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Measurement of conductive liquid flow in closed conduits — Method using electromagnetic flowmeters

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Mesure de débit d'un fluide conducteur dans les conduites fermées — Méthode par débitmètres électromagnétiques

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Contents

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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.

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.

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International Standard ISO 6817 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Sub-Committee SC 5, *Electromagnetic flowmeters*.

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The first edition cancels and replaces ISO/TR 6817:1980, of which it constitutes a technical revision.

Annexes A and B of this International Standard are for information only.

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Measurement of conductive liquid flow in closed conduits — Method using electromagnetic flowmeters

1 Scope

This International Standard describes the principle and main design features of industrial electromagnetic flowmeters for the measurement of flow-rate of a conductive liquid in a closed conduit running full. It covers their installation, operation, performance and calibration.

This International Standard does not specify safety requirements in relation to hazardous environmental usage of the meter, nor does it apply to the measurement of magnetically permeable slurries, liquid metals nor usage in medical applications.

This International Standard covers flowmeter types in both a.c. and pulsed d.c. versions.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. 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 5168:1978, *Measurement of fluid flow — Estimation of uncertainty of a flow-rate measurement.*

ISO 7066-1:1989, *Assessment of uncertainty in the calibration and use of flow measurement devices — Part 1: Linear calibration relationships.*

ISO 7066-2:1988, *Assessment of uncertainty in the calibration and use of flow measurement devices — Part 2: Non-linear calibration relationships.*

ISO 9104:1991, *Measurement of fluid flow in closed conduits — Methods of evaluating the performance of electromagnetic flow-meters for liquids.*

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ISO 6817:1992
https://standards.iteh.ai/catalog/standards/sist/bbddf874-05dc-4887-b9c8-635d42ce913e/iso-6817-1992

3 Definitions

For the purposes of this International Standard, the definitions given in ISO 4006 and the following definitions apply. Many of these are extracted from ISO 4006 for ease of reference.

3.1 electromagnetic flowmeter: Flowmeter which creates a magnetic field perpendicular to the flow, so enabling the flow-rate to be deduced from the induced electromotive force (e.m.f.) produced by the motion of a conducting liquid[1] in the magnetic field. The electromagnetic flowmeter consists of a primary device and one or more secondary devices.

3.1.1 primary device: Device containing the following elements:

— an electrically insulated meter tube through which the conductive liquid to be metered flows,

— one or more pairs of electrodes, diametrically opposed, across which the signal generated in the liquid is measured,

— an electromagnet for producing a magnetic field in the meter tube.

The primary device develops a signal proportional to the flow-rate and in some cases the reference signal.

1) In the present International Standard, for electromagnetic flowmeters, the more correct term "liquid" replaces the word "fluid" (covering liquids and gases) of the general definition in ISO 4006. This usage also aligns with that in ISO 9104.

3.1.2 secondary device: Equipment which contains the circuitry which extracts the flow signal from the electrode signal and converts it to a standard output signal directly proportional to flow-rate. This equipment may be mounted on the primary device.

3.2 meter tube: Pipe section of the primary device through which the liquid to be measured flows; its inner surface is usually electrically insulated.

3.3 meter electrodes: One or more pairs of contacts by means of which the induced voltage is detected.

3.4 magnetic field: Magnetic flux, generated by the electromagnet in the primary device, which passes through the meter tube and through the liquid.

3.5 electrode signal: Total potential difference between the electrodes, consisting of the flow signal and the signals not related to flow such as in-phase, quadrature and common mode voltages.

3.5.1 flow signal: That part of the electrode signal which is proportional to the flow-rate and the magnetic field strength and which is dependent on the geometry of the meter tube and the electrodes.

3.5.2 in-phase voltage: That part of the electrode signal in phase with the flow signal but which does not vary with the flowrate.

NOTE 1 This definition applies only to primary devices with a.c.-energized electromagnets.

3.5.3 quadrature voltage: That part of the electrode signal which is 90° out of phase with the flow signal and which does not vary with the flow-rate.

3.5.4 common mode voltage: Voltage which exists equally between each electrode and a reference potential.

3.6 reference signal: Signal, proportional to the magnetic flux created in the primary device, which is compared in the secondary device with the flow signal.

3.7 output signal: Output from the secondary device which is a function of the flow-rate.

3.8 calibration factor of the primary device: A number which enables the flow signal to be related to the volume flow-rate (or average velocity) under defined reference conditions for a given value of the reference signal.

3.9 full-scale flowrate: Flow-rate corresponding to the maximum output signal.

3.10 cathodic protection: Electrochemical means of preventing electrolytic corrosion of conduits.

3.11 reference conditions: Conditions for calibration of a flowmeter in accordance with clause 8 of this International Standard.

4 Symbols and units

The following symbols are used in this International Standard.

Symbol	Quantity	Units
B	Magnetic flux density	tesla (T)
D	Inside diameter of meter tube	metres (m)
K	Calibration constant	metres (m)
L_e	Distance between measuring electrodes	metres (m)
U	Mean axial liquid velocity	metres per second (m/s)
V	Flow signal (electromotive force)	volts (V)
k	Constant	(dimensionless)
q_V	Volume flow-rate of the liquid	cubic metres per second (m^3/s)

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ISO 6817:1992
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5 Theoretical requirements

5.1 General

When a liquid moves in a magnetic field, voltages (e.m.f.s) are generated in accordance with Faraday's law (see figure 1). If the field is perpendicular to an electrically-insulated pipe which contains the moving liquid and if the electrical conductivity of the liquid is not too low, a voltage may be measured between two electrodes on the wall of the pipe. This voltage is proportional to the magnetic flux density, the average velocity of the liquid and the distance between the electrodes. Thus the velocity and hence the flow-rate of the liquid may be measured.

5.2 Basic equation

In accordance with Faraday's law of induction, the strength of the induced voltages is given by the simplified expression as

$$V = kBL_e U \qquad \ldots (1)$$

The volume flow-rate in the case of a circular pipe is

$$q_V = \frac{\pi D^2}{4} U \qquad \ldots (2)$$

which combined with equation (1) gives

$$q_V = \frac{\pi D^2}{4kL_e} \left(\frac{V}{B} \right) \qquad \ldots (3)$$

or

$$q_V = K \left(\frac{V}{B} \right) \qquad \ldots (4)$$

Equation (4) may be interpreted in various ways to produce a calibration factor which in practice is usually determined by wet calibration, as described in clause 9 and in ISO 9104.

6 Construction and principle of operation

6.1 General

As indicated schematically in figures 1 and 2, a pipe is so placed with respect to the magnetic field that the path of the conductive liquid, flowing in the pipe, is normal to the magnetic field. In accordance with Faraday's law, motion of the liquid through the magnetic field induces an electromotive force in the liquid in a path mutually normal to the field and the direction of liquid motion. By placing electrodes in insulated mountings or by using insulated electrodes with capacitance-type coupling in the pipe in a diametrical plane normal to the magnetic field, a potential difference proportional to the flow velocity is produced which can be processed by a secondary device. Meters based on this principle are capable of measuring flow in either direction through the meter tube.

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ISO 6817:1992
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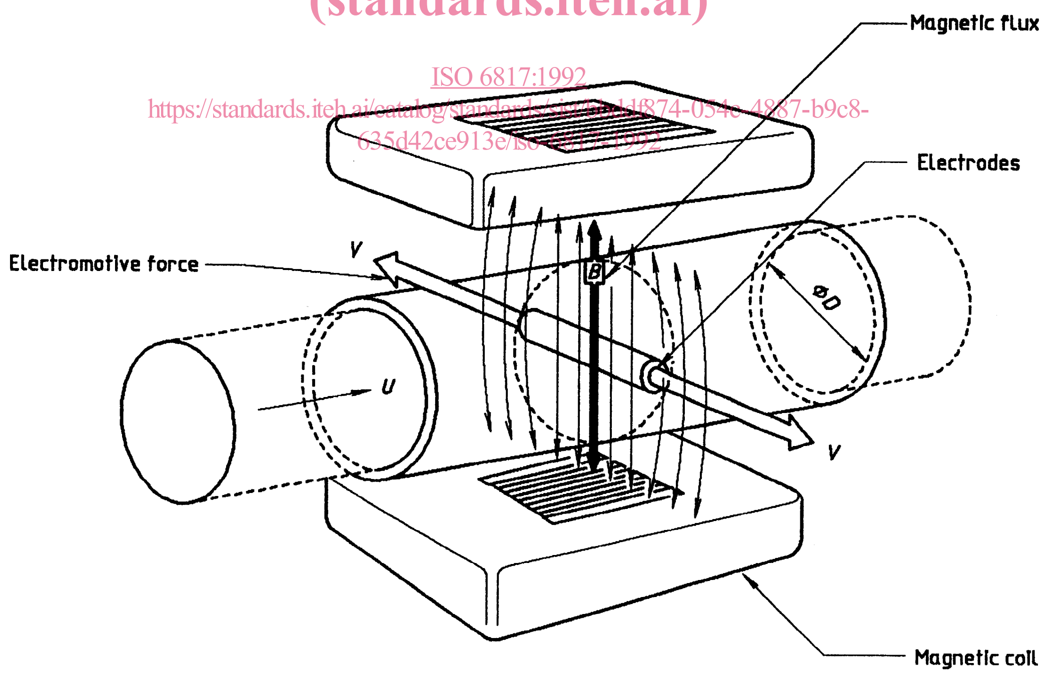

Key

B Magnetic flux density

D Inside diameter of meter tube

V Flow signal (electromotive force)

U Mean axial liquid velocity

Figure 1 — Principle of an electromagnetic flowmeter

The electromagnetic flowmeter consists of a primary device through which the process liquid flows, and a secondary device which converts the low-level signal generated by the primary device into a standardized signal for suitable acceptance by industrial instrumentation (see, for example, IEC 381). The system produces an output signal proportional to volume flow-rate (or average velocity). Its application is generally limited only by the requirement that the metered liquid shall be electrically conductive and non-magnetic.

The primary and the secondary devices can be combined in a single assembly.

6.2 Primary devices

The primary device of an electromagnetic flowmeter consists of the coils, a yoke of ferromagnetic material, the meter tube through which the liquid flows and the electrodes. The primary device may contain circuitry for deriving the reference signal.

Figure 3 shows an exploded view of an industrial primary device. The coils and the yoke are arranged to produce a magnetic field, the meter tube is a non-magnetic material such as plastic, ceramic, aluminium, brass or non-magnetic stainless steel. An insulating lining is used with metallic tubes to prevent the metal tube from short-circuiting the electrode signal. The lining may be glass, elastomer, plastic, ceramic, etc. (see annex A). The materials used for the lining and the electrodes are chosen to be compatible with the liquid to be metered.

Other specific designs are also available, for example, a cast steel case with the coils insulated inside the case and liners fitted internally to this again. Flanges are usually provided to connect the primary device to the plant pipework, although flangeless meters are available in smaller sizes.

The coils producing the magnetic field may be energized from the normal single-phase supply, or from some other supply. The coil assembly is either mounted externally or encapsulated within the pipe. In the latter case, the pipe may be made of magnetic material.

In industrial electromagnetic flowmeters, the coils in the primary device can be either

— a.c. energized, or

— d.c. energized.

The pulsed direct current (d.c.) meter is one in which the field windings of the primary device are energized from a source creating a pulsating current. The meter samples the signal at zero magnetic field and zero adjusts, but does not differentiate against all other spurious signals.

General guidance on various aspects of the primary device is set out in 7.1 and physical features are considered in annex A.

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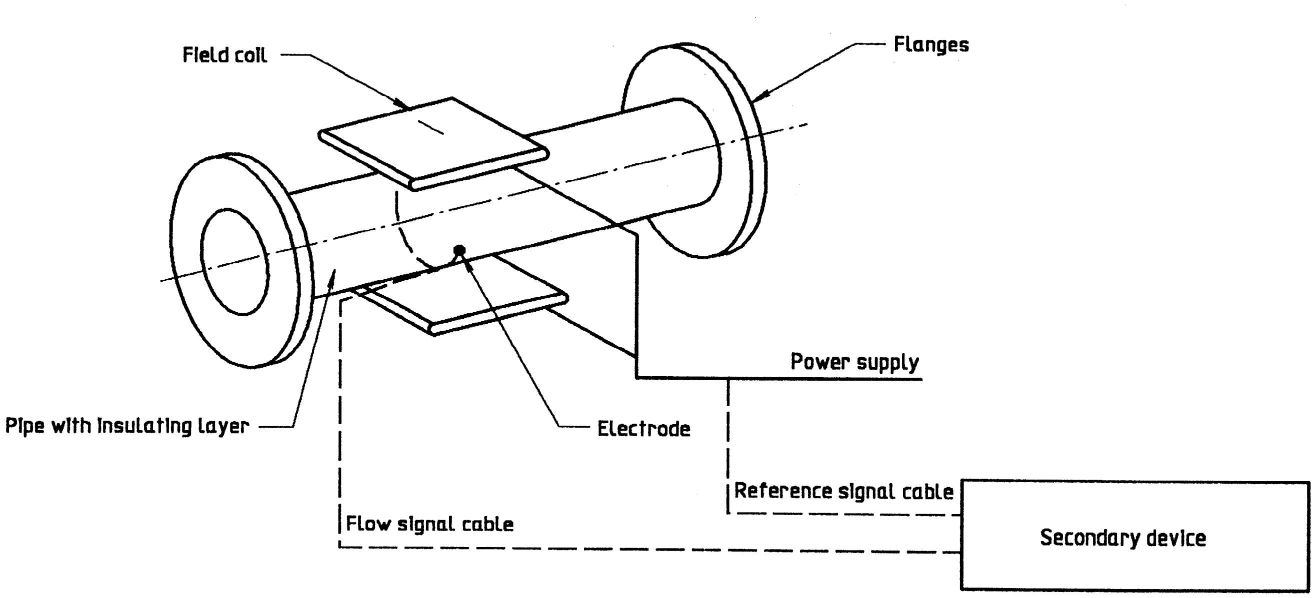
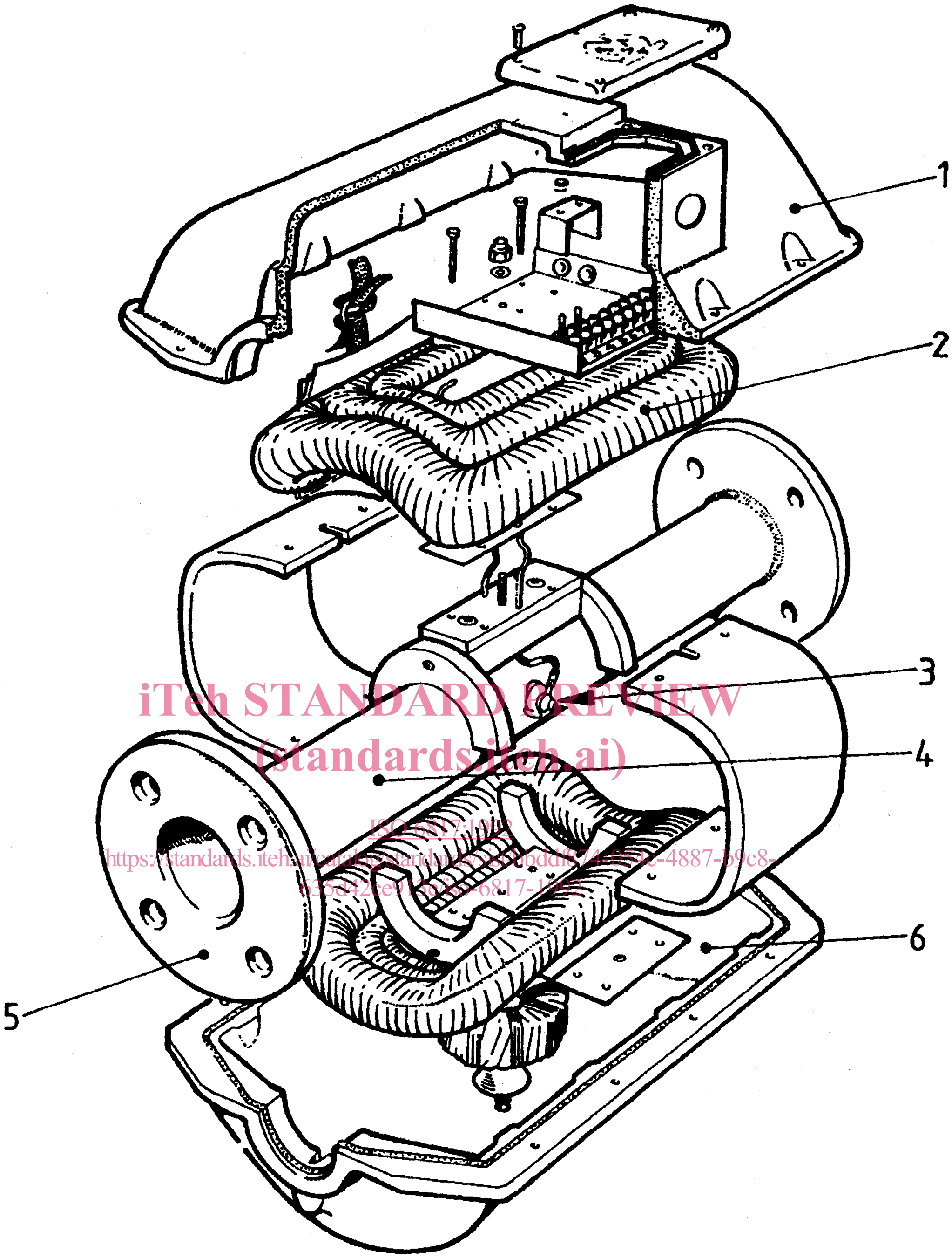


Figure 2 — Elements of an industrial electromagnetic flowmeter



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Key

1 Upper housing

2 Coil

3 Electrodes

4 Meter tube

5 Lining

6 Lower housing

Figure 3 — Exploded view of the primary device of an electromagnetic flowmeter

6.3 Secondary devices

Secondary devices carry out the following processes:

a) amplify and process the electrode and reference signals to obtain a signal proportional to flow;

b) eliminate, as far as possible, spurious e.m.fs. These include common mode and quadrature signals;

c) provide means of compensating for supply voltage and frequency variations where necessary;

d) provide means of compensating or minimizing magnetic field strength variations in the primary device. This is important since it directly affects repeatability of the voltage at the measurement electrodes.

Compensation is achieved by the following means:

a) a gain-compensated amplifier in which the gain is proportional to the supply frequency and inversely proportional to the supply voltage;

b) a system in which the output is proportional to the ratio of the flow signal and a reference signal derived from the field current. At a given flowrate both signals may vary with supply voltage and frequency, but their ratio will remain constant;

c) a system in which the field current is stabilized.

For alternating current (a.c.) energized systems with unregulated coil current, the secondary device measures the ratio of V/B (see clause 5). Voltages other than the flow signal (V) may be picked up by electrode leads. These voltages may be generated by the varying flux intersecting a loop composed of the electrode leads, the electrodes, and the liquid connecting the electrodes (transformer effect). Such a voltage will be approximately 90° out of phase with the flow signal. That portion which is 90° out of phase is called "quadrature". The remainder is called the "in-phase" component. The "in-phase" component is zeroed at no-flow during initial installation, unless the flowmeters have a device which provides this function automatically.

If the coil current is regulated, the magnetic field is considered to be constant and it is only necessary to measure the electrode signal. If the coil current is not regulated, then, in order to compensate for variations in the magnetic field, the secondary device may use a reference signal obtained from the primary element. This reference signal may be derived from the supply voltage, the supply current, the flux density in the metal or the flux density in the air gap.

In a pulsed d.c. system, under ideal or reference conditions, the peak-to-peak value of the electrode signals, $(V_p + V_n)$, is proportional to the flow velocity in the pipeline and V_p is also equal to V_n [see figure 4a)], where $V_p =$ positive voltage and $V_n =$ negative voltage.

In a practical situation, if the zero or "no-flow" signal is offset in the positive direction by an amount V_e, then the positive signal is $(V_p + V_e)$ and the negative signal is $(V_n - V_e)$ [figure 4b)]. Hence the overall value of the electrode signal is $(V_p + V_n)$ and the offset zero is eliminated. The same applies if the offset is in the negative direction.

The system thus eliminates zero errors automatically at all times and zero adjustment is not usually required, either at start-up/commissioning or at any time during subsequent operation.

General guidance on the function and installation of secondary devices is presented in 7.2.

6.4 System output

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ISO 6817:1992
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The system output can be one or more of the following:

a) analog direct current in accordance with IEC 381-1;

b) analog direct voltage in accordance with IEC 381-2;

c) a frequency output in the form of scaled or unscaled pulses;

d) digital.

6.5 Effect of the liquid conductivity

If the electrical conductivity of the liquid is uniform in the measuring section of the meter, the electric field distribution is independent of the liquid conductivity and therefore the meter output is generally independent of the liquid conductivity. Minimum operational conductivity requirements should be obtained from the manufacturers.

The internal impedance of the primary device obviously depends upon the liquid conductivity, and very large changes in this impedance may produce errors in the output signal. If the conductivity is not uniform throughout the meter, errors may also occur. A heterogeneous fluid composed of small particles uniformly distributed in a medium can be considered as a homogeneous liquid.

Deposition of electrically conducting layers on the inside surface of the liner may also lead to errors.

6.6 Reynolds number effect

In industrial electromagnetic flowmeters, the effect of Reynolds number is usually so small that for practical purposes it can be ignored.

6.7 Velocity profile effect

Distortions in velocity profiles may be caused by pipe fittings (bends, valves, reducers, etc.) placed upstream or downstream from the flowmeter; the resulting flow patterns may have an influence on the performance of the meter.

In general, the user should comply with the manufacturer's recommendations for installation in order to minimize these effects.

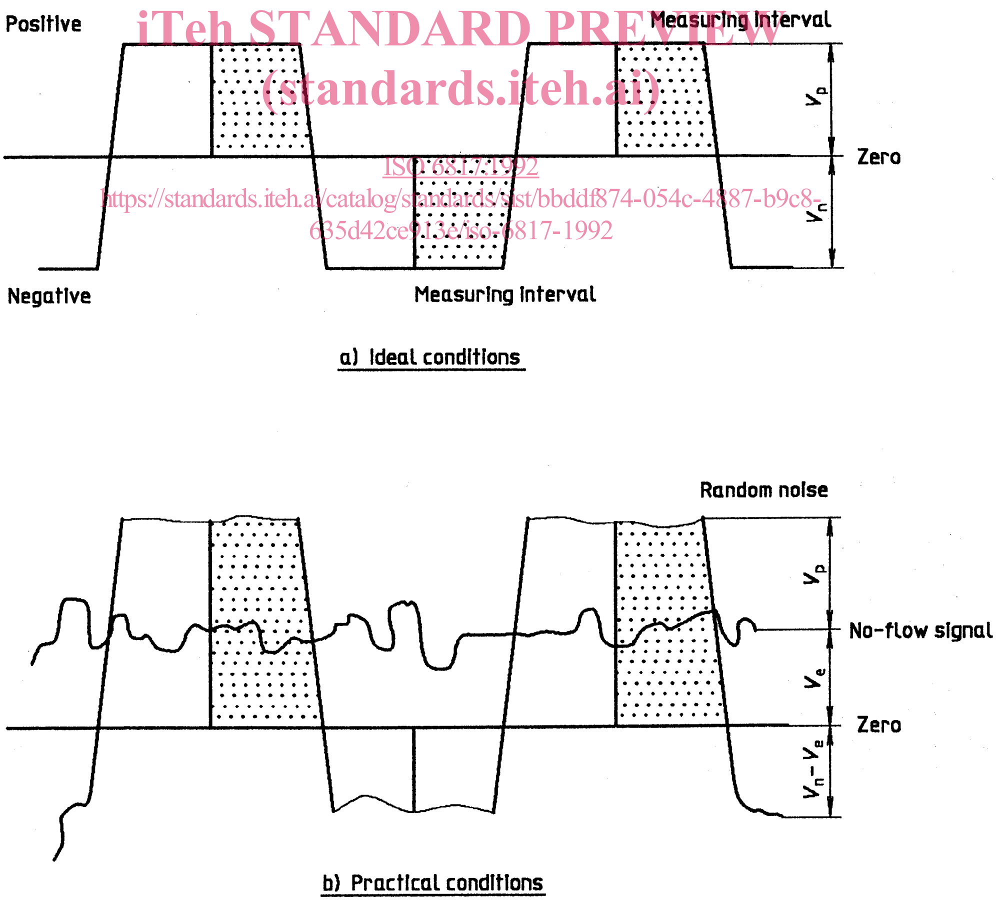
Flow pattern effects are described in 7.1.2.1.

7 Installation design and practice

7.1 Primary devices

7.1.1 Size

Usually the bore of the primary device tube will be the same as that of the adjacent pipework. If, in this case, the mean axial velocity corresponding to the maximum flow-rate is less than that recommended by the manufacturer, a primary device with a smaller bore should be used. A primary device with a bore smaller than that of the adjacent pipework may also be used for other reasons, e.g. to reduce cost or in the interests of rationalization. Information on the allowable tolerances for matching the pipe and meter tube bores is given in ISO 9104.



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ISO 6817:1992
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Figure 4 — Principle of pulsed d.c. (bipolar) system