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Measurement of fluid flow in closed conduits — Guidance for the use of electromagnetic flowmeters for conductive liquids

Mesurage du débit des fluides dans les conduites fermées — Lignes directrices pour l'utilisation des débitmètres électromagnétiques dans les liquides conducteurs

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Foreword

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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 first edition of ISO 20456 cancels and replaces ISO 6817:1992, ISO 9104:1991 and ISO 13359:1998, which has been technically revised.

Introduction

Clauses 3 to 7 cover the definitions, symbols and basic theory of electromagnetic flowmeters. This document does not cover insertion type meters, partially filled meters or meters for non-conductive and highly conductive fluids.

Clause 8 covers installation types and practice, the different types of meter construction, transmitters, lay lengths and sizing, in order to achieve the best performance of the electromagnetic flowmeter in the field.

Clauses 9 to 11 cover some methods of calibration, verification, evaluation, and uncertainty analysis, which can be useful for users or independent testing establishments to verify manufacturer's relative performance and to demonstrate suitability of application

The tests specified in this document are not necessarily sufficient for instruments specifically designed for unusually difficult duties. Conversely, a restricted series of tests may be suitable for instruments designed to perform within a limited range of conditions.

This document is for users and manufacturers.

Measurement of fluid flow in closed conduits — Guidance for the use of electromagnetic flowmeters for conductive liquids

1 Scope

This document applies to industrial electromagnetic flowmeters used for the measurement of flowrate of a conductive liquid in a closed conduit running full. It covers flowmeter types utilizing both alternating current (AC) and pulsed direct current (DC) circuits to drive the field coils and meters running from a mains power supply and those operating from batteries or other sources of power.

This document is not applicable to insertion-type flowmeters or electromagnetic flowmeters designed to work in open channels or pipes running partially full, nor does it apply to the measurement of magnetically permeable slurries or liquid metal applications.

This document does not specify safety requirements in relation to hazardous environmental usage of the flowmeter.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

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

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

3.1
electromagnetic flowmeter
flowmeter which creates a magnetic field perpendicular to the direction of flow, so enabling the flowrate to be deduced from the induced voltage, U_V, produced by the motion of a conducting fluid through the magnetic field

Note 1 to entry: The electromagnetic flowmeter consists of a *sensor* (3.2) and a *transmitter* (3.3).

3.2
sensor
device containing at least the following elements:

— an electrically insulating meter tube through which the conductive fluid to be measured flows;

— one pair of electrodes across which the signal generated in the fluid is measured;

— an electromagnet for producing a magnetic field in the *meter tube* (3.4)

Note 1 to entry: The sensor produces a signal proportional to the flowrate and, in some cases, a *reference signal* (3.9). See 6.2.

Note 2 to entry: For a sensor, the wording primary device or flowtube has previously been used.

Note 3 to entry: In some cases, further electrodes are used such as grounding electrodes, full pipe detection electrodes (empty pipe detection) (see 3.5).

3.3
transmitter
equipment which contains the circuitry which drives the field coils and extracts the flow signal

Note 1 to entry: This equipment may be mounted directly onto the *sensor* (3.2) or remotely, connected to the sensor by a cable.

Note 2 to entry: For a transmitter, the wording secondary device, converter or electronic unit has previously been used.

3.4
meter tube
pipe section of the *sensor* (3.2) through which the liquid flows, at least part of whose inner surface is electrically insulating

3.5
measuring electrodes
one or more pairs of electrical contacts or capacitor plates by means of which the induced voltage is detected

3.6
lower range value
lowest value of the measured variable that a device is set to measure

3.7
upper range value
highest value of the measured variable that a device is set to measure

3.8
span
difference between the upper and *lower range values* (3.6)

3.9
reference signal
signal which is proportional to the magnetic flux created in the *sensor* (3.2) and which is compared in the *transmitter* (3.3) with the flow signal

3.10
output signal
signal from the *transmitter* (3.3) which is a function of the flowrate

3.11
Reynolds number
dimensionless parameter expressing the ratio between the inertial and the viscous forces

Note 1 to entry: For closed pipe flow through an *electromagnetic flowmeter* (3.1), Reynolds number should be based on the nominal diameter of the meter and corresponding mean velocity through a section of that size.

3.12
accuracy
closeness of the agreement between the result of a measurement and the (conventional) true value of the measurement

Note 1 to entry: The quantitative expression of accuracy should be in terms of uncertainty (see Annex E).

Note 2 to entry: The use of the term precision for accuracy should be avoided.

3.13
uncertainty
<of measurement> range within which the true value of the measured quantity can be expected to lie with a specified value and confidence level

Note 1 to entry: See Clause 11.

3.14
calibration factor
number, determined by liquid calibration, that enables the *output signal* (3.10) to be related to the volumetric flowrate

3.15
calibration
operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

3.16
verification
<in-situ electronic verification> means of verifying that an *electromagnetic flowmeter* (3.1) is operating correctly, normally with a poorer uncertainty than under controlled laboratory conditions

3.17
calibration validation
number of runs (one or more) at flowrates between zero and the *upper range value* (3.7) in order to verify that the flowmeter does perform in the expected way and within the manufacturer's specification

3.18
measuring window
period of time during which the voltage representing the flow velocity is measured

3.19
ideal flow conditions
conditions that exist when a pipe is infinitely long and straight with no internal disturbances

Note 1 to entry: For *electromagnetic flowmeters* (3.1), it may, in addition, also be assumed that the metering liquid has a viscosity and density similar to water. Under these conditions, the flow is axisymmetric and will be fully developed and turbulent at flowrates and pipe sizes most often found in industry.

4 Symbols

Symbol	Quantity	Units (SI)
$\vec{B}$	magnetic field strength	Tesla (T)
$\bar{B}$	mean magnetic field strength	Tesla (T)
d	inside diameter of meter tube	metres (m)[a]
$\vec{E}$	electric field strength	volt per metre (V/m)
U_c	electrochemical voltage	volt (V)
U_t	transformer voltage	volt (V)
U_v	velocity related voltage	volt (V)
$F_{Lorentz}$	Lorentz force	newton (N)
k_1	constant	dimensionless (—)
k_2	constant	dimensionless (—)

Symbol	Quantity	Units (SI)
L_e	distance between measuring electrodes	metres (m)
q_V	volumetric flowrate of the liquid	cubic meters per second (m^3/s)
$\bar{v}$	mean axial liquid velocity	metres per second (m/s)
∇	Nabla or Del operator	dimensionless (—)
[a] See Annex D for a conversion table of nominal diameters from metric to US units.		

5 Theory and basic formulae

When a conductive liquid moves through a magnetic field, voltage(s), U_v, are generated in accordance with Faraday's law (see Formula 2). The strength of the induced voltages is given by the simplified expression shown in Formula (1):

$$F_{\text{Lorentz}} = q\left(\vec{E} + \vec{v} \times \vec{B}\right) = 0 \quad (1)$$

$$\vec{E} = -\vec{v} \times \vec{B} = \nabla\left(U_v\right);$$

$$\nabla\left(U_v\right) = -\vec{v} \times \vec{B}$$

Spatial integration of Formula (1) results in Formula (2):

$$U_v = k_1 \bar{B} L_e \bar{v} \quad (2)$$

The volume flowrate in the case of a circular pipe is given in Formula (3):

$$q = \frac{\pi d^2}{4} \bar{v} \quad (3)$$

Which, combined with Formula (2), gives Formula (4):

$$q = \frac{\pi d^2}{4 k_1 L_e}\left(\frac{U_v}{\bar{B}}\right) \quad (4)$$

Or Formula (5):

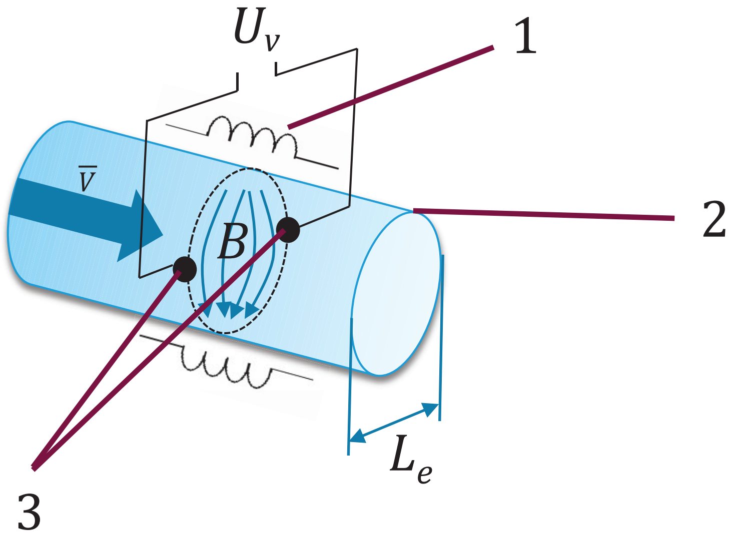
$$q = k_2 U_v \quad (5)$$

Formula (5) may be interpreted in various ways to produce a calibration factor which in practice is usually determined by wet calibration, as described in 9.1.

6 Construction and principle of operation

6.1 General

As indicated schematically in Figure 1, the magnetic field is so placed with respect to a lined meter tube that the path of the conductive liquid, flowing in the meter tube, is normal to the magnetic field. In accordance with Faraday's law, motion of the liquid through the magnetic field induces a voltage, U_v, in the liquid in a path mutually normal both to the field and the direction of liquid motion. By placing electrodes which contact the liquid in insulated mountings or by using insulated electrodes with capacitance-type coupling in the meter tube in a diametrical plane normal to the magnetic field, a voltage proportional to the flow velocity is produced which can be processed by a transmitter. Meters based on this principle are capable of measuring flow in either direction through the meter tube.



Key

1 coil system

2 lined meter tube

3 measuring electrodes

B magnetic flux density

L_e distance between measuring electrodes

U_v flow signal (velocity related voltage)

$\bar{v}$ mean axial liquid velocity

Figure 1 — Principle of Faraday's law

The electromagnetic flowmeter consists of a sensor through which the process liquid flows and a transmitter which converts the flow signal generated by the sensor into a standardized signal for suitable acceptance by industrial instrumentation (see, for example, IEC 60381-1 and IEC 60381-2).

The system produces an output signal proportional to volume flowrate (or average velocity). Its application is generally limited only by the requirement that the metered liquid shall be electrically conductive.

The sensor and transmitter can be separate, linked by one or more electrical cables, or integrated with the transmitter directly joined to the sensor.

6.2 Sensor

Figure 2 shows an exploded drawing of an industrial version of a sensor with an integrated transmitter. The principal components of the sensor are as follows.

a) The meter tube is the pipe section of the sensor through which the liquid flows. For a meter with field coils mounted outside the meter tube, this would be constructed from a non-magnetic material. On a design where the field coils are inside the meter tube, it may be made of a magnetic material.

b) An insulating liner which electrically insulates the measuring electrodes from the meter tube preventing the induced U_v from short circuiting through the meter tube. The liner may be concentric with the pipe or be profiled to provide a specific cross-section at the plane of the measuring electrodes; if the meter tube is non-conductive, then a liner is not mandatory.

c) The field coils produce the magnetic field. The most common configuration is to have two field coils mounted diametrically opposite to each other, though single field coil designs are available. Field coils may be mounted on the outside of the meter tube or within the meter tube isolated from the fluid. The field coils can be either:

— excited by sinusoidal alternating current (AC), as described in 6.3.4, or

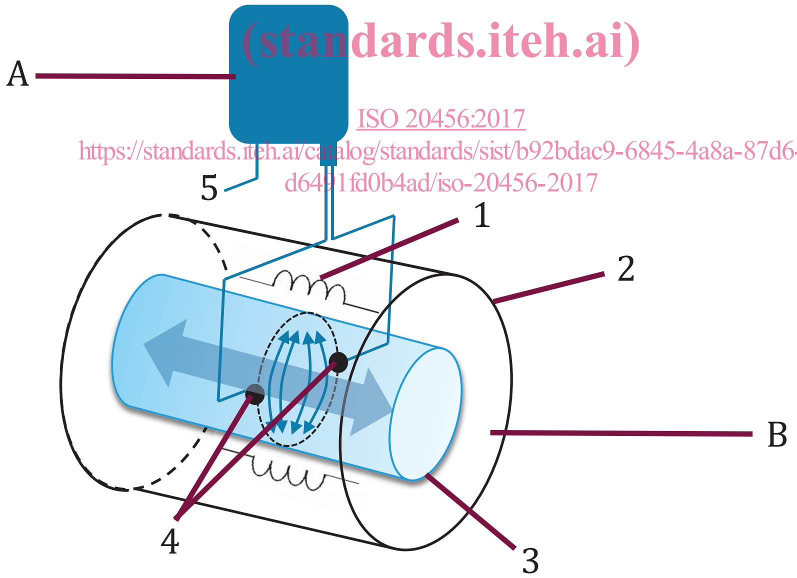
— excited by direct current. In this case, it is usual to use a pulsed direct current (DC) as described further in 6.3.3;

d) The measuring electrodes which detect the induced U_V. These normally comprise two metallic contacts diametrically opposite to each other standing slightly out from the liner which are in direct contact with the fluid. In some designs for harsh applications, capacitive electrodes may be used which are not in direct contact with the fluid.

The sensor may also contain a reference or ground electrode to provide a reference value for the measured U_V, and/or an empty pipe detection electrode which triggers an alarm when not in contact with the fluid.

The materials for the lining and for the electrodes shall be selected depending on the liquid to be measured (see Annex A).

The sensor is usually connected to the piping by means of flanges; however, measuring devices with flangeless versions and other process connections are also available. The process fluid shall be electrically connected to the body of the flowmeter by means of a grounding electrode or electrically conductive and unlined adjacent pipework or grounding (potential equalizing) rings; see 8.1.3.



Key

1 field coils
2 coil housing
3 lined meter tube
4 measuring electrodes
5 power supply
A transmitter
B sensor

Figure 2 — Elements of an industrial electromagnetic flowmeter

NOTE The sensor can have a non-circular cross-section.

