TECHNICAL REPORT

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Measurement of fluid flow in closed conduits — Methods using transit-time ultrasonic flowmeters

Mesure de débit des fluides dans les conduites fermées — Méthodes utilisant des débitmètres à ultrasons à temps de transit

ISO/TR 12765:1998(E)

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International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland
Internet iso@iso.ch

Printed in Switzerland

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 main task of technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until data they provide are considered to be no longer valid or useful.

ISO/TR 12765, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*.

This document is being issued in the type 2 Technical Report series of publications (according to subclause G.4.2.2 of part 1 of the ISO/IEC Directives, 1992) as a "prospective standard for a provisional application" in the field of ultrasonic flowmeters because there is an urgent need for guidance on how standards in this field should be used to meet an identified need.

This document is not to be regarded as an "International Standard". It is proposed for provisional application so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to the ISO Central Secretariat.

A review of this type 2 Technical Report will be carried out not later than three years after its publication with the options of: extension for another three years; conversion into an International Standard; or withdrawal.

Annexes A, B and C of this Technical Report are for information only.

Measurement of fluid flow in closed conduits — Methods using transit-time ultrasonic flowmeters

1 Scope

This Technical Report gives guidance on the principles and main design features of ultrasonic flowmeters based on the measurement of the difference in transit time for volume flowrate measurement of fluids. It covers their operation, performance and calibration. It primarily covers wetted transducers but briefly refers to clamp-on transducer arrangements.

Annex A of this Technical Report shows the calculation of volume flowrate by transit-time measurement using pulse techniques.

Annex B covers the recommendations for use and installation.

Annex C gives a list of information to be supplied by the manufacturers.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Technical Report. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 4006:1991, *Measurement of fluid flow in closed conduits — Vocabulary and symbols.*

ISO 4185:1980, *Measurement of liquid flow in closed conduits — Weighting method.*

ISO 8316:1987, *Measurement of liquid flow in closed conduits — Method by collection of the liquid in a volumetric tank.*

ISO 9300:1990, *Measurement of gas flow by means of critical flow Venture nozzles.*

ISO 9951:1993, *Measurement of gas flow in closed conduits — Turbine meters.*

International Vocabulary of Basic and General Terms in Metrology (VIM), BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, 1993.

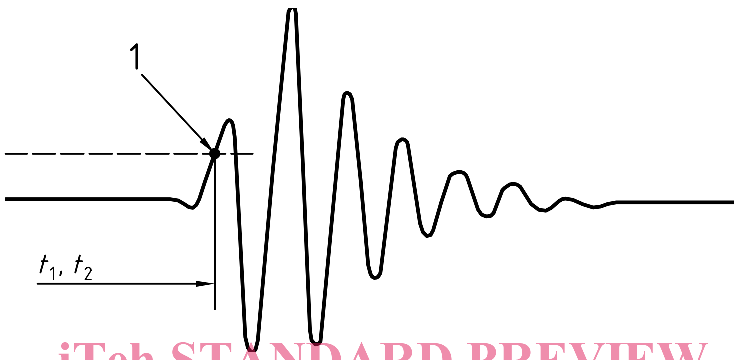
3 Definitions

For the purposes of this Technical Report, the definitions given in the *International Vocabulary of Basic and General Terms in Metrology (VIM)*, ISO 4006 and the following definitions apply.

3.1
transit-time difference method
time-of-flight method
method of flowrate measurement in which the average fluid velocity along the acoustic path $\bar{v}$ is determined from the transit-time difference of two ultrasonic signals, one travelling upstream and one downstream, over the same distance in the flowing fluid

3.2
leading-edge method
method of flowrate measurement in which the transit times of ultrasonic pulses are measured based on triggering at a predetermined amplitude level of the received signal

See Figure 1.



Key
1 Trigger point at leading edge

Figure 1 — Principle of transit-time measurement using leading-edge method

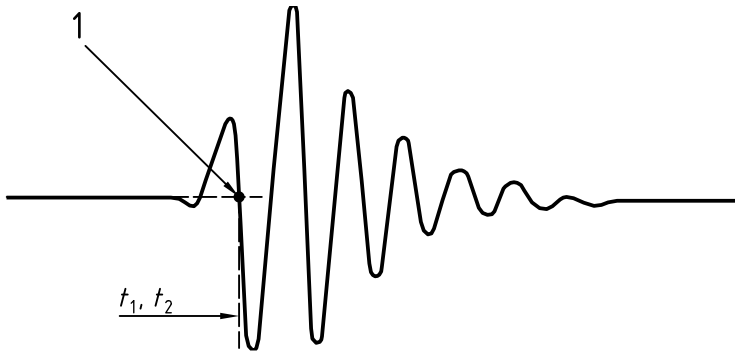
3.3
pulse-repetition frequency method
sing-around method
frequency-difference method
method of flowrate measurement used in ultrasonic flowmeters whereby two independent streams of pulses are transmitted in opposite directions, each pulse being emitted immediately after the detection of the preceding pulse in the stream, and the difference between the pulse-repetition frequencies in the two directions is measured

NOTE The difference between the pulse-repetition frequencies in the two directions is a function of the fluid velocity.

3.4
phase control method
lambda-locked-loop method
method of flowrate measurement in which a measure of the average fluid velocity along the acoustic path $\bar{v}$ is derived from the difference in frequency of sound with the same wavelength travelling in opposite directions through the flowing fluid

3.5
zero-crossing method
method of flowrate measurement in which transit times of ultrasonic pulses are measured using the first (or another predetermined) "zero-crossing" of the received signal following the first half alternance

See Figure 2.



Key

1 Trigger point at zero crossing

Figure 2 — Principle of transit-time measurement using zero-crossing method

3.6
multi-path method
method of flowrate measurement in which the average fluid velocity over a number of different paths is determined

3.7
simultaneous pulse method
method of flow measurement by which the transit times and transit-time difference are determined from signals which are transmitted simultaneously upstream and downstream over the same acoustic path

3.8
phase shift method
method of flow measurement in which the average fluid velocity along the acoustic path $\bar{v}$ is determined from the phase shift of ultrasonic signals in a fluid flow

3.9
ultrasonic flowmeter
USM
flowmeter which generates ultrasonic signals and receives them again after they have been influenced by the flow in such a way that the observed result can be used as a measure of the flowrate

NOTE An ultrasonic flowmeter normally consists of the ultrasonic transducers and equipment which evaluates the flowrate measurement from the emitted and received ultrasonic signals and converts these signals to a standard output signal proportional to the flowrate

3.10
flowrate integrator
device for volume measurement by time-integration of volume flowrate

3.11
ultrasonic transducer
element that converts acoustic energy into electrical signals and/or vice versa

NOTE Ultrasonic transducers used in transit-time flowmeters usually work as both transmitter and receiver.

3.12
clamp-on arrangement
arrangement by which the transducers are attached to the outside wall of the conduit in which the flowrate is to be measured

3.13
meter tube
specially fabricated section of conduit containing the ultrasonic transducers and conforming in all respects to the specification of the standard

3.14
measurement section
section of conduit consisting of the meter tube, the inlet section and the outlet section

3.15
acoustic path
actual path of the ultrasonic signal between both transducers

3.16
path length
L_p
length of acoustic path, in fluid at rest, from the faces of both transducers

See Figure 3 a) and b).

3.17
interrogation length
L
length of that part of the acoustic path, in fluid at rest, inside the conduit

See Figure 3 a) and b).

3.18
interrogation distance
d
projection of the interrogation length on the line parallel to the axis of the conduit or of the flow

See Figure 3 a) and b).

3.19
inclination angle
ϕ
angle between the axes of the ultrasonic transducers and a line parallel to the axis of the conduit

See Figure 3 a).

3.20
phase angle
phase position of an oscillation

3.21
propagation velocity
c
velocity of acoustic signals relative to an observer at rest

3.22
velocity of sound
c_0
velocity of acoustic signals in the fluid at rest

3.23
average fluid velocity along the acoustic path
$\bar{v}$
fluid velocity in the plane which is formed by the acoustic path and the direction of flow

3.24
mean axial fluid velocity
$\bar{v}_A$
ratio of the volume flowrate (q_V) [the integral over a cross-section of the meter tube of the axial components of the local fluid velocities (v)] to the area of the measurement cross-section (A)

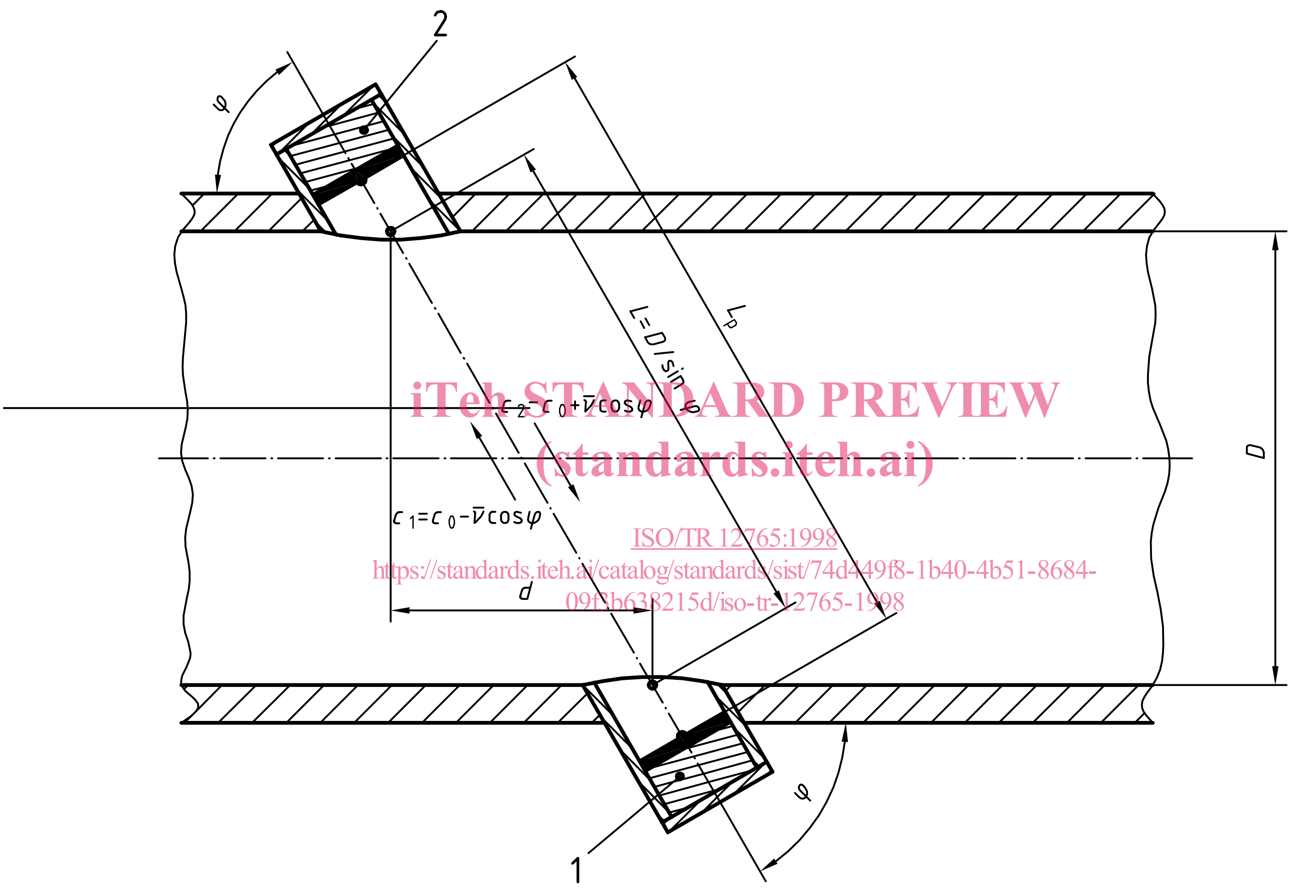
3.25
velocity distribution correction factor
k_h
ratio of the mean axial fluid velocity $\bar{v}_A$ in the meter run to the average axial flow velocity $\bar{v}$ along the acoustic path

3.26
ultrasonic pulse
signal generated by finite-duration electrical excitation of an ultrasonic transducer

3.27
continuous-wave ultrasound
signal generated by continuous electrical excitation of an ultrasonic transducer

3.28
transit time
t
time needed by an ultrasonic pulse to traverse the acoustic path

3.29
transit-time difference
Δt
difference between the transit times of the ultrasonic signals propagated upstream and downstream



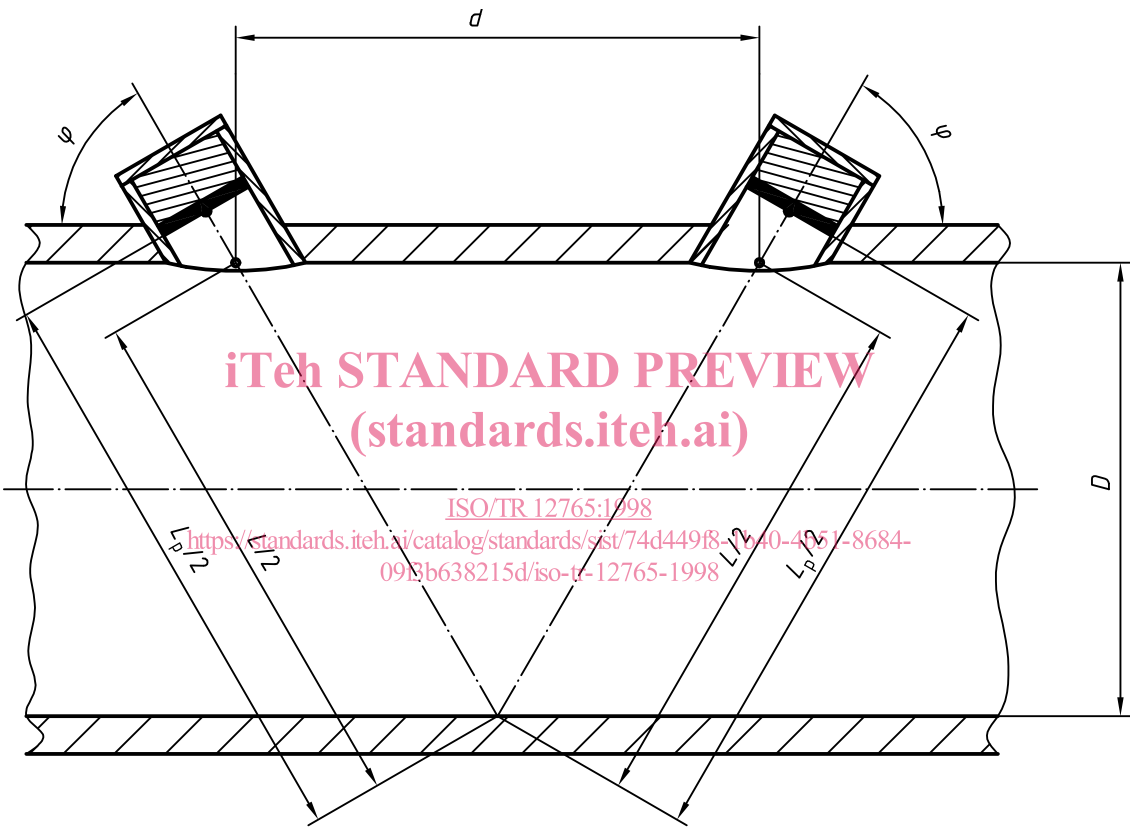
Key

1 Receiver/emitter

2 Emitter/receiver

a) Diagonal-direct beam meter

Figure 3 — Arrangements of single-path beam meter (wetted transducers)



b) Diagonal-reflected indirect beam meter

Figure 3 — Arrangements of single-path beam meter (wetted transducers)

4 Symbols and subscripts

Table 1 — Symbols

Quantity	Symbol	Dimensions[1)]	Corresponding SI unit
Cross-sectional area	A	L^2	m^2
Propagation velocity in the flowing fluid	c	LT^{-1}	m/s
Velocity of sound in fluid at rest	c_0	LT^{-1}	m/s
Inside diameter of pipe	D	L	m
Interrogation distance	d	L	m
Frequency	f	T^{-1}	s^{-1}
Relative uncertainty	E	2)	
Absolute uncertainty	e	3)	
Integer	i	2)	
Velocity distribution correction factor	k_h	2)	
Interrogation length	L	L	m
Path length	L_p	L	m
Integer	m	2)	
Integers (1, 2, 3, ..)	n	2)	
Volume flowrate	q_V	L^3T^{-1}	m^3/s
Reynolds number (related to D)	Re_D	2)	
Transit time	t	T	s
Transit-time difference	Δt	T	s
Local velocity of the fluid	v	LT^{-1}	m/s
Average fluid velocity along the acoustic path	$\bar{v}$	LT^{-1}	m/s
Mean axial fluid velocity	$\bar{v}_A$	LT^{-1}	m/s
Weight of measurement	w_i	2)	
Phase angle	γ	2)	rad
Wavelength of an ultrasonic oscillation	λ	L	m
Inclination angle	ϕ	2)	rad
Cyclic frequency	ω	T^{-1}	$rad \cdot s^{-1}$
Density of the fluid	ρ	ML^{-3}	kg/m^3

1) M = mass, L = length, T = time.
2) Dimensionless quantity.
3) The dimension of this parameter is the dimension of the quantity to which it relates.

Table 2 — Subscripts

1	upstream
2	downstream

5 General principles of measurements

The basic principle used by the ultrasonic flowmeters described in this Technical Report is that sound travelling with the fluid flow will travel faster than sound travelling against the flow. The transit times and the time difference are functions of the fluid velocity. The measurement can be made either by measuring transit times directly or by using frequency or phase measurement. Ultrasonic flowmeters are inherently bidirectional.

Volume flowrate (q_V) is determined by the product of the cross-sectional area (A) and the mean axial fluid velocity $\bar{v}_A$.

5.1 Generation of ultrasonic signals

The ultrasonic signals required for the flow measurement are generated and received by ultrasonic transducers (e.g. using piezoelectric crystals).

Piezoelectric transducers employ crystals or ceramics which are sent into vibration when alternating voltage is applied to their terminals. The vibrating element thus generates longitudinal pressure waves (sound waves) in the fluid. Sound waves incident on such piezoelectric elements will produce electric signals at their terminals, as the piezoelectric effect is reversible.

The acoustic properties of the transducer (beam pattern, resonance frequency, bandwidth, etc.) depend strongly on the construction of the transducer. Figure 4 shows a possible transducer design, and the beam pattern of a transducer is shown in Figure 5.