INTERNATIONAL STANDARD

ISO 17089-1

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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

Reference number
ISO 17089-1:2010(E)

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

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

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

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

See Figure 2.

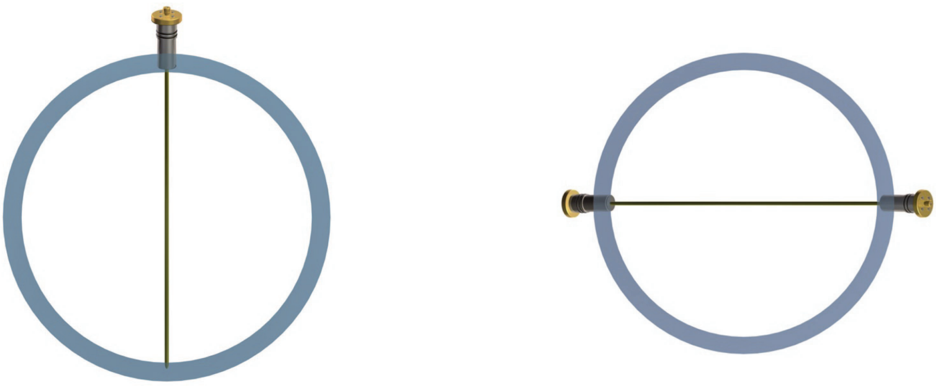


Figure 2 — Diametrical paths

3.1.3.5
chordal path
accoustic path whereby the acoustic wave travels parallel to the diametrical path

See Figure 3.

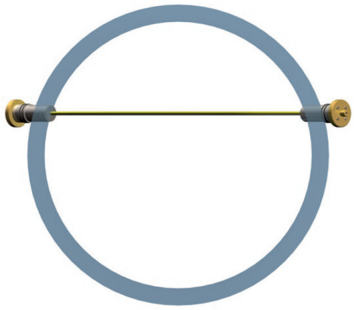


Figure 3 — Chordal paths

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·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
$q_{V,\,\mathrm{max},\,20}$	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

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):

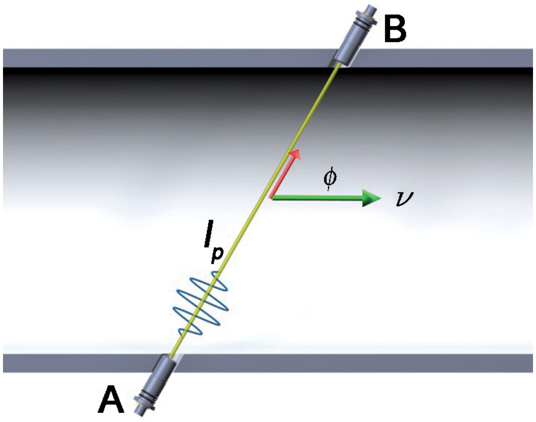
$$t_{AB} = \frac{l_p}{(c + v\cos\phi)} \quad (1)$$

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):

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

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:

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

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 Equation (5), even for a given number of paths, the exact form of $f(v_1 \ldots v_n)$ 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:

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

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.