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Measurement of fluid flow in closed conduits — Clamp-on ultrasonic transit-time meters for liquids and gases

Mesurage du débit des fluides dans les conduites fermées — Débitmètres non-intrusifs à ultrasons à temps de transit pour les liquides et les gaz

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Contents

Page

Foreword v
Introduction vi
1 Scope 1
2 Normative references 1
3 Terms and definitions 1
  3.2 Meter design 2
  3.3 Thermodynamic conditions 2
  3.4 Statistics 3
  3.5 Calibration 4
  3.6 Symbols and subscripts 5
4 Principle of measurement 6
  4.1 General 6
  4.2 Generic description 6
    4.2.1 Transducers 7
    4.2.2 Ultrasonic path configurations 8
    4.2.3 Electronic unit functionality 10
  4.3 Special considerations 10
    4.3.1 Gas 10
    4.3.2 Extreme temperatures 10
  4.4 Additional measurements 11
    4.4.1 Standard volume flow 11
    4.4.2 Heat flow 11
    4.4.3 Mass flow 11
5 Test and calibration 11
  5.1 General 11
  5.2 Individual testing — Flow calibration under flowing conditions 12
    5.2.1 General 12
    5.2.2 Laboratory flow calibration 12
6 Installation 13
  6.1 General 13
  6.2 Installation location 13
    6.2.1 Upstream and downstream straight pipe length requirements and path configuration 13
  6.3 Transmitter programming 14
  6.4 Pressure and temperature inputs 15
  6.5 Transducer installation 15
    6.5.1 Transducer type 15
    6.5.2 Transducer orientation 15
    6.5.3 Coupling 15
    6.5.4 Transducer mounting 16
  6.6 Gas considerations 17
  6.7 Cable 18
  6.8 Additional installation effects 18
    6.8.1 Non-steady flow 18
    6.8.2 Contamination by secondary phase 18
    6.8.3 Vibration 18
    6.8.4 Thermal insulation 19
    6.8.5 Stratification 19
    6.8.6 Wall roughness signal considerations 19
    6.8.7 Non-Newtonian fluids 19
  6.9 Operational diagnostics 19
    6.9.1 Fluid speed of sound 19

6.9.2 Gain 20
6.9.3 Signal to noise ratio 20

7 Maintenance 20

8 Uncertainty in measurement 21
8.1 General 21
8.2 Mathematical model 21
8.3 Evaluation of the contributory variances 22
8.3.1 Uncertainty of the cross-sectional area, $u(A)$ 22
8.3.2 Uncertainty in the velocity profile, $u(K_p)$ 24
8.3.3 Uncertainty of the path-geometry factor, $u(K_g)$ and time measurement 24
8.3.4 Uncertainty of time measurement 25
8.3.5 Uncertainty of the delay time, $u(t_0)$ 25
8.3.6 Effect of multiple paths 25
8.4 Additional effects on measurement uncertainty 25
8.4.1 Effect of pipe material on sound speed 25
8.4.2 Effect of fluid sound speed 26
8.4.3 Reproducibility of transmitter mounting 26
8.4.4 External influences 26

Annex A (informative) **Example of uncertainty calculation 27**

Bibliography 34

Foreword

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Introduction

Non-intrusive (clamp-on) ultrasonic meters (USMs) have become one of the accepted flow measurement technologies for a wide range of applications, including process and control measurements. Non-intrusiveness also brings characteristics relevant for economics, safety, and environment. Ultrasonic technology has inherent features such as no pressure loss and wide rangeability. USMs can deliver diagnostic information through which it may be possible to demonstrate that an ultrasonic flowmeter is performing in accordance with specification.

This document provides a description of the non-intrusive (clamp-on) meter, typical application areas, the measures which should be used in assessing the likely performance in terms of error, repeatability and reproducibility when used under ideal and non-ideal operational conditions.

Measurement of fluid flow in closed conduits — Clamp-on ultrasonic transit-time meters for liquids and gases

1 Scope

This document specifies requirements and recommendations for non-intrusive (clamp-on) ultrasonic flowmeters (USMs), which use the transit time of ultrasonic signals to measure the volumetric flowrate in closed conduits. Transit time flowmeters are predominantly used on single-phase fluids (liquid and gases) but can also be used where small quantities of additional phases are present.

This document specifies performance, calibration, and output characteristics, and deals with installation conditions.

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*

3 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 terminology databases for use in standardization at the following addresses:

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

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

3.1 Quantities

3.1.1
volume flowrate
q_V

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

where

V is volume;

t is time

[SOURCE: ISO 80000-4:2006, 4-31[2]]

3.1.2
mean flow velocity
v_p
volume flowrate (3.1.1) divided by the cross-sectional area of the pipe

3.1.3

path velocity

v_l

average fluid velocity on an ultrasonic path

3.1.4

Reynolds number

Re_D

dimensionless parameter expressing the ratio between the inertia and viscous forces in the fluid

$$Re_D = \frac{\rho v_A D}{\mu} = \frac{v_A D}{v_{\mathrm{kv}}}$$

where

ρ is density;

v_A is the mean flow velocity;

D is the pipe internal diameter;

μ is the dynamic viscosity;

v_{kv} is the kinematic viscosity

3.2 Meter design

3.2.1

ultrasonic path

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

3.2.2

electronic unit

part of the meter that controls the transducers, processes the signals into a flow-rate and provides outputs (see 4.2.3)

3.3 Thermodynamic conditions

3.3.1

metering conditions

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

Note 1 to entry: Also known as operating conditions or actual conditions.

3.3.2

standard conditions

defined temperature and pressure conditions used in the measurement of fluid quantity so that the standard volume is the volume that would be occupied by a quantity of fluid if it were at standard temperature and pressure

Note 1 to entry: Standard conditions may be defined by regulation or contract.

Note 2 to entry: Not preferred alternatives: reference conditions, base conditions, normal conditions, etc (see ISO 91[3]).

Note 3 to entry: Metering and standard conditions relate only to the volume of the fluid to be measured or indicated and should not be confused with rated operating conditions or reference conditions (see ISO/IEC Guide 99:2007, 4.9 and 4.11[4]), which refer to influence quantities (see ISO/IEC Guide 99:2007, 2.52[4]).

3.4 Statistics

3.4.1

error

measured quantity value minus a reference quantity value

[SOURCE: ISO/IEC Guide 99:2007, 2.16[4]]

3.4.2

repeatability (of results of measurements)

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: These conditions are called repeatability conditions.

Note 2 to entry: Repeatability conditions include:

- the same measurement procedure;
- the same observer;
- the same measuring instrument, used under the same conditions;
- the same location;
- repetition over a short period of time.

Note 3 to entry: Repeatability may be expressed quantitatively in terms of the dispersion characteristics of the results.

[SOURCE: ISO/IEC Guide 98-3:2008, B.2.15[5]]

3.4.3

reproducibility (of results of measurements)

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

Note 1 to entry: A valid statement of reproducibility requires specification of the conditions changed.

Note 2 to entry: The changed conditions may include:

- principle of measurement;
- method of measurement;
- observer;
- measuring instrument;
- reference standard;
- location;
- conditions of use;
- time.

Note 3 to entry: Reproducibility may be expressed quantitatively in terms of the dispersion characteristics of the results.

Note 4 to entry: Results are here usually understood to be corrected results.

[SOURCE: ISO/IEC Guide 98-3:2008, B.2.16[5]]

3.4.4

resolution

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

3.4.5

zero flow

meter reading when the fluid is at rest, i.e. both axial and non-axial velocity components are essentially zero

3.4.6

uncertainty (of measurement)

parameter, associated with the result of measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

Note 1 to entry: The parameter may be, for example, a standard deviation (or a given multiple of it), or the half-width of an interval having a stated level of confidence.

Note 2 to entry: Uncertainty of measurement comprises, in general, many components. Some of these components may be evaluated from the statistical distribution of the results of a series of measurements and can be characterized by experimental standard deviations. The other components, which can also be characterized by standard deviations, are evaluated from assumed probability distributions based on experience or other information.

Note 3 to entry: It is understood that the result of the measurement is the best estimate of the value of the measurand, and that all components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion.

[SOURCE: ISO/IEC Guide 98-3:2008, B.2.18[5]]

3.4.7

standard uncertainty

u

uncertainty of the result of a measurement expressed as a standard deviation

[SOURCE: ISO/IEC Guide 98-3:2008, 2.3.1[5]]

3.4.8

expanded uncertainty

U

quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand

[SOURCE: ISO/IEC Guide 98-3:2008, 2.3.5[5]]

Note 1 to entry: The large fraction is normally 95 % and is generally associated with a coverage factor $k = 1{,}96$.

Note 2 to entry: The expanded uncertainty is often referred to as the uncertainty.

3.4.9

coverage factor

numerical factor used as a multiplier of the standard uncertainty in order to obtain an *expanded uncertainty* (3.4.8)

[SOURCE: ISO/IEC Guide 98-3:2008, 2.3.6[5]]

3.5 Calibration

3.5.1

flow calibration

calibration of a meter against a reference using fluid flowing through the meter

3.6 Symbols and subscripts

The symbols and subscripts used in this document are given in Table 1 and Table 2.

Table 1 — Symbols

Quantity	Symbol	Dimension[a]	SI unit
Cross-sectional area of pipe	A	L^2	m^2
Speed of sound in fluid	c	LT^{-1}	m/s
Internal pipe diameter	D_i	L	m
External pipe diameter	D_e	L	m
Integers (1.2.3. ,,,)	i,j,n	—	1
Calibration factor	K	—	1
Path-geometry factor	K_g	L[b] or LT^{-1} [c]	m[b] or m/s [c]
Velocity profile correction factor	K_p	—	1
Minimum distance to a specified upstream flow disturbance	l_{min}	L	m
Path length	l_p	L	m
Absolute pressure	p	$ML^{-1}T^{-2}$	Pa
Volume flowrate	q_V	L^3T^{-1}	m^3/s
Pipe Reynolds number	Re_D	—	1
Transit time	t_{tr}	T	s
Time delay	t_0	T	s
Mean axial fluid velocity	v	LT^{-1}	m/s
Mean axial fluid velocity of the cross-sectional area	v_A	LT^{-1}	m/s
Mean axial fluid velocity on ultrasonic path, *l*	v_l	LT^{-1}	m/s
Compressibility	Z	$M^{-1}LT^{-}$	Pa^{-1}
Pipe wall thickness	δ	L	m
Dynamic viscosity	μ	$ML^{-1}T^{-1}$	Pa s
Kinematic viscosity	v_{kv}	L^2T^{-1}	m^2/s
Density of the fluid	ρ	ML^{-3}	kg/m^3
Angle between ultrasonic path and pipe axis	ϕ	—	rad

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

[b] Non-refracting configuration.

[c] Refracting configuration.

Table 2 — Subscripts

Subscript	Meaning
cal	under calibration conditions
meas	measured (uncorrected)
op	under operational conditions
true	actual (corrected)

4 Principle of measurement

4.1 General

This subclause is a generic description of USMs for liquids and gases. It 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 and mounting arrangement

b) electronic data processing and presentation unit.

4.2 Generic description

Ultrasonic transit time clamp-on flowmeters measure non-intrusively. Figure 1 outlines the basic system setup to demonstrate the principle. A pair of transducers is located on the outside of the pipe. The transducers are alternatively working as transmitter and receiver. Ultrasonic pulses are sent through the fluid, in the flow direction, and against it. The transit-time $t_{\mathrm{me\_dn}}$ of the ultrasonic signal propagating in the flow direction (down-stream) is shorter than the transit-time $t_{\mathrm{me\_up}}$ of the signal propagating against the flow direction (up-stream). The average flow velocity v_l on the sound path is directly proportional to the measured difference Δt in transit time[6]:

$$v_l = \frac{c_t}{\cos\phi_t} \frac{\Delta t}{\left(t_{\mathrm{me\_up}} + t_{\mathrm{me\_dn}} - 2t_0\right)} \tag{1}$$

The delay time t_0 is the portion of the transit time outside the flowing fluid. The average of the transit times measured upstream and downstream is the transit time t_{tr} at zero flow:

$$t_{\mathrm{tr}} = \frac{1}{2}\left(t_{\mathrm{me\_up}} + t_{\mathrm{me\_dn}}\right) \tag{2}$$

The angle ϕ_δ and the sound speed c_δ in the coupling wedge define the propagation angles β and γ in the pipe wall and the fluid according to Snell's law:

$$K_{\mathrm{g}} = \frac{c_\delta}{\cos\phi_\delta} = \frac{c_\beta}{\cos\beta} = \frac{c_\gamma}{\cos\gamma} \tag{3}$$

K_{g} could be denoted as the path-geometry factor, according to.[6] The ultrasonic signal is shifted in axial direction while propagating through the flowing fluid. K_{g} defines the ratio of the shift to the time difference measured. With Formulae (2) and (3), Formula (1) results in:

$$v_l = K_{\mathrm{g}} \frac{\Delta t}{2(t_{\mathrm{tr}} - t_0)} \tag{4}$$

When multiple paths are installed a weighted sum of the path velocities is calculated.

The mean velocity is obtained by applying a velocity profile factor, K_{p}, which expresses the relationship between the mean velocity v_A and the measured path velocity v_l:

$$v_A = K_{\mathrm{p}} \cdot v_l \tag{5}$$

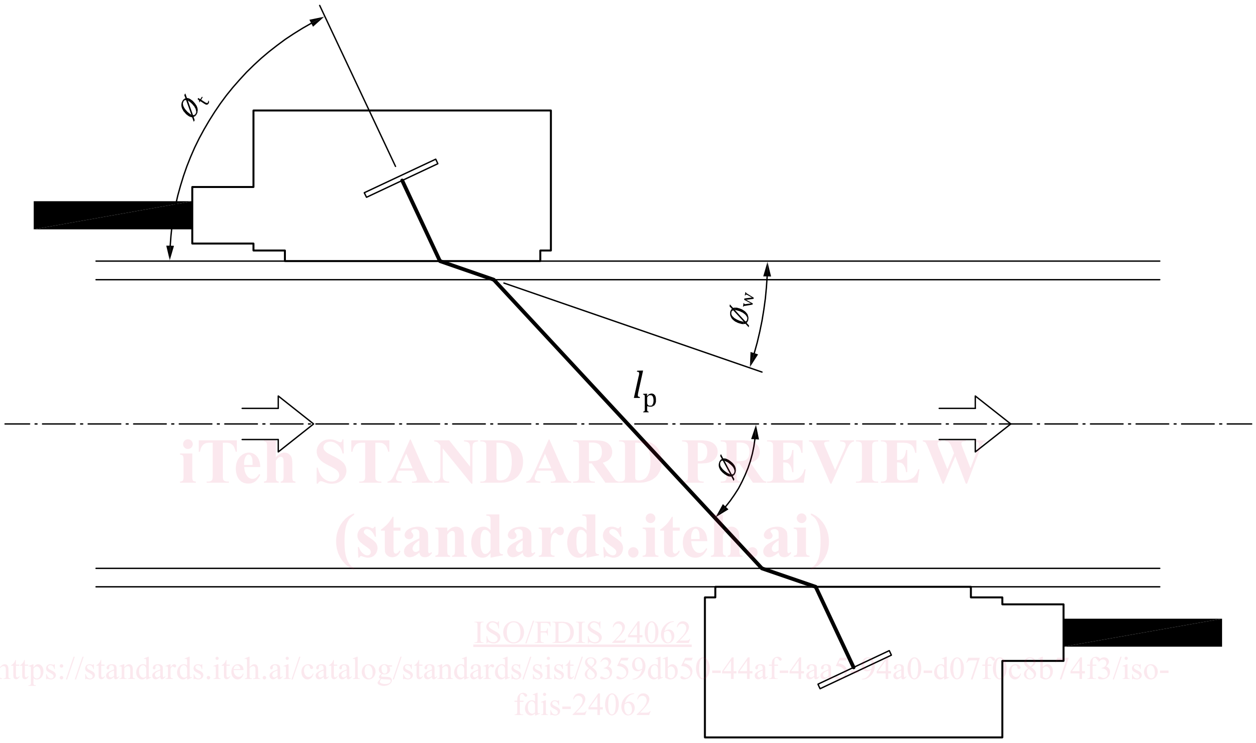
The velocity profile factor K_{p} is calculated by the meter based on an empirical model of the flow profile assuming a fully developed turbulent flow profile. The model is parameterized by the Reynolds number and the roughness of the inner pipe wall. The influence of upstream flow disturbances can be corrected based on experimental or validated computational evaluation.

The volume flowrate is given as the product of the mean velocity and the cross-sectional area A of the pipe:

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

With Formulae (4), (5) and (6) the meter formula for the volume flowrate would be:

$$q_V = A \cdot K_\mathrm{p} \cdot K_\mathrm{g} \frac{\Delta t}{2(t_\mathrm{tr} - t_0)} \tag{7}$$



Key

ϕ_t	incident wedge angle
ϕ_w	pipe wall refracted angle
l_p	path length
ϕ	angle between ultrasonic path and pipe axis

Figure 1 — Basic system setup of clamp-on flow meter

4.2.1 Transducers

Transducers are the transmitters and receivers of the ultrasonic signal. They 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 frequency is defined by the materials used and its dimensions, in the case of piezoelectric elements, the lateral dimensions and thickness of this element.

Selection of an appropriate frequency will be dependent on the application. It mainly depends on the pipe diameter. As a rough orientation, the proportion of the ultrasonic wavelength to the pipe diameter should be kept within a certain range. As the wavelength decreases with increasing frequency, lower frequencies are used on bigger pipes and higher frequencies on smaller pipes. In addition, the attenuation increases with the frequency. Therefore, if the fluid has a high ultrasonic attenuation, a lower frequency