INTERNATIONAL STANDARD

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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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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.

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;

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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.

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/

3.1.1 Quantities

3.1.1.1
volume flow rate

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

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.

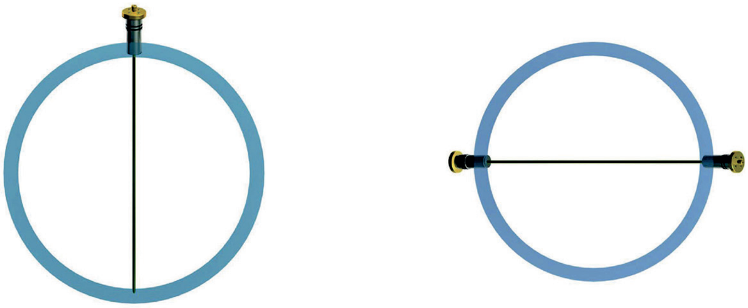

Figure 2 — Diametrical paths

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.

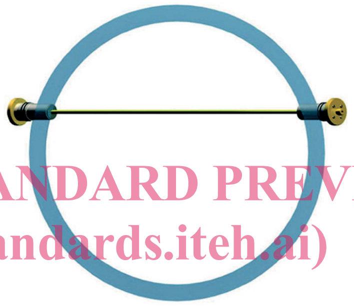

Figure 3 — Chordal paths

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.

3.1.4.2
calibration curve
set of measurement 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

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 dis-turbance	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.

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