow computer attached to the USM. This is valid either when actual pressure and actual temperature are entered as fixed values or from live inputs.

Reynolds correction parameters are density and viscosity.

Body expansion correction parameters are actual pressure, calibration pressure, actual temperature, calibration temperature, thermal expansion coefficient, Young modulus, Poisson ratio and dimensional measurements.

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Calibration curve correction parameters are either a set of flow rates and deviations, or a set of parameters that determine polynomial correction according to the design of the calibration curve correction mechanism.

The software of the USM and/or the flow computer attached to the USM should allow the operator to enter the correct settings of these parameters. Care should be given not to activate a correction mechanism twice, both in the USM and in the flow computer attached to the USM.

5.5.7 Inspection and verification functions

It shall be possible to view and print the flow measurement configuration parameters used by the ES, e.g. calibration constants, meter dimensions, time averaging period, and sampling rate. Provisions shall be made to prevent an accidental or undetectable alteration of those parameters that affect the performance of the meter. Suitable provisions include a sealable switch or jumper, or a permanent programmable read-only memory chip with verifiable checksum/event log alarms.

Provide the following alarm status output:

a) output invalid: when the indicated flow rate output is invalid (required);

b) partial failure: when one or more of the multiple ultrasonic path results is not usable (required);

c) warning: when any of several monitored parameters fall outside normal operation for a significant length of time (optional).

5.6 Exchange of components

It should be possible to replace or relocate similar types of transducers, electronic parts and software without a significant change in meter performance. The fault due to the interchange of such a component shall not be more than one third of the MPE for the corresponding meter class. Otherwise the meter shall be recalibrated.

The above statements shall be made clear in the meter metrological approval.

Procedures to be used when such components have to be exchanged, including possible mechanical, electrical or other measurements and adjustments, shall be specified.

From every event with the ultrasonic flowmeter (calibration, repair, etc.), a full list of the relevant “as-found”, “as-calibrated” and “as-left” parameters shall be available.

If parts are replaced by newer or different versions, advantages and disadvantages shall be specified.

The manufacturer shall provide a reputable method of version management.

5.7 Secondary measurements

5.7.1 General

For the conversion of volume flow under metering conditions to mass flow or volume flow under base conditions, secondary measurements are required.

5.7.2 Pressure measurement

The pressure tapping marked “p_m” shall be used as the pressure sensing point (see 5.2.6).

5.7.3 Temperature measurement

For unidirectional flow, the thermowell shall be installed $2D \leq x \leq 5D$ downstream of the USM, but upstream of any outlet valve, diameter steps or flow restrictions. It is important that the thermowell be correctly installed to ensure the heat transfer from the piping and the thermowell attachment and

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radiation effects of the sun do not influence the temperature reading. The recommended insertion length for thermowells shall be such that the tip protrudes between $D/10$ and $D/3$. Special probe designs may be required for insertion lengths greater than $D/3$.

In case of density meters are used, the same installation rules for the pockets apply.

Some installations require the installation of two or even three thermowells (back-up measurement or validation measurement). Additionally, safety regulations may prescribe large well dimensions. The thermowell shall be installed such that the ambient temperature does not influence the gas temperature measured.

For applications where the ambient temperature can be significantly different (>5 °C) from the gas temperature, thermal insulation or shading of the upstream pipe section, the USM assembly and the downstream section, as far as $1D$ beyond the furthest thermowell, shall be installed, unless the meter is operating above $q_{V,t}$.

For bidirectional use with two USMs in series, it is possible for the thermowell to be installed in between the two meters. An example of a bidirectional flow installation where two USMs are employed with the thermowell located in the centre section is given in Figure 11. Both the number and sizes of the thermowells or densitometer pockets exacerbate the flow perturbation.

The thermowell vortex shedding frequency at high gas velocities shall not excite the natural vibration frequency of the thermowell to the point of failure; conical thermowells are advised. With the thermowell(s) upstream of the USM, they shall be positioned such that it is not in line with one of the acoustic paths. Also they should not be placed in line with each other in order to avoid the amplification of the vortex generated by the thermowell.

In Figure 9 an example is shown whereby 2 thermowells are used in combination with an ultrasonic flow meter having horizontal paths.

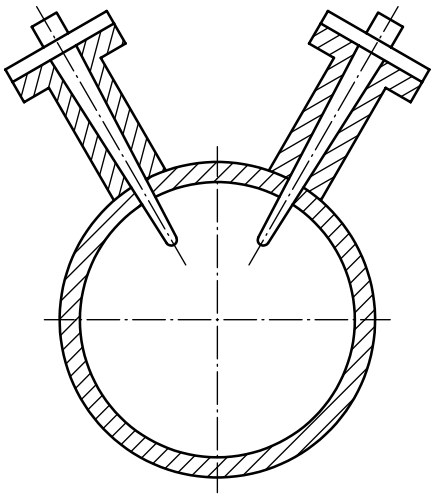

Figure 9 — Thermowells positioned not in line with any of the ultrasonic paths

For smaller pipe diameters (<6”) alternatives to intrusive thermowell-based technologies, like surface mounted temperature measurement elements, may be considered where it can be demonstrated that both the accuracy and the response time of the temperature measurement device are such that it does not compromise the overall uncertainty of the calculated flow rate. This may be particularly advantageous when considering bidirectional metering systems where flow disturbances are to be minimized.

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5.8 Performance requirements

5.8.1 General

The USM shall be designed and manufactured such that its errors do not exceed the applicable MPE over the full operating pressure, temperature, and gas composition ranges, with inputs or a correction algorithm, if necessary. The necessary correction algorithms and inputs shall be specified. If a correction algorithm is not necessary, an additional uncertainty due to pressure, temperature, and composition changes shall be specified. If the USM requires a manual input to characterize the flowing gas condition, e.g. gas density and viscosity, the sensitivity of the USM to these parameters shall be specified so that the operator can determine the need to change these parameters as operating conditions change. The concerning parameter settings shall be documented both during calibration and in operation.

5.8.2 Accuracy requirements

Table 5 — Accuracy requirements

Subject	Accuracy class		
	0.5	1.0	1.5
Maximum permissible error (MPE)			
for $q_V \geq q_{V,t}$	±0,5 %	±1,0 %	±1,5 %
for $q_{V,\min} < q_V < q_{V,t}$	±1,0 %	±2,0 %	±3,0 %
Maximum peak-to-peak error			
for $q_V \geq q_{V,t}$	<0,5 %	<1,0 %	<1,0 %
for $q_{V,\min} < q_V < q_{V,t}$	<1,0 %	<2,0 %	<2,0 %
Maximum permissible flow weighted mean error prior any adjustment (see 6.3.3)			
FWME	0,5 %	1,0 %	1,5 %
Repeatability under flowing conditions during calibration r_{cal}			
for $q_V \geq q_{V,t}$	0,17 %	0,33 %	0,5 %
for $q_{V,\min} < q_V < q_{V,t}$	0,33 %	0,66 %	1,0 %
Reproducibility			
for $q_V \geq q_{V,t}$	0,17 %	0,33 %	0,5 %
Transition flow rate			
$q_{V,t}$	$q_{V,t} \leq 0{,}1\ q_{V,\max,cal}$		
Speed of Sound deviation			
MSOS deviation from TSOS	≤±0,2 %		
MSOS spread between acoustic paths	≤0,5 m/s		

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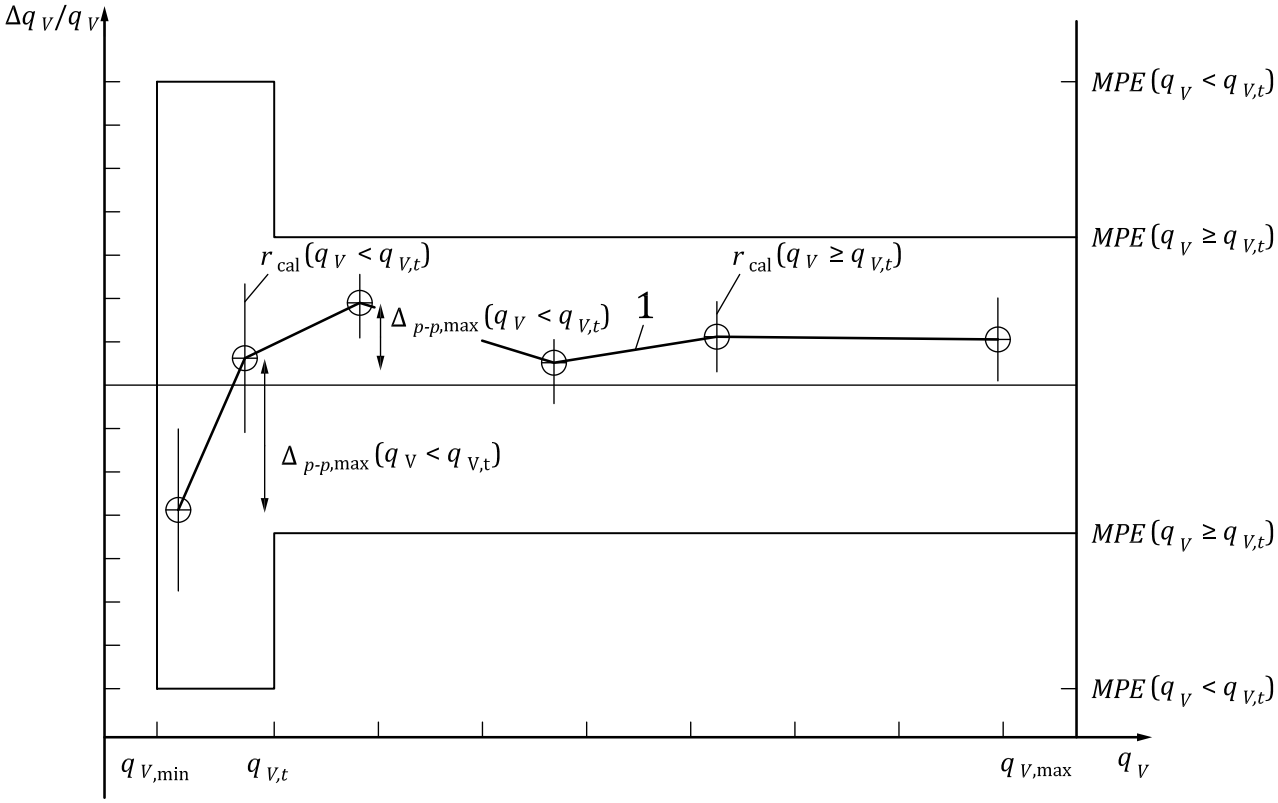

Key

q_V	volume flow rate
$\Delta q_V/q_V$	flow rate measurement error, in %
1	unadjusted meter curve calibration results
MPE	maximum permissible error
$q_{V,0}$	zero flow rate limit
$q_{V,t}$	transition flow rate
$q_{V,\max}$	designed maximum flow rate
$q_{V,\min}$	designed minimum flow rate
r_{cal}	uncertainty in the mean meter error, see chapter 6.3.2.2
$\Delta_{p\text{-}p,\max}$	maximum peak-to-peak error for meters

Figure 10 — Performance requirements envelope

5.8.3 Influence of pressure, temperature, and gas composition

The USM shall meet the above accuracy requirements over the full operating pressure, temperature, and gas composition ranges, with inputs or a correction algorithm, if necessary. The necessary correction algorithms and inputs shall be specified. If a correction algorithm is not necessary, an additional uncertainty due to pressure, temperature, and composition changes shall be specified. If the USM requires a manual input to characterize the flowing gas condition, e.g. gas density and viscosity, the sensitivity of the USM to these parameters shall be specified so that the operator can determine the need to change these parameters as operating conditions change. The concerning parameter settings shall be documented both during calibration and in operation.

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5.9 Operation and installation requirements

5.9.1 General

All influences from the installation, or the way the installation is operated, that increase the uncertainty of the USMP shall either be neutralized or compensated. Minimum distances to flow disturbing objects shall be specified. Subclause 5.9 applies to calibration (see Clause 6) as well as to operation (see Clause 8).

Various combinations of upstream fittings, valves, bends, and lengths of straight pipe can produce velocity profile distortions at the meter inlet that may result in flow rate measurement errors. The magnitude of the meter error is dependent on the type and severity of the flow distortion and the ability of the meter to compensate for it. This error can be reduced by increasing the length of upstream straight pipes or by using flow conditioners. Alternatively, carrying out flow calibrations under conditions similar to field conditions is the most effective way to compensates for this error. Research work on installation effects is ongoing, so the installation designer may consult with the USM manufacturer to review the latest test results and evaluate how a specific USM design may be affected by the upstream piping configuration of the planned installation. In order to achieve the desired meter performance, it may be necessary for the installation designer to alter the original piping configuration or include a flow conditioner as part of the meter run.

5.9.2 Operational requirements

5.9.2.1 Sound, noise, and pressure-regulating valves

The function and accuracy of an USM can be adversly affected by noise generated by pressure-regulating valves; see also Reference [55] and 8.1. As the acoustic signal of the meter is stronger at higher pressures and as the noise transmitted by single trim valves is lower upstream, it is strongly recommended to locate the control valve downstream of the USM. (See Annex D).

In the worse cases, the meter can become inoperable under certain conditions. The following recommendations are given in respect of valve-generated noise:

a) position USMs well away from throttling control valves, ideally with process equipment such as vessels or heat exchangers between them, upstream of the regulator;

b) improve noise immunity of USMs by:

   1) increasing meter transducer frequency,

   2) increasing meter transducer power,

   3) using signal processing techniques for signal detection, e.g. signal averaging (stacking), digital correlation, or signal coding;

c) by the installation of blind tees, heat exchangers, out-of-plane bends and/or a flow conditioner between the USM and the valve (i.e. by blocking the line of sight) isthe most effective use of standard pipe fittings for attenuating ultrasonic noise;

   NOTE 1 A straight pipe is not considered effective for the attenuation of ultrasonic noise.

   NOTE 2 Potential operational issues may occur associated with blind tees, which have the potential to introduce undesireable installation effects that distort flow profiles (see 5.9.3.2), collect liquids and become difficult to purge.

d) lowering the differential pressure across a valve reduces the noise generated at all frequencies.

Note that it is essential that the upstream straight length of the meter is not compromised in following these recommendations. The general sensitivity of the USM to sound (noise) generated by pressure-regulating valves and other sources shall be described.

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5.9.2.2 Contamination

Accumulation of deposits due to a mixture of particles and liquid contaminants should be avoided.

Filtration of the gas flow upstream is recommended and in bidirectional applications, filtration both upstream and downstream is recommended. The potential for flow profile disturbance caused by filtration equipment, however, should be recognized.

To avoid severe accumulation, a pipe configuration having a low point downstream of the meter is recommended.

5.9.2.3 Ambient temperature

The influence of the ambient temperature should be minimized as described in 5.7.3. Stratification, especially at low flow velocities, may occur when the temperature difference between the outside temperature and that of the gas is more than 5 °C[87]. The USM diagnostics may be utilized to determine the presence of stratification.

Also, at least a shade should over the full length of the measurement section be supplied to protect themeter run and electronics against direct sun radiation. The best way to protect from ambient temperature is thermal insulation of the upstream pipe (until 10*D*), the USM and the downstream pipe including the temperature measurement.

5.9.2.4 Vibration

USMs shall not be exposed to vibration levels or vibration frequencies that might excite the natural frequencies of ES boards, components, or ultrasonic transducers.

5.9.2.5 Electrical noise

Even though a USM design has been tested to withstand the electrical noise influences described in 7.5, the USM or its connected wiring shall not be exposed to any unnecessary electrical noise, including alternating current, solenoid transients or radio transmissions.

5.9.2.6 Non-steady flow

Pulsations and non-steady flow beyond the manufacturer's specifications shall be avoided (see 5.4.4).

5.9.3 Installation requirements

5.9.3.1 General

A fully developed flow profile is the most desirable condition at the meter. In practice, undisturbed flow conditions may be the highest achievable.

Due to the large variety of USM types, upstream piping configurations, and flow conditioners, it is practically impossible to standardize upstream lengths. Furthermore, USM technology continues to improve, which makes standardization on this point even more difficult. The lengths between the USM and the flow conditioner and upstream of the flow conditioner shall be specified in the manufacturer instructions.

5.9.3.2 Distance to perturbations, upstream and downstream straight pipe length requirements

Typical upstream piping conditions (operating conditions), e.g. bends, headers, T-joints, flow conditioners, filtration equipment, diameter changes (steps, expanders or reducers), and valves, introduce swirl, an asymmetric flow profile, a flat flow profile, a peaked flow profile or combinations of these. Research has demonstrated that asymmetric profiles may require a length measuring 50*D* of straight pipe without a flow conditioner, and swirling profiles may require 200*D* of straight pipe

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without a flow conditioner before a fully developed flow profile can be expected. Installing such lengths of upstream straight pipe is impractical. The current ability of USMP to compensate for disturbed flow profiles allows shorter lengths of straight upstream pipe.

It is recommended to utilize the USM diagnostics to determine if the flow conditions in operation are not severely disturbed. Secondly it should be determined if the flow conditions are representative with the calibration conditions of the USM by comparing the diagnostics of the USM during calibration and in operation.

The minimum length of straight upstream pipe, l_{min}, shall be such that the addition of an extra straight length measuring 10*D* alters the reading of the USM (FWME) by not more than the combined reproducability of the calibration facility and the USM. The value of l_{min} differs in accordance with the upstream piping configuration and can only be found using a set of reference standards. Determination of the values of l_{min} for a standard set of upstream piping configurations is a major task during type testing; see 7.3. Determine l_{min} such that the maximum additional error due to flow perturbations is less than one third of the MPE for the corresponding meter class. The manufacturer shall specify the values of l_{min} for the different flow perturbations defined in 7.3.

A configuration for which l_{min} is unknown:

— requires a length of 50*D* of straight upstream piping the application of a USM, or

— requires a length of 10*D* for the application of a USMP.

The minimum length of straight downstream pipe is 3*D.*

5.9.3.3 Protrusions and diameter step

Changes in inside diameters (*D*) and protrusions should be avoided at the USM inlet to avoid the disturbance of the velocity profile.

The flanges and adjacent upstream pipe shall be straight, cylindrical, and have the same inside diameter throughout as the inside diameter of the inlet of the meter, at maximum of 1 %. These components shall be carefully aligned to minimize flow disturbances, especially at the upstream flange. Experience with class 1 meters has shown that diameter steps between the upstream pipe and the meter cause metering errors of the order of 0,05 % systematic error per 1 % diameter step; an error that can be reduced by chamfering as long as the angle of inclination is less than 7°.

NOTE This value can only be considered as a guide to estimate the additional uncertainty due to diameter steps.

For a minimum upstream length of 2*D*, there shall be no flow disturbances from flanges, flow straighteners, etc. Over a length of at least 10*D* or l_{min} upstream of the meter, whichever is smaller, the pipe section(s) shall fulfil the following requirements:

a) the pipe shall be straight, i.e. have no bends >5°;

b) two pipes are said to be aligned when local diameter steps are <3 %;

c) the internal weld of the downstream flange of the upstream piping shall be ground smooth and no part of the upstream gasket or flange face edge shall protrude into the flow stream;

d) the pipe is said to be cylindrical when no diameter in any plane differs by more than 3 % from the average inside diameter, *D*, obtained from the measurements specified;

e) The USM manufacturer shall prove that the additional bias due to the diameter steps greater than 1 % is below one third of the MPE for the corresponding meter class within type testing, see 7.3.

5.9.3.4 Thermowells and density cells

For thermowells and density cells, see 5.7.2.

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