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

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

Reference number
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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.

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*.

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.*

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)

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

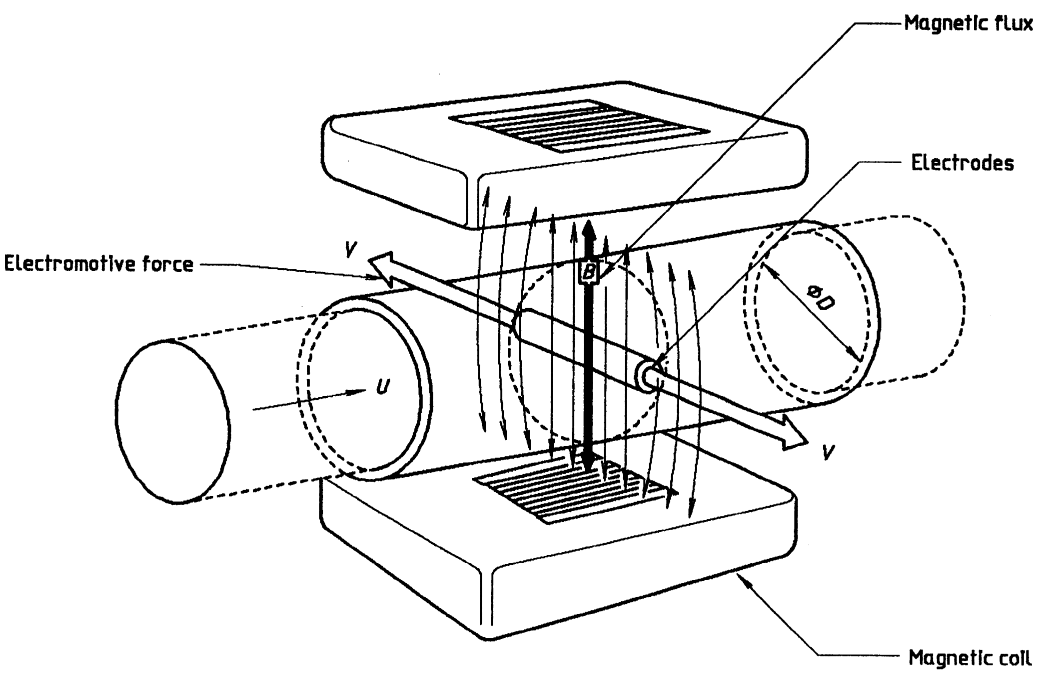
$$q_V = K \left(\frac{V}{B} \right) \qquad \ldots (4)$$

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.



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.

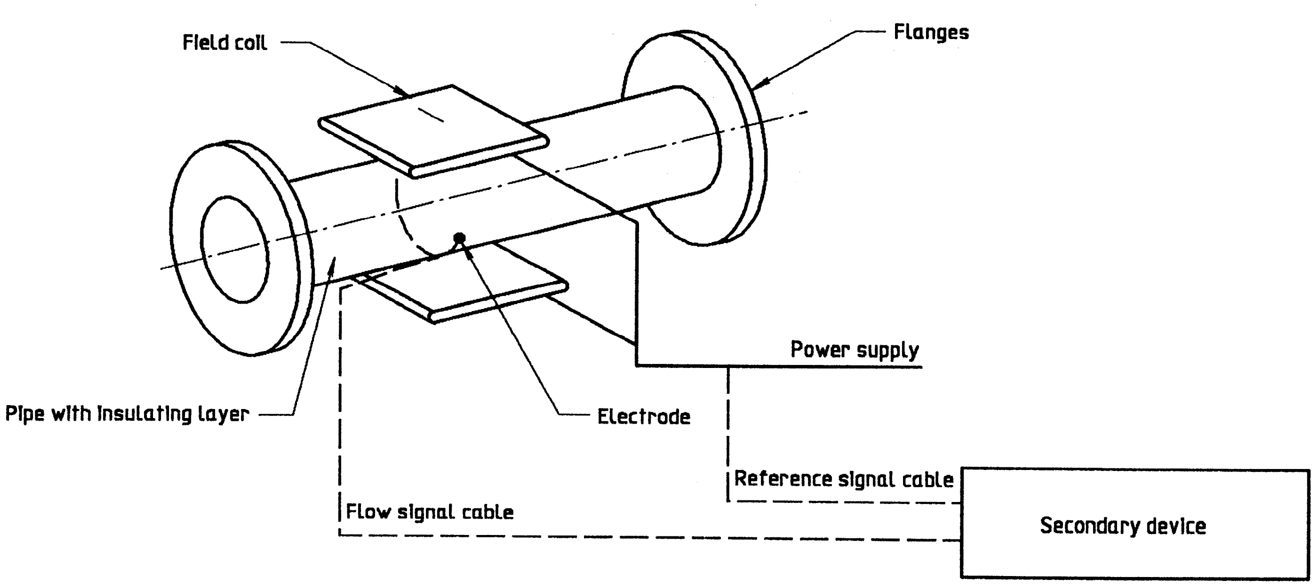
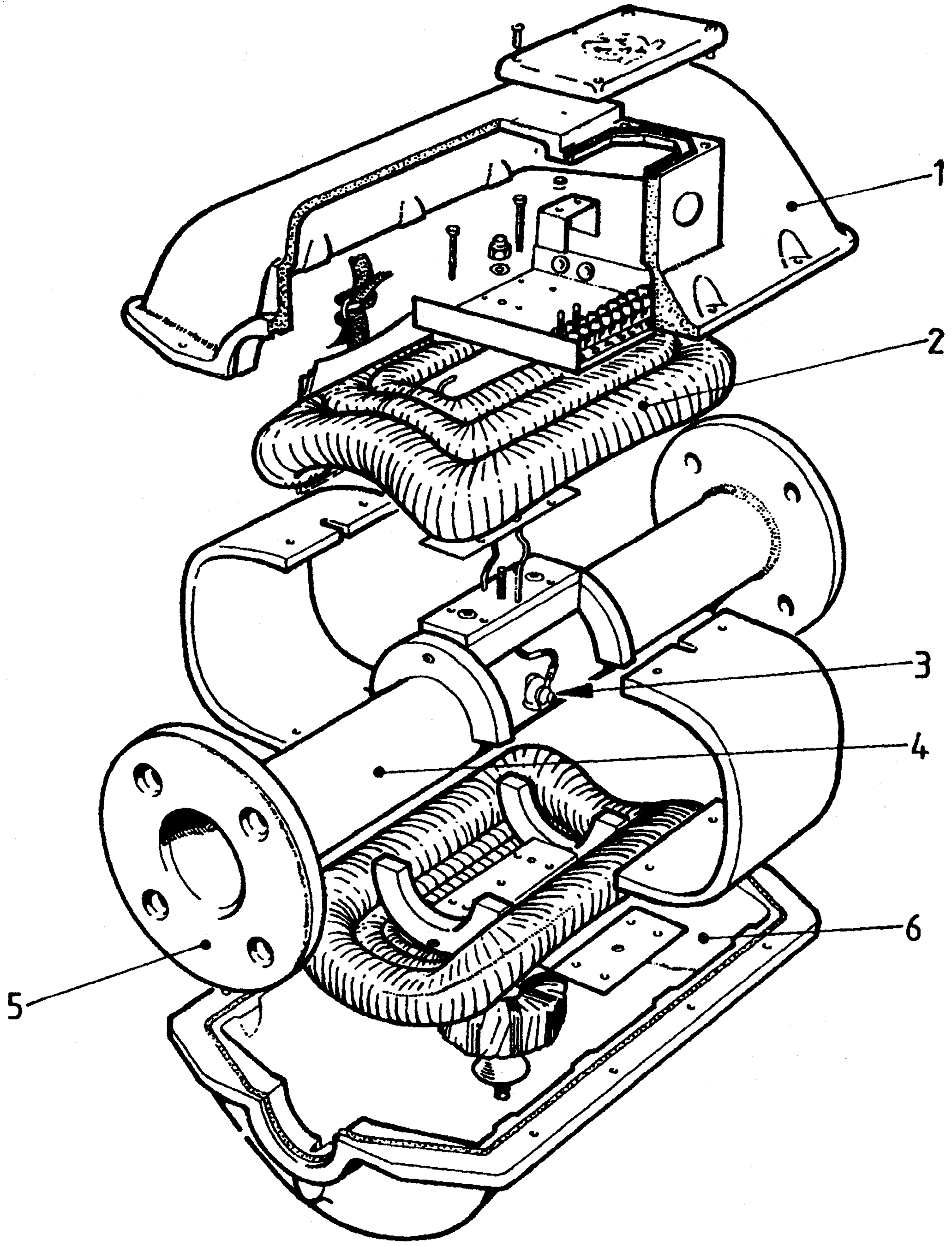


Figure 2 — Elements of an industrial electromagnetic flowmeter



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

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.

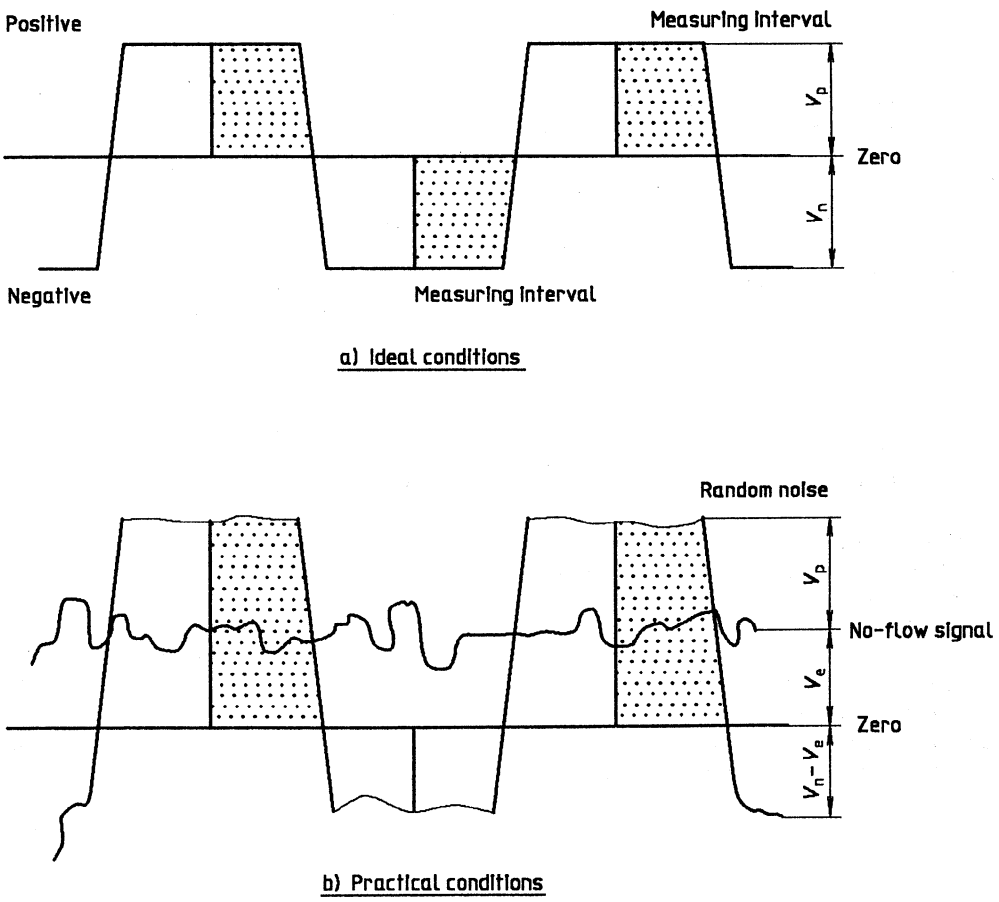


Figure 4 — Principle of pulsed d.c. (bipolar) system

7.1.2 Layout

There is no theoretical restriction on the attitude at which a primary device may be mounted, provided the pipe remains full at all times. Locations close to electrical equipment which may interfere with the flow measurement signal, or locations where currents may be induced in the primary device, should be avoided.

7.1.2.1 Effect of layout on velocity distribution

Ideally, the magnetic field should be so arranged that the calibration factor is always the same, irrespective of the flow pattern. Though this can be done in flowmeters with special electrode arrangements, it cannot be achieved if small electrodes are used. In practice, when a flow velocity profile which is significantly different from that in the original calibration is presented to the electrode plane, an electromagnetic flowmeter may exhibit a shift in calibration. The arrangement of pipe fittings upstream of the primary device is one of the factors which can contribute to the creation of a particular velocity profile.

Precise data on the effects of flow disturbances is not always available, but for most electromagnetic flowmeters it is recommended that any source of flow disturbance, such as a bend, should be at least ten pipe diameters upstream of the electrode plane if the performance is not to be altered by more than 1 %. When the distance is unavoidably less than this, the manufacturer's advice should be sought.

Swirling flow can also alter the calibration factor because, although flow components perpendicular to the pipe axis cannot contribute to the flow-rate, they may contribute to the signal. Furthermore, the amount and distribution of swirl arising from various upstream pipe configurations, such as several bends in different planes, is difficult to predict from the geometry of the pipework. When swirling flow is suspected, it is good practice to insert a swirl reducer upstream of the primary device; some types of swirl reducers are described in ISO 7194.

When the primary device is connected to the circuit by means of conical pieces, the effect on the calibration factor due to the irregular flow pattern may be either reduced or amplified according to the type of irregularity (swirl, asymmetry, etc.) and the design of the connecting piece (convergence, divergence, value of total angle, etc.).

7.1.2.2 Full pipe requirement

The primary device shall be mounted in such a position that it will be completely filled with the liquid being metered, otherwise the measurement will not be within the manufacturer's stated accuracy. If necessary, warning devices should be installed to preserve measurement integrity. Partially-filled primary device meters are used, for example in sewage applications, but these merit special consideration outside the scope of this International Standard.

7.1.2.3 Electrode position

Since any gas bubbles will rise and collect at the top of the pipe, or sediment may collect at the bottom of the pipe, the primary device should be mounted so that neither electrode is in these positions (see also 7.1.3.1).

7.1.2.4 Zero-checking provision

In order to check the flowmeter zero, means should be provided to stop the flow through the primary device, leaving it filled with stationary liquid.

However, in the case of a synchronous d.c. pulsed field supply with an automatically adjusting zero, this provision may not be necessary.

7.1.2.5 Multiphase flow through the primary device

7.1.2.5.1 Entrained solids

For the measurement of liquids containing abrasive materials, vertical mounting is recommended to ensure evenly distributed lining wear. Where there is a possibility that material may settle in the primary device, it should be mounted vertically or provision should be made to flush it through.

A ring to protect the leading edge of the magnetic flowmeter is sometimes used. This ring shall be designed to ensure streamlined flow.

7.1.2.5.2 Entrained gases

An electromagnetic flowmeter measures total volume flow. Entrained gases cause measurement inaccuracies in direct relation to the volume percentage of gas to liquid. Precautions should be taken to reduce this effect by increasing the liquid pressure, e.g. by locating the primary device on the high-pressure side of a restrictor such as a control valve, or by eliminating the entrained gas.

7.1.2.5.3 Phase slippage

In the case of entrained solids and/or gases, relative average motion of the phases can affect the performance. This condition is particularly likely if the tube is mounted vertically. In such situations the user should consult the manufacturer.

7.1.3 Pipework connections

7.1.3.1 Design

When designing the piping system, access for installing and removing the primary device as well as access to the electrical connections should be provided. Means should be provided for adjusting and aligning the adjacent pipework. Extra care should be taken during pipework construction to prevent excessive strain on the primary device, both during and after installation.

Every effort should be made to minimize piping loads and resulting strains at the primary device connecting flanges, particularly in plastic meters which are not intended to sustain piping loads. Permissible values should be checked with the manufacturer.

7.1.3.2 Pipework adjustment

There should be means for adjusting the distance between pipework flanges used for mounting the flowmeter and for aligning the adjacent pipework.

It is essential that the primary device is correctly aligned on the pipe axis when it is bolted into the pipework. Wafer types require special care.

Flange bolts should be tightened evenly and in moderation in order to avoid damage to the lining. The manufacturer should state the maximum permissible torque.

Care should be taken when handling the primary device; slings around the primary device, or lifting lugs, should be used. Lifting by any means that could damage the liner, for example, hooks in the bore, shall not be used.

7.1.3.3 Connecting pieces

To minimize pressure loss and flow disturbances in cases where an undersized meter is installed, it is advisable to connect the primary device into the pipework by means of shallow tapered cone pieces (recommended maximum included angle 15°) (see figure 5). In this case, the inlet and outlet straight pipe sections shall be the same size as the flowmeter (see 7.1.2).

Eccentric taper pipes shall be used when the pipeline is horizontal, to prevent air pockets from forming.

7.1.4 Electrical installation

7.1.4.1 General requirements

The metered liquid and the primary device body should be at the same potential, preferably earth potential. In the case where cathodic protection is used to protect buried pipework, this precaution becomes essential (see 7.1.4.3).

The connection between the liquid and the primary device body may be made by contact with the adjacent pipework; or, where insulated or non-conductive pipework is used, by conductive (earthing) rings or electrodes. Equipotential conductive links (usually copper braids) should be fitted across both flange joints (see figure 6).

The manufacturer's instructions should be carefully followed for interconnections between the primary device and the secondary device. The power supply should be taken from a point that is as free as possible from transient voltages. Instructions in relation to electrical grounding of the flowmeter system shall be rigidly observed.

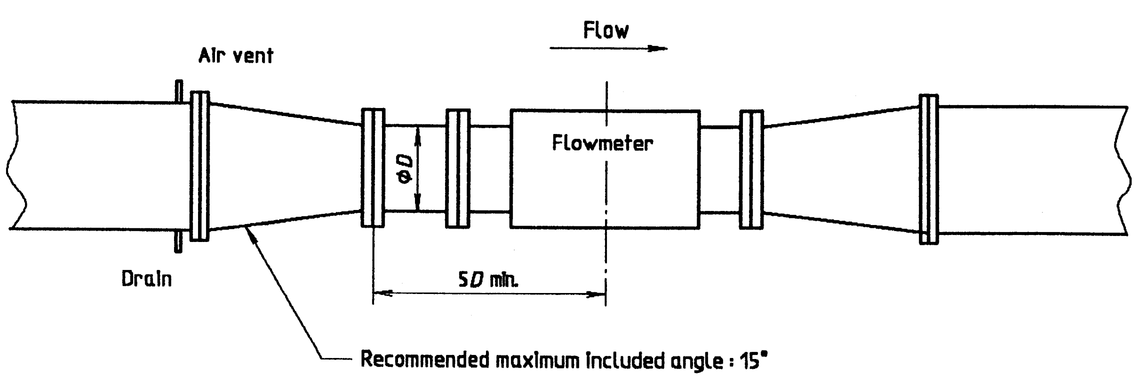


Figure 5 — Shallow taper entry and exit reducers

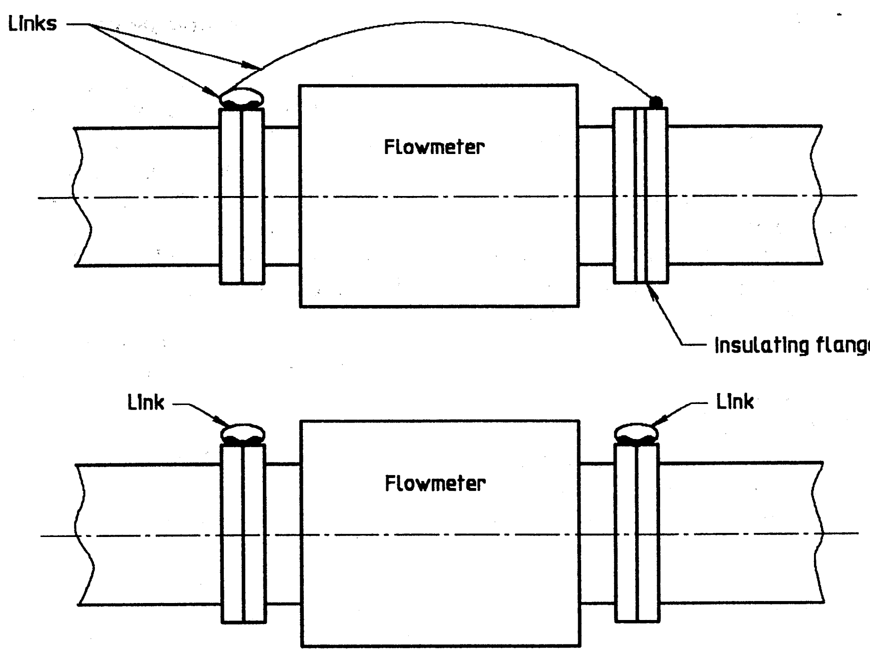


Figure 6 — Cathodically protected pipelines: conductive links across flange joints

7.1.4.2 Power factor (a.c. systems only)

As the primary device has coils to provide the magnetic field, it is an inductive device and causes the field current to lag the supply voltage by an angle approaching 90°, thus giving a poor power factor. Typical values range from 0,1 to 0,4 depending on the size of the primary device. To improve the power factor, correction capacitors may be connected in parallel with the supply and may be fitted externally or within the primary device enclosure, by arrangement with the manufacturer.

7.1.4.3 Precautions to be observed where cathodic protection is used

When an electromagnetic flowmeter primary device is installed in a cathodically protected pipeline, special precautions are necessary to ensure that the d.c. component of the cathodic current does not affect the accuracy and stability of the flowmeter system. In such a case, the flowmeter manufacturer should always be consulted for installation advice.

The precautions necessary will depend on the location of the primary device relative to other parts of the cathodic protection system.

The first requirement is that the primary device body and the liquid be at the same potential. This may be achieved simply by adequate electrical bonding between the primary device body and the adjacent piping, or, where insulated or non-conductive pipework is used, one of the conductive "earthing" rings or electrodes. Series-mode voltage cannot be rejected by the secondary device.

Under bonded conditions with cathodic protection the electric supply earth should not be connected to the primary device body, otherwise the protection current will be bypassed to the supply earth.

With cathodic protection systems on long pipelines, the cathodic current is often obtained from several sources. These may be a considerable distance apart, and at different potentials owing to variation in earth resistance along the length of the pipeline. This may cause high currents to flow in the pipeline, which, if allowed to flow through a primary device body, may cause inaccuracy in measurements. Provision of an insulating flange and conductive links, as shown in figure 6 (upper drawing), obviates this effect.

7.1.5 Cleaning and maintenance of the primary device

If insulating materials are likely to be deposited from the conducting liquid onto the electrodes or the walls of the meter tube, provision should be made for mechanical, electrical or chemical cleaning, with the flowmeter connected to the pipework or removed from it (see 7.1.5.1).

Bullet-shaped electrodes to reduce coating, ultrasonic cleaning methods and capacitative signal pick-up may minimize such effects.

Currently used cleaning methods are described in 7.1.5.1 to 7.1.5.4.

7.1.5.1 Withdrawable electrodes

Withdrawable electrodes can be provided by using mechanical valving and sealing arrangements so that the electrodes can be withdrawn (usually at full pipeline pressure) for external inspection and cleaning.

7.1.5.2 Mechanical scraper

In this system a rotary scraper is fitted to each electrode such that its scraping edge is perpendicular to the electrode face. The scraper is driven by an external electric motor via fluid pressure seals. It may be used continuously or intermittently. This method is becoming less commonly used in modern electromagnetic flowmeters.

7.1.5.3 Ultrasonic cleaning

A high energy ultrasonic wave is induced in each electrode shaft by means of an external oscillator and transducer. The shaft length and the frequency of ultrasound are chosen to produce an antinode at the electrode face. Deposits are removed by the resultant local cavitation at the electrode. This approach is generally used on crystalline-type coatings.

7.1.5.4 Electrolytic or "burn-off" method

In this method a voltage from the mains supply is connected between the electrodes (the secondary instrument being automatically disconnected during this operation), causing electrolysis on the surface of each electrode. The resultant rapid gas evolution causes removal of deposits. This approach is generally used on oily, greasy and sludge-type coatings.

Heating of the electrodes can also be used to remove fat or grease deposits from sewage.

7.2 Secondary devices

7.2.1 Location

Secondary devices should be installed in an accessible position free from excessive vibration, due regard being given to the manufacturer's specifications for ambient temperature and humidity. In particular, direct solar irradiation shall be avoided.

7.2.2 Electrical installation

The cables carrying the electrode and reference signals should be of the type approved by the manufacturer. These cables should be as short as possible and not exceed the limit imposed by the manufacturer. Care should be taken to ensure that signal cables are not routed in proximity to high current cables. Good earthing practice should be observed with particular attention being paid to the prevention of "earth loops".

8 Equipment marking

8.1 Primary device

8.1.1 Mandatory data

The following data shall be impressed either on the primary device or on a name plate:

a) instrument type and serial number;

b) rated pressure and temperature;

c) power supply: voltage, frequency and power (when independently powered).

8.1.2 Optional data

The following data may be optionally provided:

a) enclosure protection rating (in conformity with ISO/IEC publications);

b) nominal diameter;

c) calibration factor;

d) lining material;

e) electrode material.

NOTE 2 Additional information such as trademark, mass of unit, date of manufacture, flow direction arrow, etc., may be included if the size of the name plate permits.

8.2 Secondary device

8.2.1 Mandatory data

The following data shall be impressed on a name plate:

a) instrument type and serial number;

b) power supply: voltage, frequency and power;

c) output signals;

d) limiting load impedance.

8.2.2 Optional data

The following data may be optionally provided:

a) enclosure protection rating (in conformity with ISO/IEC publications).

NOTE 3 Additional information such as trademark, date of manufacture, etc., may be included if the size of the name plate permits.

9 Calibration and test conditions

9.1 Wet calibration

The calibration factor should be determined by a wet calibration using water in the test facility at reference (nominal calibration) conditions (see 9.2). The conditions under which this is carried out should be such that the measurements are traceable to national or International Standards, and hence that the calibration is to a known uncertainty. For example, ISO 4185 and ISO 8316 describe suitable calibration methods. ISO 9104 can also be consulted for methods used in evaluation of electromagnetic flowmeters.

Where the primary device is too large to be installed in a manufacturer's test facility, or where the facility has insufficient flow capacity, another higher capacity test facility can be used or, if this is not possible, a site calibration may be carried out using the user's tank or reservoir or by a comparison with another reference flowmeter in the system. The overall uncertainty shall be determined as specified in clause 10.

The method of computing the primary device signal based on magnetic field strength measurements and on physical dimensions, commonly referred to as "dry calibration", is beyond the scope of this International Standard.

9.2 Nominal calibration conditions

Nominal calibration conditions are those conditions which shall exist at the time of calibration. These nominal calibration conditions should be specified by the manufacturer. For comparison purposes, the flowmeter should be tested within the range of ambient and flow conditions defined in ISO 9104.

Provided that the flowmeter has reached thermal equilibrium, it is normally assumed that influencing factors have a negligible effect on the metrological characteristics of the flowmeter, so far as they remain within the operating limits stated by the manufacturer.

9.3 Interpretation of results

9.3.1 Reference accuracy envelope

The manufacturer should provide the range of operating conditions, together with the effect of these on the performance. Reference should also be made to ISO 9104 for fuller information on this subject.

It is current practice to specify a reference accuracy envelope over a designated flowrate range. Typical reference accuracy envelopes are shown in figure 7.

9.3.2 Accuracy at reference conditions

Flowmeter accuracy, at reference conditions, is determined by the combined random and systematic uncertainties in the measurement of the flowmeter signal and the volume flow-rate. A summary of uncertainty analysis in this context is given in clause 10.

The upper and lower uncertainty limits on each data point shall be within the manufacturer's accuracy envelope (see figure 7).

9.3.3 Deviation from reference conditions

Deviation from reference test conditions may affect flowmeter performance. While these effects are normally compensated for in the secondary device, limits of error for each influencing quantity should be specified by the manufacturer.

9.4 Pressure testing

The primary device or meter tube shall be subjected to testing in accordance with an appropriate pressure code standard if required.

10 Uncertainty analysis

The calculation of the uncertainty in the measurement of flow-rate shall be carried out as specified in ISO 5168. However, it is useful to recall some general principles and to present the way in which they apply to measurement using an electromagnetic flowmeter. The fitting of curves to specific sets of calibration or user data from flow measurement devices is covered in ISO 7066-1 and ISO 7066-2.

10.1 General

10.1.1 Definition of the error

The error in the measurement of a quantity is the difference between the measured and the true values of the quantity.

No measurement of a physical quantity is free from uncertainties arising either from systematic errors or from the random dispersion of measurement results. Systematic errors cannot be reduced by repeating measurements, since they arise from the characteristics of the measuring apparatus, the installation and the flow characteristics. However, a reduction in the random error may be achieved by repetition of measurements, since the random error of the mean of n independent measurements is $\sqrt{n}$ times smaller than the random error of an individual measurement.

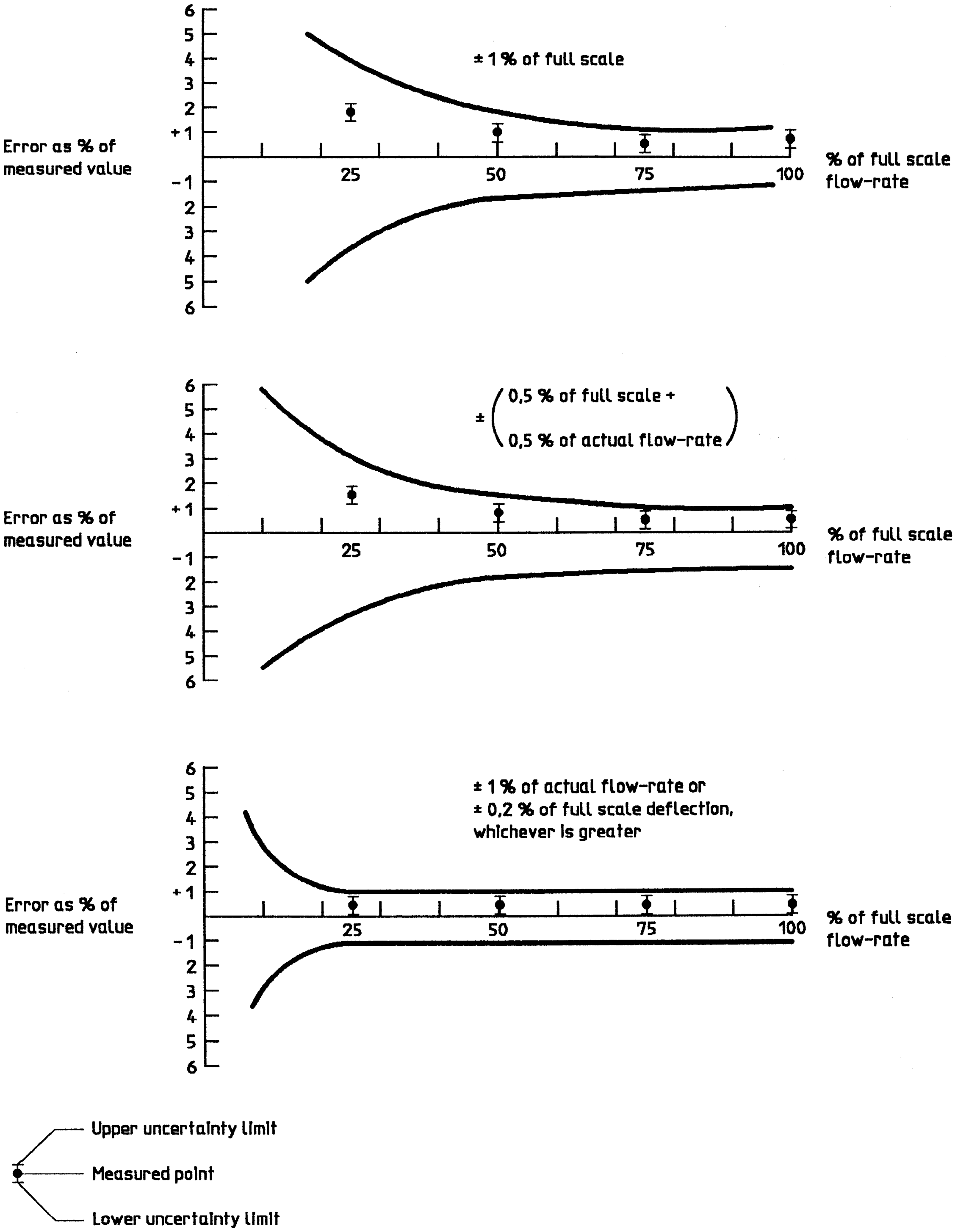


Figure 7 — Typical accuracy envelopes

10.1.2 Definition of the standard deviation

10.1.2.1 If variable X is measured several times, each measurement being independent of the others, then the standard deviation s_X of the distribution of n measurements, X_i, is

$$s_X = \left[\frac{\sum_{i=1}^{n} (\overline{X} - X_i)^2}{n-1} \right]^{1/2}$$

where

$\overline{X}$ is the arithmetical mean of the n measurements of the variable X;

X_i is the value obtained by the ith measurement of the variable X; and

n is the total number of measurements of X.

For brevity, s_X is normally referred to as the standard deviation of X.

10.1.2.2 If repeated measurements of a variable X are not available or are so few that direct computation of the standard deviation on a statistical basis is likely to be unreliable, and if the maximum range of the measurements may be estimated, the standard deviation may be taken as one-quarter of this maximum range (i.e. as one-half of the estimated uncertainty above or below the adopted value of X). In the same way, it is assumed that a systematic component of the error may be characterized by a standard deviation equal to one-half of the plus or minus maximum expected value range of that component.

10.1.3 Definition of the uncertainty

10.1.3.1 For the purpose of this International Standard, the uncertainty in a measurement of a variable is defined as twice the standard deviation of the variable. The uncertainty shall be calculated and quoted under this appellation whenever a measurement is claimed to be in conformity with this International Standard.

10.1.3.2 When partial errors, the combination of which gives the uncertainty, are independent of one another, are small and numerous, and have a Gaussian distribution, there is a probability of 0,95 that the true error is less than the uncertainty.

10.1.3.3 Having estimated the standard deviation s_{q_V} of the flow-rate measurement q_V, the uncertainty e_{q_V} is given by

$$e_{q_V} = \pm 2 s_{q_V}$$

The relative uncertainty E_{q_V} is defined by

$$E_{q_V} = \frac{e_{q_V}}{q_V} = \pm 2 \frac{s_{q_V}}{q_V}$$

The result of a flow measurement shall always be given in one of the following forms:

a) flow-rate $= q_V \pm e_{q_V}$ (at the 95 % confidence level);

b) flow-rate $= q_V (1 \pm E_{q_V})$ (at the 95 % confidence level);

c) flow-rate $= q_V$ within $\pm 100\, E_{q_V}$ % (at the 95 % confidence level).

10.2 Calculation of the uncertainty in flow-rate measurement

10.2.1 Sources of error

In the case of a flow-rate measurement carried out by an electromagnetic flowmeter, the possible sources of error are essentially as follows:

a) systematic error in the measurement of the output signal, arising from the equipment used;

b) random error in the measurement of the output signal;

c) error due to the flow conditions, which are generally different from those prevailing during the calibration of the flowmeter; this error comprises both systematic and random components;

d) error arising from the uncertainty in the relationship $q_V(X)$ between the flow-rate q_V and the output signal X. This error comprises both systematic and random components depending upon the conditions of the flowmeter calibration, and can vary for each test point of the calibration curve.

10.2.2 Propagation of the individual uncertainties

The uncertainty in the flow-rate measurement is assessed by combining the individual uncertainties arising from the various sources listed in 10.2.1. Although systematic errors have been distinguished from random errors, the probability distribution of the possible values of each systematic component is essentially Gaussian. The combination of the random and systematic errors may therefore be treated as though all were truly random and, according to the ISO 5168, the relative standard deviation of the flow-rate measurement may be taken as the square root of the sum of the squares of the relative standard deviations arising from the various sources.

Thus the result of the flow-rate measurement is

$$q_V(1 \pm E_{q_V}) = q_V \left\{ 1 \pm 2 \left[\left(\frac{s_{sX}}{q_V} \frac{\partial q_V}{\partial X} \right)^2 + \left(\frac{s_{RX}}{q_V} \frac{\partial q_V}{\partial X} \right)^2 + \left(\frac{s_f}{q_V} \right)^2 + \left(\frac{s_c}{q_V} \right)^2 \right]^{1/2} \right\}$$

at the 95 % confidence level,

where

s_{sX} is the standard deviation associated with the systematic error in the output signal measurement;

s_{RX} is the standard deviation of the random error in the output signal measurement;

s_f is the standard deviation arising from flow conditions; and

s_c is the standard deviation in the calibration relationship.

In the case where the calibration relationship offers the simple form $q_V = K_1 X$, the above formula reads

$$q_V = 1 \pm 2 \left[\left(\frac{s_{sX}}{X} \right)^2 + \left(\frac{s_{RX}}{X} \right)^2 + \left(\frac{s_f}{q_V} \right)^2 + \left(\frac{s_c}{q_V} \right)^2 \right]^{1/2}$$

Annex A
(informative)

Materials for construction of primary devices

A.1 Introduction

It is very important to choose construction materials suitable for the liquid to be metered. It is essential that account is taken of any other chemicals liable to pass through the meter tube, such as sterilizing agents, cleaners and solvents. As the user knows the properties of the liquid to be metered, the ultimate decision on the materials to be used should rest with him.

It is also important that the lining material is not subjected to temperatures outside the range recommended by the manufacturer. The maximum permissible pressure of the primary device is normally decreased as the temperature of the process fluid is increased.

A.2 Meter tube linings

The following are examples of types of lining materials that are available.

A.2.1 Elastomers

A.2.1.1 Hard rubber (ebonite)

Hard rubber is generally suitable for use within the temperature range 0 °C to 90 °C. It has excellent abrasion resistance against small particles and good chemical resistance, particularly to leaching agents, acid and alkalis.

A.2.1.2 Abrasion-resistant rubbers (natural)

Abrasion-resistant natural rubbers are generally suitable for use within the temperature range − 20 °C to + 70 °C. They exhibit excellent wear resistance and good chemical resistance.

A.2.1.3 Neoprene

Neoprene is generally suitable for use within the temperature range 0 °C to 100 °C. It has good chemical and wear resistance properties, particularly in the presence of oil and greases.

NOTE 4 All rubber-based materials are attacked by high concentrations of free halogens, aromatic and halogenated hydrocarbons and high concentrations of oxidizing chemicals.

A.2.1.4 Polyurethane

Polyurethane is generally suitable for use within the temperature range of − 50 °C to + 50 °C. It exhibits excellent wear and impact resistance.

A.2.1.5 Other elastomers

Other elastomers are generally suitable for use as lining materials and may be used, as agreed between the user and the manufacturer.

A.2.2 Plastics

A.2.2.1 Polytetrafluoroethylene (PTFE)

Usually as an extruded sleeve form not bonded to the meter tube, PTFE is generally suitable for use within the temperature range − 50 °C to + 200 °C. It has excellent wear resistance against small particles, and is chemically inert. It may collapse when subjected to sub-atmospheric pressures.

For medium temperatures above 120 °C, advice on the maximum permissible pressure should be sought from the manufacturer.

A.2.2.2 Polyamide

Polyamide is generally suitable for use at temperatures below 65 °C. It has good wear resistance properties.

A.2.2.3 Chlorinated polyether

Chlorinated polyether is generally suitable for use at temperatures below 120 °C. It has excellent chemical resistance to caustic soda, acids in concentrations up to 30 % and brine.

A.2.2.4 Glass-reinforced plastics (GRP)

GRP may be used as a lining material or for the meter tube itself. It is generally for use within the temperature range − 20 °C to + 55 °C and is particularly suitable for the largest size of primary devices.

A.2.3 Ceramics

This construction material requires no lining, exhibits high form and measuring stability under pressure and temperature variations, and possesses excellent abrasion resistance. Additionally, high chemical resistance to acids and alkaline solutions is characteristic of high-purity Al_2O_3 ceramics. The service temperature range is from -60 °C to $+250$ °C with full vacuum resistance.

A.2.4 Vitreous enamel

Vitreous enamel is generally suitable for temperatures up to 150 °C, with excellent chemical and wear resistance, but requires careful handling and avoidance of exposure to hydrofluoric acid.

A.3 Examples of electrode materials

A.3.1 For non-corrosive liquids

Stainless steel is generally used.

A.3.2 For corrosive liquids

The following may be suitable, depending on the chemical properties of the liquid to be metered:

- stainless steel;
- some nickel-based alloys;
- platinum;
- platinum/iridium;
- tantalum;
- titanium.

A.4 Meter tube and enclosure

The materials used for the meter tube, flanges and enclosure are usually specified by the manufacturer. It is essential that they be compatible with the environmental conditions in which they are to be used.

The materials listed in A.3 may be used for parts of meter tubes that come into contact with the metered liquid, i.e. partially lined tubes.

Annex B
(informative)

Bibliography

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Descriptors: liquid flow, pipe flow, flow measurement, electromagnetic equipment, flowmeters, installation, specifications, performance evaluation, tests, calibration, marking.

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