



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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Documents

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 17089-1 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 5, *Velocity and mass methods*.

ISO 17089 consists of the following parts, under the general title *Measurement of fluid flow in closed conduits — Ultrasonic meters for gas*:

— *Part 1: Meters for custody transfer and allocation measurement*

The following part is planned:

— *Part 2: Meters for industrial applications*

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 part of ISO 17089 advocates the addition and use of automated diagnostics instead of labour-intensive quality checks.

This part of ISO 17089 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, will be the subject of part 2.

Typical performance factors of the classification scheme are:

Class	Typical applications	Typical uncertainty	Reference
1	Custody transfer	<0,7 %	This part of ISO 17089
2	Allocation	<1,5 %	This part of ISO 17089
3	Utilities and process		ISO 17089-2 ^a
4	Flare gas and vent gas		ISO 17089-2 ^a

^a Planned.

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.

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

Part 1: Meters for custody transfer and allocation measurement

IMPORTANT — The electronic file of this document contains colours which are considered to be useful for the correct understanding of the document. Users should therefore consider printing this document using a colour printer.

1 Scope

This part of ISO 17089 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 part of ISO 17089 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 part of ISO 17089 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 part of ISO 17089 specifies construction, performance, calibration, 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 part of ISO 17089.

2 Normative references

The following referenced documents are indispensable for the application 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/TR 7871, *Cumulative sum charts — Guidance on quality control and data analysis using CUSUM techniques*

ISO 12213 (all parts), *Natural gas — Calculation of compression factor*

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

3 Terms, definitions, and symbols

3.1 Terms and definitions

3.1.1 General

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

3.1.2 Quantities

3.1.2.1

volume flow rate

q_V

$$q_V = \frac{dV}{dt}$$

where

V is volume;

t is time.

NOTE Adapted from ISO 80000-4:2006^[83], 4-30.

3.1.2.2

working range rangeability

set of values of quantities of the same kind that can be measured by a given measuring instrument or measuring system with specified instrumental uncertainty, under defined conditions

NOTE 1 Adapted from ISO/IEC Guide 99:2007^[33], 4.7, “working interval”.

NOTE 2 For the purposes of this part of ISO 17089, the “set of values of quantities of the same kind” are volume flow rates whose values are bounded by a maximum flow rate, $q_{V, \max}$, and a minimum flow rate $q_{V, \min}$; the “given measuring instrument” is a meter.

3.1.2.3

metering pressure

p

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

3.1.2.4

average velocity

v

volume flow rate divided by the cross-sectional area

3.1.3 Meter design

3.1.3.1

meter body

pressure-containing structure of the meter

3.1.3.2

acoustic path

path travelled by an acoustic wave between a pair of ultrasonic transducers

3.1.3.3

axial path

path travelled by an acoustic wave entirely in the direction of the main pipe axis

NOTE 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

3.1.3.4

diametrical path

acoustic path whereby the acoustic wave travels through the centre-line or long axis of the pipe

See Figure 2.

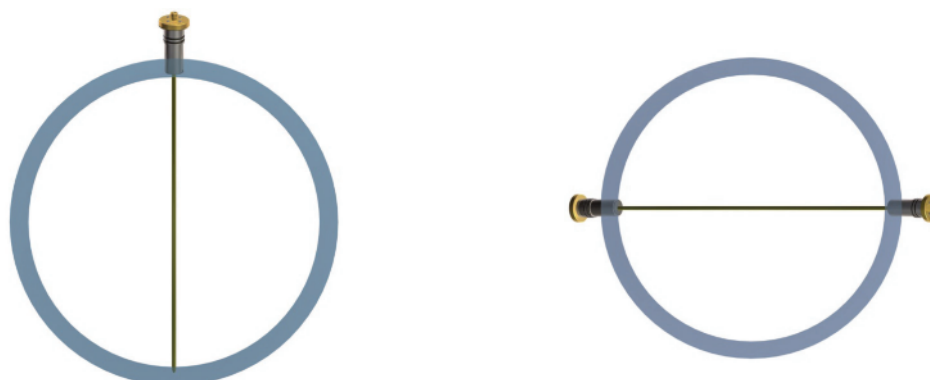


Figure 2 — Diametrical paths

3.1.3.5

chordal path

acoustic path whereby the acoustic wave travels parallel to the diametrical path

See Figure 3.

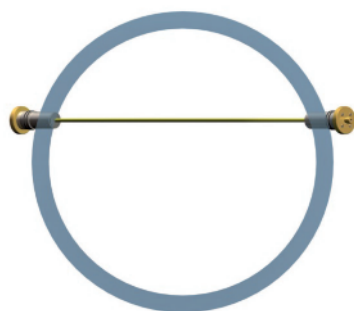


Figure 3 — Chordal paths

3.1.4 Thermodynamic conditions

3.1.4.1

metering conditions

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

NOTE 1 Metering conditions include gas composition, temperature, and pressure.

NOTE 2 Adapted from ISO 9951:1993[2], 3.1.6.

3.1.4.2

base conditions

conditions to which the measured volume of the fluid is converted

NOTE 1 Base conditions include base temperature and base pressure.

NOTE 2 Adapted from ISO 9951:1993[2], 3.1.7.

3.1.4.3

specified conditions

conditions of the fluid at which performance specifications of the meter are given

NOTE Adapted from ISO 9951:1993[2], 3.1.8.

3.1.5 Statistics

3.1.5.1

measurement error

error of measurement

error

measured quantity value minus a reference quantity value

[ISO/IEC Guide 99:2007^[33], 2.16]

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

3.1.5.2

error curve

interconnection of the curve (e.g. polynomial) fitted to a set of error data as a function of the flow rate of the reference meter

3.1.5.3

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

NOTE Adapted from ISO/IEC Guide 99:2007^[33], 4.26.

3.1.5.4

maximum peak-to-peak error

maximum difference between any two error values

3.1.5.5

repeatability

measurement precision under a set of repeatability conditions of measurement

[ISO/IEC Guide 99:2007^[33], 2.21]

3.1.5.6

measurement precision

closeness of agreement between output values of the test meter, obtained by replicate measurements on the same meter under specified conditions

NOTE Adapted from ISO/IEC Guide 99:2007^[33], 2.15.

3.1.5.7

reproducibility

measurement precision under reproducibility conditions of measurement

[ISO/IEC Guide 99:2007^[33], 2.25]

3.1.5.8

resolution

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

NOTE Adapted from ISO 11631:1998^[3], 3.28.

3.1.5.9

velocity sampling interval

interval between two consecutive gas velocity measurements, each being the set of true quantity values of a measurand with a stated probability, based on the information available

3.1.5.10

zero flow reading

datum measurement error where the gas is at rest, when both axial and non-axial velocity component values are zero

3.1.5.11

linearization

way of reducing the non-linearity of the ultrasonic meter, generally by applying corrections in the software

NOTE 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.

3.1.5.12

slope

gradient of a line joining data points

EXAMPLE Gradient of the best fitting straight line, determined by the least squares method, through the calibration points in an error curve.

3.2 Symbols and subscripts

The symbols and subscripts used in this part of ISO 17089 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	E	$ML^{-1}T^{-2}$	MPa
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
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 (related to d)	Re_d	—	1
Absolute temperature of the gas	T	Θ	K
Temperature difference	ΔT	Θ	K
Transit time	t	T	s
Average velocity	v	LT^{-1}	m/s
Velocity of the acoustic path i	v_i	LT^{-1}	m/s
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	$L^{-1}MT^{-1}$	$Pa \cdot s$
Wavelength of ultrasonic oscillation	λ	L	m
Poisson ratio	μ	—	1
Density of fluid	ρ	ML^{-3}	kg/m^3
Path angle	ϕ	—	rad
Angular velocity	ω	T^{-1}	$rad \cdot s^{-1}$

^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
$q_{V, \max, \text{op}}$	Operational maximum flow rate; defined only when smaller than designed maximum
$q_{V, \max, \text{cal}}$	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

3.3 Abbreviations

CMC	calibration and measurement capability
ES	electronics system
FAT	factory acceptance test
FC	flow conditioner
FRMM	flow reference meter method
FWME	flow-weighted mean error
HDF	historic difference footprint
HDH	historic difference histogram
M&R	metering and regulating stations
MDF	monthly difference footprint
MSOS	measured speed of sound
S/N	signal-to-noise ratio
SOS	speed of sound
TSOS	theoretical speed of sound
USM	ultrasonic flowmeter
USMP	USM package, including meter tubes, flow computer, 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 waves 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 pulses. These transducers transmit sound pulses 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 pulse from A to B decreases and the one from B to A increases, according to (ignoring second order effects, such as path curvature):

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

and

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

where

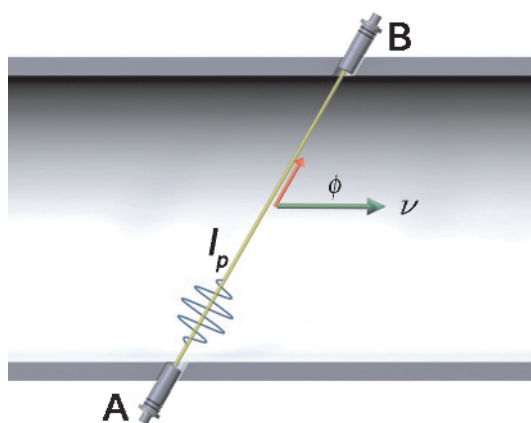
l_p is the path length;

c is the SOS;

v is the average velocity;

ϕ is the path angle;

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



Key

A, B positions

l_p path length

v average velocity

ϕ path angle

Figure 4 — Basic system setup

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

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

Note that the term for the SOS in the gas has been eliminated in Equation (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. However, if the transducers are recessed, there is an additional time delay component, which is SOS dependent.

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

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

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

$$v = f(v_1 \dots v_n) \quad (5)$$

where n is the total number of paths. Due to variations in path configuration and different proprietary approaches to solving Equation (5), even for a given number of paths, the exact form of $f(v_1 \dots v_n)$ can differ.

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:

$$q_V = A v \quad (6)$$

4.2 Factors affecting 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:

- a) the geometry of the meter body and ultrasonic transducer locations and the uncertainty with which these are known (including the temperature and pressure coefficient);
- b) the accuracy and quality of the transducers and electronic components used in the transit time measurement circuitry (e.g. the electronic clock stability);
- c) 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);
- d) calibration (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:

- 1) the flow velocity profile;
- 2) the temperature distribution;
- 3) flow pulsations;
- 4) the noise, both acoustic and electromagnetic;
- 5) solid and liquid contamination;
- 6) the dimensional integrity over time.

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 can be 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, or threaded or may be more mechanically complex, e.g. to allow the removal of transducers from a pressurized line. The active element is usually isolated from the fluid by an acoustic coupling element. Once in operation, the active element transmits ultrasonic waves 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) close proximity to high pressure drop throttle valve (potential of in-pipe ultrasonic noise);
- e) rapid or cyclic temperature or pressure changes;
- f) corrosive or erosive gas (sour gas);
- g) gas with traces of moisture or dirt.

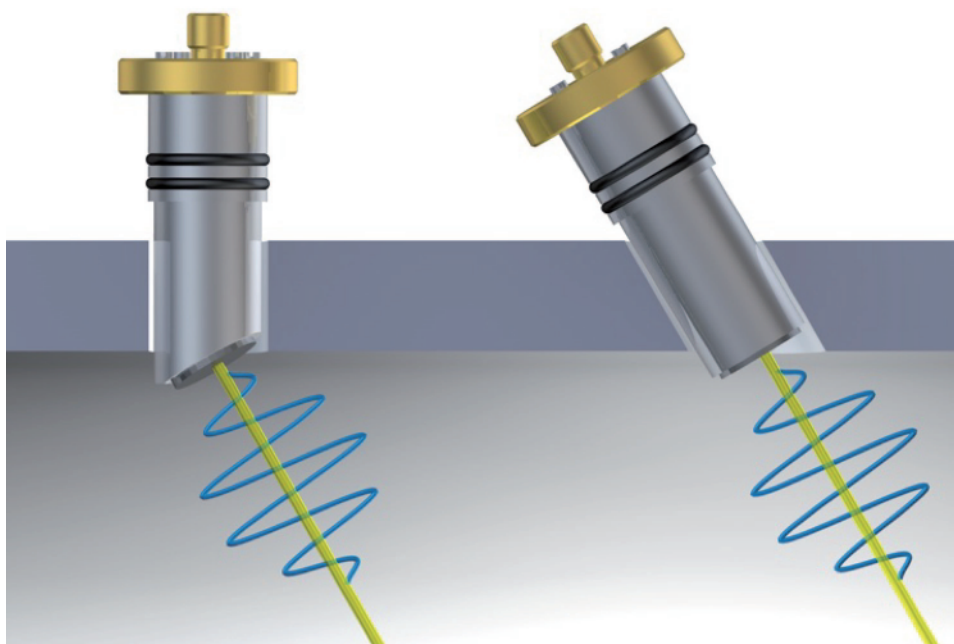


Figure 5 — Typical transducer arrangements

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 wave 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

The most common acoustic path types are illustrated in Figure 6.

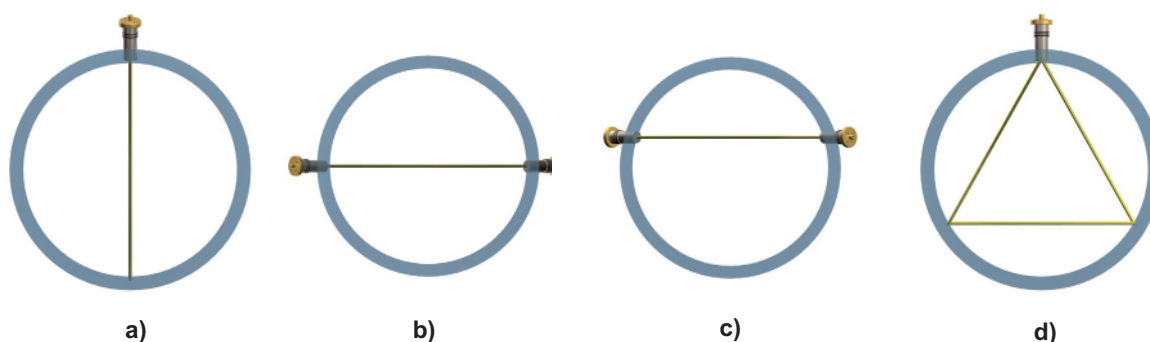


Figure 6 — Basic acoustic path types for multi-path meters

Velocity measurements made on a diametric path are more susceptible to changes in flow profile than off-centre paths such as the mid-radius path. Double traverses in a single plane are much less sensitive to non-axial velocity components than single traverse paths. Other configurations such as the triple traverse mid-radius path may be sensitive to non-axial components, but can be used in combination to eliminate or reduce the effects of swirl and cross-flow. Direct paths can be single, double or crossed.

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.

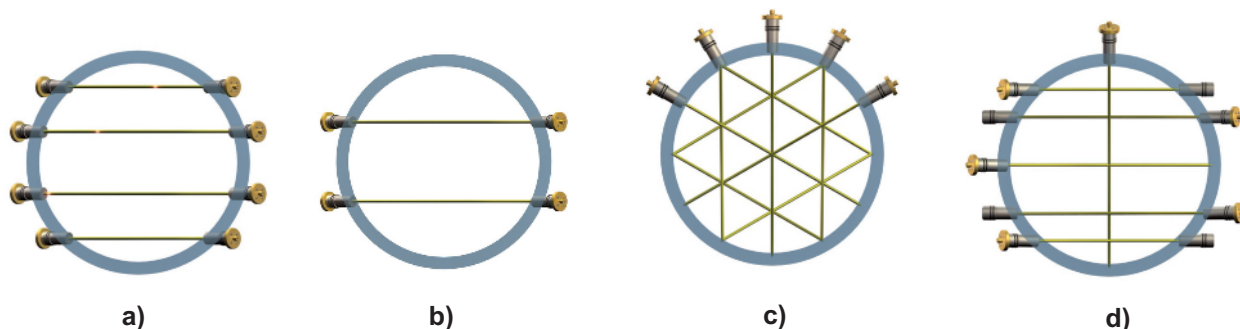


Figure 7 — Some typical cross-sectional acoustic path configurations

4.3.3.4 Meters with paths of equal radial displacement

Meters with paths of equal radial displacement [e.g. Figure 7 b)] 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.

$$v = k_h \frac{\sum_{i=1}^n v_i}{n} \quad (7)$$

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.

4.3.3.5 Meters with paths at off-diameter positions

In the case of these meters [e.g. Figure 7 a), c), 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:

$$v = \sum_{i=1}^n w_i v_i \quad (8)$$

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:

$$v = \sum_{i=1}^n f_i v_i \quad (9)$$

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.

$$q_V = K A v \quad (10)$$

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

4.4 Contributions to the uncertainty in measurement

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

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

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

- the uncertainty in the calibration factor, K ;
- the uncertainties in the measurements of the transducers and in the geometry of the meter body;
- the uncertainty in the live input weighting factor or flow profile correction factor, f ;
- 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 t , 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 . 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 USM classification

To aid the user in making a meter selection based on the overall uncertainty required for the measurement, a USM can be classified. This process involves dividing the meters available into classes of performance as outlined in Table 4. Other classes deal with other measurement applications.

Table 4 — USM classification

Class	Typical applications	Typical uncertainty 95 % confidence level (volume flow rate) ^a
1	Custody transfer	Within ±0,7 % for $q_V > q_{V,t}$
2	Allocation	Within ±1,5 % for $q_V > q_{V,t}$

^a Meter performance, inclusive of total meter uncertainty, repeatability, resolution, and maximum peak-to-peak error, depends upon a number of factors which include pipe inside diameter, acoustic path length, number of acoustic paths, gas composition and associated SOS, and meter timing repeatability.

The two classes represent different 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.

4.6 Reynolds number

The flow profile is a function of the Reynolds number, for changes in which, most USMs correct. The Reynolds number is calculated from the known inside diameter of the body, d , the measured average velocity, v , a preset value of the actual density, ρ , and the dynamic viscosity, η .

$$Re = \frac{v d \rho}{\eta} \quad (12)$$

During calibration, as well as during operation, the actual values for the density and the dynamic viscosity should be entered in the USM computer. See also 5.8.3.

For values over 50 000, the impact of fluctuations in the Reynolds number is not large and ranges from approximately 1 % per decade for the path through the centre of the pipe to less than 0,3 % per decade for the half-radius path. For most ultrasonic multi-path meters, the impact on the measurement is less than 0,1 % for a change of a factor of 2 in the Reynolds number (to be confirmed by the manufacturer).

4.7 Temperature and pressure correction

4.7.1 Introduction

During dynamic (wet) calibration, all of the systematic errors are brought down to zero by determining and then applying the meter flow calibration factor. From that moment onwards, the pressure and temperature reference conditions of the meter are those encountered during the dynamic calibration. Any subsequent change in temperature or pressure alters the physical dimensions of the meter and, if not corrected for, introduces a systematic flow measurement error. In general, the pressure and temperature during calibration differ from those encountered under operating conditions.

In 4.7.2 to 4.7.5, a simple approach is given to allow an initial estimate to be made of the flow error caused by temperature and pressure conditions that differ from the calibration reference condition. If this error is significant relative to the uncertainty required for custody transfer or allocation purposes, a more detailed assessment of flow error has to be performed as described in 4.7.6. Annex E provides an extensive and detailed explanation of the process which readers are advised to consult for the background to many of the statements made in 4.7.2 to 4.7.6.

4.7.2 Correction for the temperature

For all meter types, the geometry-related temperature correction can be given as a straightforward analytical solution (see E.2). In consequence, the correction has a very high precision and the only uncertainties related to this correction are the uncertainties related to the material constants.

The flow correction factor due to a body temperature change, ΔT , is given by:

$$\frac{q_{V,1}}{q_{V,0}} = (1 + \alpha \Delta T)^3 = \left[1 + 3\alpha \Delta T + 3(\alpha \Delta T)^2 + (\alpha \Delta T)^3 \right] \quad (13)$$

where

$q_{V,1}$ is the volume flow rate under operating conditions;

$q_{V,0}$ is the volume flow rate under the conditions at which the meter was calibrated;

ΔT is $T_1 - T_0$

in which

T_1 is the temperature under operating conditions,

T_0 is the temperature under the conditions at which the meter was calibrated.

Other than in extreme situations, $\alpha \Delta T$ is generally very small and Equation (13) can be simplified to:

$$\left(\frac{q_{V,1}}{q_{V,0}} \right)_{b,T} = 1 + 3\alpha \Delta T \quad (14)$$

Or alternatively, expressed as a flow error:

$$\left(\frac{\Delta q_V}{q_V} \right)_{b,T} = 3\alpha \Delta T \quad (15)$$

Table 5 gives typical coefficients of thermal expansion for common body materials.

Table 5 — Common coefficients of thermal expansion in the 0 °C to 100 °C range

Material	Thermal expansion coefficient α K^{-1}
Carbon steel	12×10^{-6}
Stainless steel AISI 304	17×10^{-6}
Stainless steel AISI 316	16×10^{-6}
High elastic-limit stainless steel AISI 420	10×10^{-6}

The thermal expansion coefficients for a given material vary with temperature and the treatment process of the steel. The values given in Table 5 and used in the example in Figure 8 are for illustrative purposes only. It is consequently recommended that, for more precise calculations, the coefficient of thermal expansion data be obtained from the material manufacturer.

A graphical presentation of Equation (15) is shown in Figure 8 for two materials from Table 5.

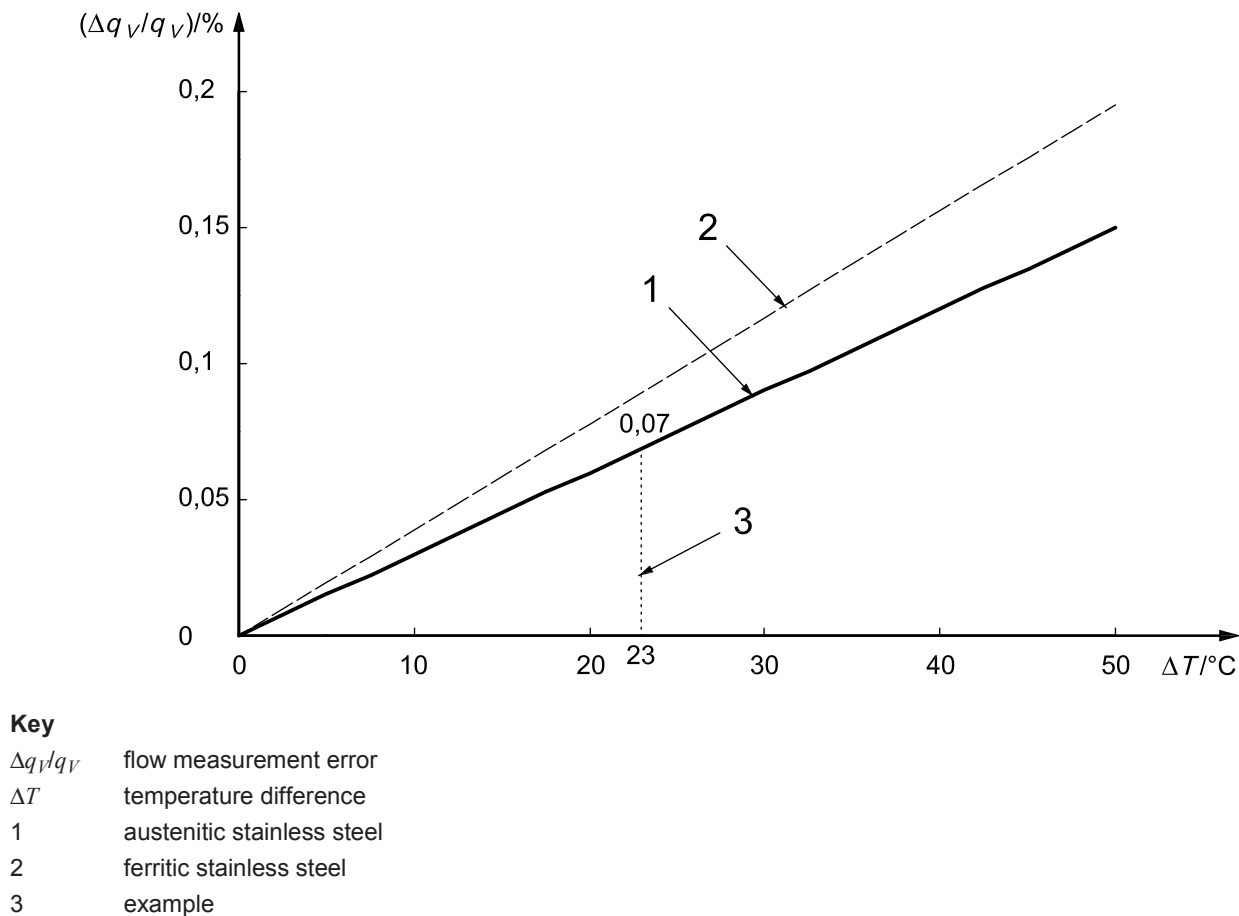


Figure 8 — Temperature related flow error for two example material types

Figure 8 can be used to quickly estimate the percentage correction required for a given temperature change. The example point for a +23 °C temperature change with an austenitic stainless steel body shows a +0,07 % correction (i.e. the meter would underestimate the flow by 0,07 % without the correction). If ΔT is negative, $\Delta q_v/q_v$ is negative (i.e. the meter will overestimate the flow).

4.7.3 Pressure correction

4.7.3.1 General

The geometry-related pressure correction is complex and depends on the design of the meter body, its end connections and the way the meter ends are supported in operation. Looking at the market, the various meter designs offered can be grouped into three broad categories:

- a) welded-in cylindrical body designs;
- b) meter bodies consisting of a pipe with welded-on flanges;
- c) non cylindrical meter body designs, for example those based on casting.

In 4.7.3.2 to 4.7.3.4, a means of making an initial estimate of the flow error for any body type is provided.

4.7.3.2 General simplified expression for any body type

As a first stage in estimating the pressure effects, a general basic expression can be derived assuming the meter body consists simply of a cylindrical pipe. An estimate of the maximum expected flow error due to a body pressure change, Δp , is (as described in E.5) given by:

$$\left(\frac{\Delta q_V}{q_V} \right)_{b, p, \max} = 4 \frac{\Delta r}{r} = 4 \left(\frac{R^2 + r^2}{R^2 - r^2} + \mu \right) \frac{\Delta p}{E} \quad (16)$$

If the meter body is irregular or non-cylindrical (e.g. as might be the case for a cast body), then, for the purposes of this initial estimate, the outside radius value, R , should be taken as the point where the wall is thinnest since this gives the largest estimate of flow error.

Equation (16) can be presented in graphical form as shown in Figure 9 for a range of values of δ/r , i.e. the ratio of wall thickness to internal radius.

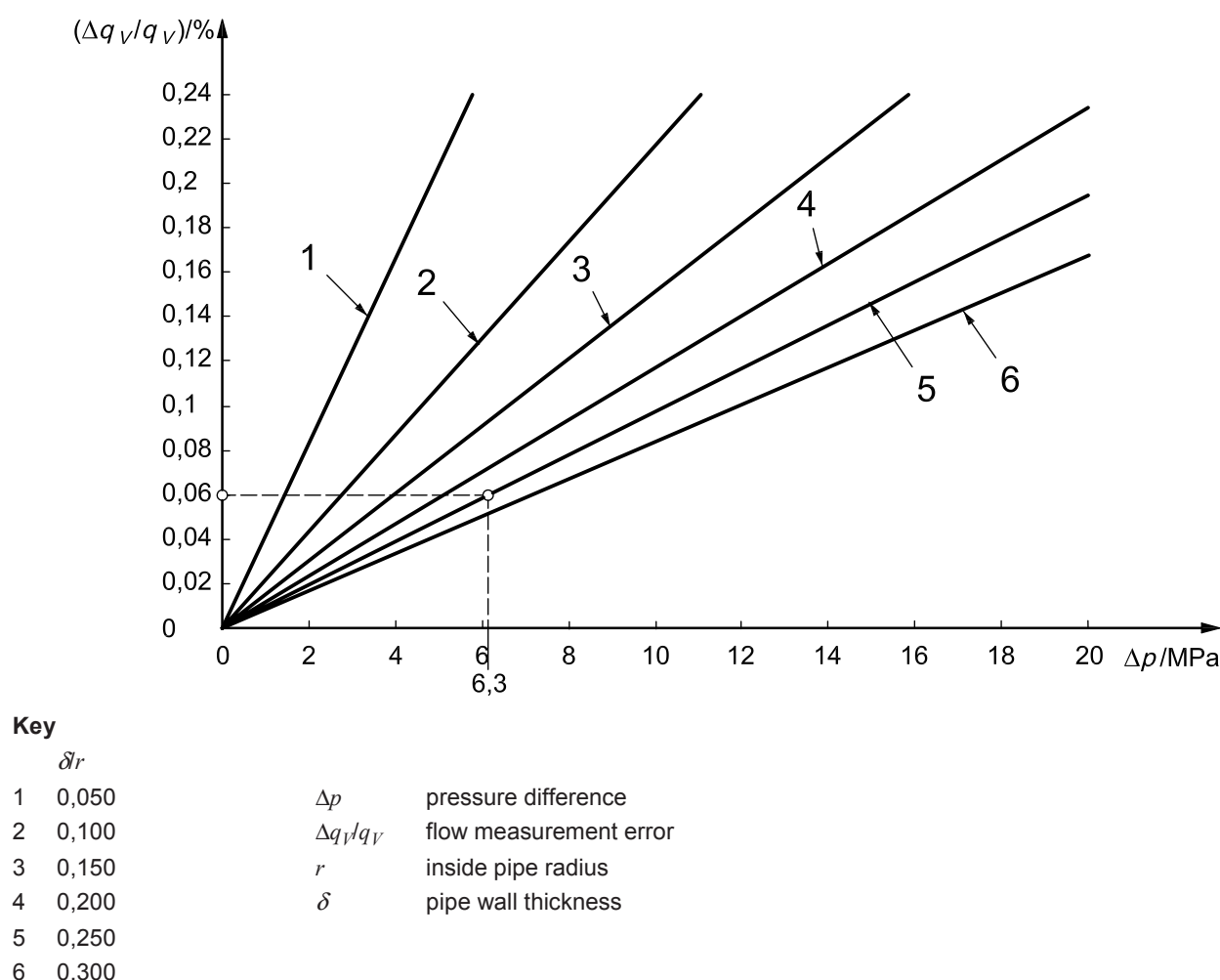


Figure 9 — Maximum expected pressure-related flow error for different δ/r ratios

Figure 9 provides a rapid means of estimating the maximum expected flow error due to body pressure changes. The figure is plotted for a body material with a Young modulus of 2×10^{11} Pa and a Poisson ratio of 0,3. The example of $\Delta p = 6,3$ MPa shows the maximum expected pressure-induced error to be 0,06 % for a $\delta/r = 0,25$. If Δp is negative, $\Delta q_V/q_V$ is negative (i.e. the meter will overestimate the flow).

Since Equation (16) and Figure 9 provide a maximum expected error, the reader can, if desired, go straight to 4.7.5 (taking $K_E = K_S = 1$) to assess the significance of the error without the need of the refinement in the initial estimate provided in 4.7.3.3 and 4.7.3.4 since these result in a lower value for the flow error.

4.7.3.3 Refinement in initial estimate to account for different meter body designs

Flanged ends or irregular shape to the body stiffen the body compared to the simple cylindrical pipe approach used in 4.7.3.2. Consequently, the body expansion and resulting flow error is less than that given by Equation (16) and Figure 9. To compensate for this local stiffening effect, a body style correction factor, K_s , is used to give a revised estimate of the flow error:

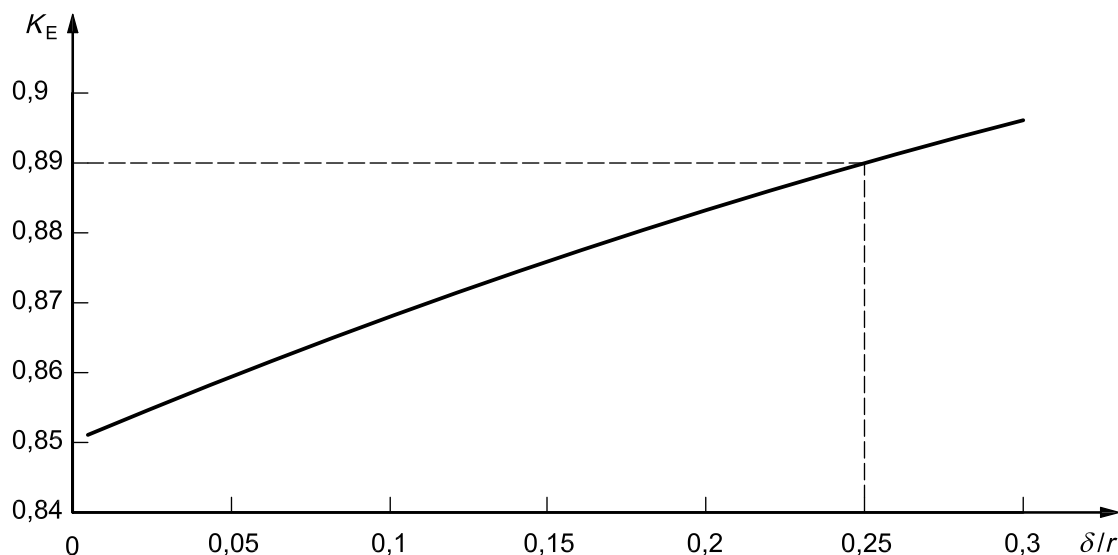
$$\left(\frac{\Delta q_V}{q_V} \right)_{b, p, rev1} = K_s \left(\frac{\Delta q_V}{q_V} \right)_{b, p, max} \quad (17)$$

K_s is always less than or equal to 1. The value of K_s to be used for a given body type is as follows:

- for a welded-in body with no flanges within $2R$, where R is the outside pipe radius, of the ultrasonic transducer locations, $K_s = 1$, i.e. the meter body behaves as a simple pipe;
- for a flanged meter body (e.g. consisting of two flanges welded to a pipe) or welded-in design where neighbouring flanges are within $2R$ of the transducer positions, the value of K_s has to be calculated as described in E.2.3;
- for irregularly shaped meter bodies, for example cast bodies, K_s is obtained as follows based on an average flow error:
 - Equation (16), or Figure 9, are used to obtain a second flow error, y , but this time based on the thickest wall section,
 - K_s is then calculated as, $K_s = 0,5 \times (1 + y/x)$ where x is the initial estimate based on the thinnest wall section.

4.7.3.4 Refinement in initial estimate for effects of end loading and end support or constraint

Equation (16) and Figure 9 are based on the worst-case conditions for radial body expansion (no end loads and free ends). The effect of the best-case conditions (pressure end loads and free ends) for minimal radial body expansion can be taken into account by introducing an end correction factor, K_E , given in Figure 10 for a Poisson ratio of 0,3.



Key

K_E end correction factor

r inside pipe radius

δ pipe wall thickness

$$K_E = -0,122\,9(\delta/r)^2 + 0,191\,3(\delta/r) + 0,850\,1$$

Figure 10 — End loading and support correction factor, K_E

The end correction factor is derived simply from the ratio of Equations (E.12) and (E.14). In the example in Figure 10, $K_E = 0,89$ for $\delta/r = 0,25$. Note that the smallest value K_E can have is 0,85.

The flow error $\Delta q_V/q_V$ then becomes:

$$\left(\frac{\Delta q_V}{q_V} \right)_{b,p} = K_E K_S \left(\frac{\Delta q_V}{q_V} \right)_{b,p,\max} \quad (18)$$

Note, Equation (18) gives an estimate of the expected minimum flow error. It can therefore be used in combination with the maximum flow error (i.e. with $K_E = K_S = 1$) to provide an initial estimate of the range or tolerance in expected flow error.

4.7.4 Effects of transducer ports

The combined impact of the transducer and the transducer port are normally an order of magnitude smaller than the effect on the meter body and can be neglected for most cases. However, for reference, in E.2.5, a simple calculation method is provided that includes an estimate of port effects. In these equations, the transducer material coefficients have to be known (obtainable from the manufacturer).

4.7.5 Total metering error

The initial estimate of the combined flow error, $(\Delta q_V/q_V)_{c, \text{est}}$, due to a temperature and a pressure difference is given by:

$$\left(\frac{\Delta q_V}{q_V} \right)_{c, \text{est}} = \left(\frac{\Delta q_V}{q_V} \right)_{b,T} + K_E K_S \left(\frac{\Delta q_V}{q_V} \right)_{b,p,\max} \quad (19)$$

If the flow error is deemed not significant, then it can be dismissed.

If, however, the flow error is deemed significant and hence requires correction, the detailed calculation described in 4.7.6 needs to be performed to obtain a more precise flow correction factor.

NOTE If calculations in 4.7.3.3 and 4.7.3.4 were omitted in the estimate for pressure effect, a repeat estimate can be performed using those sections to provide a lowered estimate before reassessing the need for the more detailed calculation.

4.7.6 Detailed calculation procedure

Annex E describes the detailed calculation, and includes the pressure and temperature effects on the transducer ports as well as on the meter body, effects of body style, and end loading.

The ratio between $q_{V,0}$ at a reference calibration condition and $q_{V,1}$ at different conditions can be written (see E.1) as a flow correction factor, $q_{V,1}/q_{V,0}$, given by:

$$\frac{q_{V,1}}{q_{V,0}} = \left(\frac{d_1}{d_0} \right)^2 \left(\frac{l_1}{l_0} \right)^2 \left(\frac{x_0}{x_1} \right) \quad (20)$$

The detailed calculation contains estimates of extremes and allows the flow error to be described in either of the following equivalent forms:

$$q_{V,1}/q_{V,0} = x,xxxx \pm x,xxxx \quad (21)$$

$$\Delta q_V/q_V = (x,xx \pm x,xx) \% \quad (22)$$

Stating the final flow correction factor, $q_{V,1}/q_{V,0}$, to four decimal places and the flow error, $\Delta q_V/q_V$, to two decimal places is representative of the general level of accuracy of the calculation method. Since there is always some uncertainty as to the actual end-loading conditions on the meter, the flow estimates are never more precise than the tolerance magnitudes given in Equations (21) and (22).

For meter bodies that are generally cylindrical in shape and either welded in or have attached flanges, Annex E provides a simple procedure based on direct calculation from the physical characteristics of the meter. Annex E provides a worked example of such a direct calculation.

Where the meter body is such that the body shape is not a simple cylinder, flanges take up a significant proportion of the total body length or ports are not simple tubes, a finite element (FE) model provides a more accurate estimate of the body and port dimensions, and consequent flow error obtained from Equation (20) than that given by the direct calculations of E.2.2 to E.2.5. E.3 provides guidance on the use of FE modelling to predict the temperature and pressure expansion effects.

Regardless of the complexity of the meter, an FE model of the body and ports can be used. It is recommended that Equations (E.12) to (E.15), including any body style correction effects (E.2.3) where relevant, can be used as a means of checking the predicted dimensions from the FE model to provide added confidence in the FE model. Equation (20) is still used to predict the flow error along each path based on the changes in physical dimensions between conditions.

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 pressure (density) to ensure acoustic coupling of the sound pulses to and from the gas. Therefore, the expected 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.

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

- a) when the acoustic-wave-attenuating carbon dioxide levels are above 3 % volume fraction or the occurrence of carbon dioxide in large meters ($\geq 12''$);
- b) when the operation is near the critical density of the natural gas mixture;
- c) when the total sulfur level, from materials such as hydrogen sulfide, mercaptans (thiols), and elemental sulfur, exceeds 320 $\mu\text{mol/mol}$;
- d) salt deposits.

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 sound waves.

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

The flanges of the USM shall both have the same inside diameter to within 1 % of each other. A USM with an inside diameter equal to the flange diameter shall be indicated as "full bore". A 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.

5.2.5 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 tapings

At least one metering-pressure tapping, drilled perpendicular in the top $\pm 85^\circ$, shall be provided on the meter or on the piping adjacent to the meter to enable direct measurement of the static pressure under metering conditions. For a reduced bore meter, the tapping shall be in the reduced bore section. The connection of this pressure tapping shall be marked "pm". If more than one pm tapping is provided, the difference in pressure readings shall not exceed 100 Pa at maximum flow rate with an air density of 1,2 kg/m³.

A meter may be equipped with other pressure tapings in addition to the pm 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 tapings 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.

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 (a device intended to improve both the stability and the shape of the flow profile) irremovably attached to the meter is regarded as part of the equipment. For purposes of this part of ISO 17089, the combination of flow conditioner and meter is regarded as the USM.

A flow conditioner, not attached to the meter but intended to be connected permanently to it, plus the linking meter tube, forms a USM package (USMP). In a bidirectional setup, a thermowell may also be part of the USMP.

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;

- d) maximum and minimum operating pressure, and operating temperature range;
- e) maximum and minimum actual volume flow rate per hour;
- f) direction of positive or forward flow;
- g) orientation of the meter ("this side up");

Nameplates may include the following:

- h) purchase order number or shop order number;
- i) legal metrology approval identification.

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

If markings are stamped on the meter body, low stress stamps may be used which produce a rounded-bottom impression.

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 (range) shall be specified.

5.3.2 Rate of pressure change

Rapid depressurization of a USM may cause damage to the transducer or change the characteristics of the meter. Meter users should therefore ensure that the transducers 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.

5.4 Electronics

5.4.1 General requirements

The ES of a USM usually includes 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 6.4.2. 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 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.

5.4.3 Pulse detection method

The pulse 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.

5.4.4 Sampling or pulsating flow

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

5.4.5 Signal-to-noise ratio

The USM shall indicate the S/N ratio per transducer or per acoustic path. An alarm shall be triggered when the signal is lost. An alarm may also be given at low performance.

5.4.6 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.

5.4.7 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) frequency representing non-linearized flow rate.

The time-integrated values of these outputs shall match better than 0,02 % in every arbitrary interval of 100 s under flowing conditions above $q_{V,min}$.

The meter may be equipped with the following output:

- c) frequency, representing linearized flow rate;
- d) an analogue (4 mA to 20 mA) output for flow rate at line conditions.

Flow rate outputs shall function up to 120 % of the maximum flow rate, $q_{V,max}$, 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 (not applicable to serial data output).

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.

The USM may be equipped with a display for presenting measured and other values.

For control purposes, the update frequency of the output signal(s) to the measured flow shall be specified and be at least 1 Hz.

5.4.8 Cable jackets and insulation

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

5.4.9 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 in a non-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 checksum and event log shall be provided to validate that no unauthorized changes have been made to the firmware.

5.5.2 Discontinuity

Being an electronic meter, the firmware may introduce discontinuities due, for example, to level settings. Therefore, the firmware shall be designed to avoid discontinuities.

5.5.3 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.

5.5.4 Configuration and monitoring software

The meter shall be specified to have a capability for local or remote configuration of the ES and for monitoring the operation of the meter. As a minimum, the ES shall be able to display and record the following measurements:

- a) actual volume flow rate;
- b) average velocity;
- c) average SOS;
- d) individual path velocity and SOS per path;
- e) ultrasonic acoustic signal quality received by each transducer.

As an option, these functions may be provided as part of the embedded software of the meter.

5.5.5 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) warning: when any of several monitored parameters fall outside normal operation for a significant length of time (optional);
- c) partial failure: when one or more of the multiple ultrasonic path results is not usable (optional).

5.5.6 Diagnostic parameters

As a minimum, the following measurements shall be provided for diagnostic purposes:

- a) non-linearized average velocity through the meter;
- b) flow velocity for each acoustic path (or equivalent for evaluation of the flowing velocity profile);
- c) SOS along each acoustic path;
- d) average SOS;
- e) velocity sampling interval;
- f) averaging time interval;
- g) percentage of accepted pulses for each acoustic path;
- h) S/N ratio or equivalent (gain control);
- i) status and measurement quality indicators;
- j) alarm and failure indicator.

The provision of the linearized average flow velocity is optional.

The meter shall be supplied with a facility for storing these values in a data file.