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Measurement of fluid flow — Methods of specifying flowmeter performance

Mesure de débit des fluides — Méthodes de spécification des performances des débitmètres

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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 11631 was prepared by Technical Committee TC 30, *Measurement of fluid flow in closed conduits,* Subcommittee SC 9, *General topics.*

Annex B forms a normative part of this International Standard. Annex A is for information only.

Measurement of fluid flow — Methods of specifying flowmeter performance

1 Scope

This International Standard applies to technical specifications and descriptions issued by manufacturers of flowmeters. It specifies methods of describing the performance of any flowmeter, for use in either closed conduits or open channels. It indicates how flowmeters may be classified according to their traceability group, and specifies how manufacturer's statements on traceability, quality assurance and conditions of use should be expressed, although further statements may be required for other conditions of use.

NOTE The terms and definitions given in clause 3 include a large number of associated terms to encourage common usage of these terms in technical specifications.

2 Normative reference

The following normative document contains provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, this publication do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent edition of the normative document indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO/TR 5168, *Measurement of fluid flow — Estimation of uncertainty of a flowrate measurement*.

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in ISO 5168 apply, adapted where appropriate to refer specifically to flowmeters and to describe the characteristics of flowmeters.

3.1
accuracy (deprecated)
⟨of a flowmeter⟩ ability of a flowmeter to give responses close to a true value

NOTE Accuracy is a commonly used term and can include the effects of systematic and random errors, hysteresis, deadband, etc. Although it is convenient to combine all these errors under the heading of "accuracy", it is a qualitative term: no numerical value is attached to it, and it is not used in the performance specification of a flowmeter.

3.2
accuracy class
class of flowmeters which meets certain metrological requirements that are intended to keep errors within specified limits

NOTE An accuracy class is usually denoted by a number or symbol which is adopted by convention and is called the class index.

3.3
bias
⟨of a flowmeter⟩ systematic error of the indication of a flowmeter

3.4
calibration
set of operations which establish, under specified conditions, the relationship between values of quantities indicated by a flowmeter and the corresponding values indicated by a standard of reference

NOTE 1 The result of a calibration permits either the assignment of values of measurands to the indications or the determination of corrections with respect to indications.

NOTE 2 A calibration may also determine other metrological properties, such as the effect of influence quantities.

NOTE 3 The result of a calibration may be recorded in a document, sometimes called a calibration certificate or a calibration report.

NOTE 4 The result of a calibration is often expressed as a calibration factor, or as a series of calibration factors, or as a calibration curve.

NOTE 5 Calibration does not include adjustment.

3.5
confidence limits
lower and upper limits within which the true value is expected to lie with a specified probability, assuming negligible systematic error

3.6
confidence level
probability that the value will lie between the specified confidence limits, assuming negligible systematic error

NOTE This is generally expressed as a percentage, e.g. 95 %.

3.7
conformity
⟨of a curve⟩ closeness to which a curve approximates a specified curve (e.g. linear, logarithmic, parabolic, cubic, square root, etc.), expressed quantitatively

NOTE 1 Conformity is usually measured in terms of nonconformity and expressed as conformity; e.g. the maximum deviation between an average curve and a specific curve. The average curve is determined after making two or more full-measuring-range calibrations in each direction. The value of conformity is referred to the output span unless otherwise stated.

NOTE 2 As a performance specification, conformity may be expressed as independent conformity, terminal-based conformity, or zero-based conformity.

3.7.1
independent conformity
maximum deviation of the actual characteristic (average of upscale and downscale readings) from a specified curve so positioned as to minimize the maximum deviation

NOTE The maximum deviation can be minimized by using the method of least squares (see ISO 7066-1 and ISO 7066-2).

3.7.2
terminal-based conformity
maximum deviation of the actual characteristic (average of upscale and downscale readings) from a specified curve coinciding with the actual characteristic at upper and lower range-values

3.7.3
zero-based conformity
maximum deviation of the actual characteristic (average of upscale and downscale readings) from a specified curve so positioned as to coincide with the actual characteristic at the lower range-value and to minimize the maximum deviation

3.7.4
linearity
specific, but often used, case of conformity in which the specified curve is a straight line

NOTE Illustrations of linearity are given in annex A.

3.8
deadband
maximum interval through which a stimulus can be changed in both directions without producing a change in response of the flowmeter

NOTE Some flowmeters (turbines for example) may have a “deadband” from zero flow to some flowrate but thereafter have a small discrimination threshold; ie. they have a minimum starting flow. [See **minimum detectable flow** (3.20).]

3.9
discrimination
ability of a flowmeter to respond to small changes in the value of the stimulus

3.10
discrimination threshold
largest change in a stimulus that produces no detectable change in the response of a flowmeter, the change in the stimulus taking place slowly and monotonically

NOTE The discrimination (threshold) may not be constant through the flowrange.

3.11
drift
slow change with time of a metrological characteristic of a flowmeter

NOTE Unlike “stability”, “drift” is always considered with respect to time.

3.12
error
result of a measurement minus a true value of the measurand

NOTE 1 Since a true value cannot be determined, in practice a conventional true value is used.

NOTE 2 When it is necessary to distinguish “error” from “relative error”, the former is sometimes called “absolute error of measurement”. This should not be confused with “absolute value of error”, which is the modulus of the error.

3.13
experimental standard deviation
s
quantity characterizing the dispersion of the results of a series of n measurements of the same measurand

$$s = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}}$$

where

x_i is the result of the i th measurement;

$\bar{x}$ is the arithmetic mean of the n results considered.

NOTE 1 Considering the series of n values as a sample of a distribution, x is an unbiased estimate of the mean μ, and s^2 is an unbiased estimate of the variance σ^2, of that distribution.

NOTE 2 The expression $s/\sqrt{n}$ is an estimate of the standard deviation of the distribution of $\bar{x}$ and is called the experimental standard deviation of the mean.

NOTE 3 The term “experimental standard deviation of the mean” is sometimes incorrectly called “standard error of the mean”.

3.14
flowmeter
flow-measuring device which indicates the measured flowrate

3.15
hysteresis
property of a flowmeter whereby its response to a given stimulus depends on the sequence of the preceding stimuli

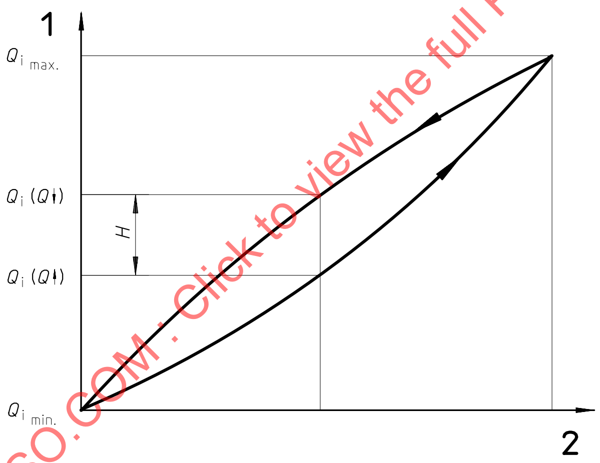
NOTE 1 Hysteresis may be expressed quantitatively as the maximum difference between the value of the measurand when the stimulus is increasing and the value of the measurand when the stimulus is decreasing. An example is shown in Figure 1.

NOTE 2 Hysteresis may be quoted in terms of the measurand or, more usually, as a percentage given by the equation:

$$\text{Hysteresis} = \frac{H}{Q_{i\max} - Q_{i\min}} \times 100\ (\%)$$

where the terms H, $Q_{i\max}$ and $Q_{i\min}$ are expressed in cubic metres per second and shown in Figure 1.

NOTE 3 Hysteresis does not include the effects of deadband.



Key
1 Indicate flowrate Q_i
2 Reference flowrate Q

Figure 1 — Typical hysteresis loop

3.16
K-factor
output signal of a flowmeter, expressed in number of pulses per unit quantity

NOTE Where required, this term may carry a subscript to show the unit quantity (e.g. K_m -factor for pulses per unit mass, K_v-factor for pulses per unit volume).

3.17
maximum scale value
full scale
full-scale deflection
FSD
full-scale reading
FSR
value of the quantity measured corresponding to the maximum limit of the scale

3.18
measuring range
working range
set of values of a measurand for which the performance of a flowmeter is intended to lie within specified limits

3.19
meter factor
numerical factor by which the meter output is multiplied to obtain the measurand

NOTE This may vary with flowrate and is determined by calibration.

3.20
minimum detectable flow
flowrate at which, when increased from zero, the flowmeter first shows a response

3.21
operating range
region, between the extreme lower and upper range-values, outside which irreversible change in the performance of the flowmeter will occur

NOTE The operating range may be wider than the "specified measuring range".

3.22
precision
closeness of agreement between the results obtained by applying the experimental procedure several times under prescribed conditions

NOTE 1 The smaller the random part of the experimental errors which affect the results, the more precise the procedure.

NOTE 2 This term should not be used as a synonym for accuracy, and no numerical value should be attached to it.

3.23
rangeability
ratio between the maximum and minimum upper range-values

NOTE This term applies to those flowmeters for which the upper range value may be set, by the user, to any value between upper and lower limits, nominated by the manufacturer, and still maintain the specified performance.

3.24
range of indication
set of values bounded by the extreme indications

NOTE 1 For an analog display, this may be called the "scale range".

NOTE 2 The range of indication is expressed in the units marked on the scale, regardless of the units of the measurand, and is normally stated in terms of its upper and lower limits, for example 10 l/s to 20 l/s.

3.25
lower range-value
lowest value of the measurand that a flowmeter is adjusted to measure

3.26
upper range-value
highest value of the measurand that a flowmeter is adjusted to measure

3.27
repeatability
value below which the absolute difference between two single successive test results obtained with the same flowmeter on the same fluid under the same conditions (same operator, same test facility, and a short interval of time, but without disconnecting or dismounting the flowmeter) can be expected to lie with a probability of 95 %

NOTE The method for calculating repeatability is given in annex B.

3.28
resolution
smallest difference between indications of a flowmeter that can be meaningfully distinguished

NOTE For a digital-display device, the resolution is the change in the indication when the least significant digit changes by one step.

3.29
response time
time interval between the instant when a stimulus is subjected to a specified abrupt change and the instant when the response reaches and remains within specified limits around its final steady value

EXAMPLE 0,5 s to reach and remain within 1 % of the final steady value following an abrupt change of 80 % span from 90 % to 10 % span.

NOTE Time constant is a special case of response time.

3.30
scale length
for a given scale, the length of a smooth line drawn between the first and the last scale marks and passing through the centres of all the shortest scale marks

NOTE 1 The line may be real or imaginary, curved or straight.

NOTE 2 “Scale length” is expressed in units of length, regardless of the units of the measurand or the units marked on the scale.

3.31
sensitivity coefficient
influence coefficient
θ
ratio of the change in result R to a change in input parameter x

$$\theta = \frac{\Delta R}{\Delta x}$$

NOTE 1 In relative terms this becomes

$$\theta' = \frac{\Delta R / R}{\Delta x / x}$$

NOTE 2 The sensitivity coefficient may depend on the value of the stimulus.

NOTE 3 The sensitivity coefficient is measured in the steady state and is specified with the units of the response and the stimulus stated.

3.32
settling time
warm-up time
time interval between the instant when electrical power is applied to the flowmeter and when the response reaches specified limits

3.33
span
modulus of the difference between the two limits of a nominal range of a flowmeter

EXAMPLE Nominal range −10 l/s to +10 l/s; span 20 l/s.

3.34
spindown time
time taken for the flowmeter moving parts to come to rest, from some indicated flowrate higher than the minimum flow to register, in still air

3.35
stability
ability of a flowmeter to maintain constant its metrological characteristics

NOTE It is usual to consider stability with respect to time. Where stability with respect to another quantity is considered, this should be stated explicitly.

3.36
traceability
property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or International Standards, through an unbroken chain of comparisons, all having stated uncertainties

NOTE See clause 5

3.37
turndown
turndown ratio
maximum flowrate divided by the minimum flowrate of the measuring range

EXAMPLE Maximum flowrate 5 000 m^3/h; minimum flowrate 250 m^3/h

Turndown ratio 20:1

3.38
uncertainty of measurement
estimate characterizing the range of values within which the true value of the measurand lies

NOTE Uncertainty of measurement comprises, in general, many components. Some of these components may be estimated on the basis of the statistical distribution of the results of series of measurements and can be characterized by experimental standard deviations. Estimates of other components can only be based on experience or other information.

4 General requirements

The flowmeter specification shall enable the potential user to predict the flowmeter's performance at any flowrate and environmental condition within the limits of the specification. In this context, environment includes not only climatic conditions but any other operating conditions or disturbances which influence performance, e.g. pressure of the fluid, configuration of the conduit, presence of impurities in the fluid.

The term "flowmeter" refers to the total flowmeter package which may comprise a primary and a secondary device, specified by the manufacturer. The technical specifications shall give a clear description of the "flowmeter" to which the performance specifications refer, together with a reference or order number by which they can be related to a particular flowmeter or model of flowmeter. Compliance with relevant International Standards should be indicated and these may refer to the flowmeter as defined in the technical specification or to individual components.

The traceability group of the flowmeter shall always be given (see clause 8). Only terms defined in this International Standard shall be used in the performance specification and they shall be accompanied by statements of traceability and conditions of use. If it is essential for any other new or trade terms to be employed, they shall be carefully defined in order to make their meaning absolutely clear.

In the calibration of a flowmeter, it is essential that the terms "dry calibration" and "wet calibration" NOT be used. If the performance of a flowmeter is theoretically predicted, then this fact should be stated together with the method of prediction.

Repeatability shall be calculated in accordance with annex B.

5 Traceability

Any performance specification produced by the manufacturer shall be accompanied by a statement of how the specification was produced, with reference being made to relevant national or International Standards.

A statement of the "traceability group" of the flowmeter (see clause 8) should include additional information on the test sample size, any quality assurance standard used and the traceability (e.g. to national or International Standards) of the measurements taken in determining the calibration.

6 Uncertainty of flow measurement

Statements of the uncertainty of measurement of a flowmeter shall be accompanied by a record of the condition limits at which the uncertainty was derived. If the device is used outside these limits, the uncertainty does not strictly apply.

The uncertainty shall be calculated in accordance with ISO/TR 5168.

EXAMPLE Uncertainty: ±1 % of measured flowrate (calculated in accordance with ISO/TR 5168 using the root-sum-square method to give 95 % coverage).

Calibration: 50 m^3/h to 1000 m^3/h at 500 kPa, 20 °C on air (in accordance with ISO 11631, traceability group A1).

7 Conditions of use

7.1 Measuring range

The range of properties over which the manufacturer has designed the flowmeter to operate such that the performance is within the specified limits shall be clearly stated. This shall include relevant environmental/operational conditions such as ambient temperature, fluid type and pressure, etc.

EXAMPLE Fluid Natural gas

Measuring range 20 m^3/h to 1000 m^3/h

Maximum working pressure 1500 kPa

Fluid temperature range −15 °C to +20°C

Permissible ambient temperature −15 °C to +60°C

7.2 Uncertainty over measuring range

The specification shall enable the user of a flowmeter to predict the uncertainty of the flow measurement at any flow within the measuring range. Use of a flowmeter outside the measuring range will undoubtedly give rise to an increase in uncertainty.

The environmental/operational conditions in which the flowmeter operates may also affect the uncertainty of the measurement. Therefore a table of flows, environmental conditions and consequent uncertainty values may be required. The table should be drawn up so that the uncertainty of measurement can be easily established for any combination of the flow and environmental conditions within the specified limits.

Where the uncertainty of measurement is not significantly affected by environmental conditions, a table relating flow to uncertainty is acceptable. In many cases only two values are required, viz.:

a) uncertainty as a percentage of flow, for flow within a specified range, and

b) uncertainty as a numerical value, for flows below a specified value.

If it is necessary to express uncertainty as a percentage of full-scale flow, this full-scale flow shall be stated.

8 Traceability group

8.1 General

In order to specify uncertainty of measurement (see clause 6), the systematic uncertainty must be estimated. This can only be done if either a calibration has been undertaken or a large amount of calibration data exists for the type of flowmeter concerned.

If the flowmeter performance specification specifies the uncertainty of measurement, then the traceability group into which the flowmeter falls shall be stated as shown.

8.2 Traceability Group A: calibrated in an Accredited Calibration Laboratory.

Flowmeters in this group are calibrated in an Accredited Laboratory by comparison with another flowmeter, or by some other means of calibration, traceable to national standards.

NOTE The criteria to be satisfied by an Accredited Laboratory are given in ISO/IEC Guide 25.

This traceability group is subdivided thus:

a) **Traceability Group A1**: every flowmeter calibrated

Every flowmeter in this group is calibrated as described above. Each flowmeter may be supplied with a calibration certificate or report stating the associated uncertainty of calibration.

b) **Traceability Group A2**: a sample of flowmeters calibrated

Flowmeters in this group are calibrated using a recognized batch testing or Quality Assurance procedure. The method or procedure used shall be stated. Flowmeters tested by an ad hoc batch testing method are not included in this group.

8.3 Traceability Group B: calibrated against a traceable standard in a non-accredited laboratory

Flowmeters in this group are calibrated in a non-accredited laboratory by comparison with another flowmeter which itself has a calibration traceable to national standards, or by some other means of calibration using equipment which has a calibration that is traceable to national standards.

This group is subdivided into traceability groups B1 and B2 as described for traceability groups A1 and A2.

8.4 Traceability Group C: calibrated against a non-traceable standard

Flowmeters in this group are calibrated as for traceability group B, but by reference to the manufacturer's or other body's standards. Traceability to national standards cannot be quoted, but a calibration certificate which indicates the calibration source and the associated uncertainty may be issued.

This group is subdivided into traceability groups C1 and C2 as described for traceability groups A1 and A2.

8.5 Traceability Group D: manufactured in accordance with an International Standard

Flowmeters in this group are not calibrated as described in traceability groups A or B, but are manufactured in accordance with a relevant International Standard which specifies the associated uncertainty. The International Standard used shall be stated (e.g. ISO 5167-1).

8.6 Traceability Group E: type-tested

An early or pre-production batch of flowmeters in this group are calibrated to establish a typical uncertainty. The flowmeter specification may then quote a typical uncertainty.

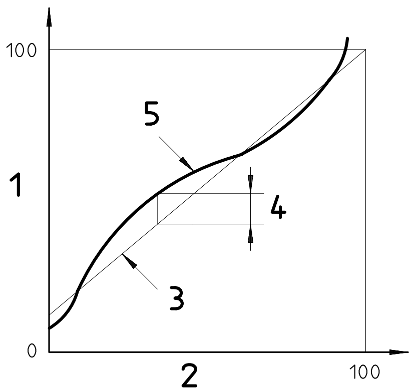
8.7 Traceability Group F: uncalibrated

Flowmeters in this group are not calibrated or built to a standard which allows the estimation of uncertainty. As such, no statement of the uncertainty of measurement can be ascribed to them

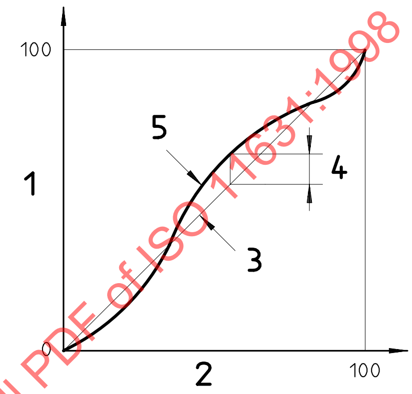
Annex A
(informative)

Illustrations of linearity

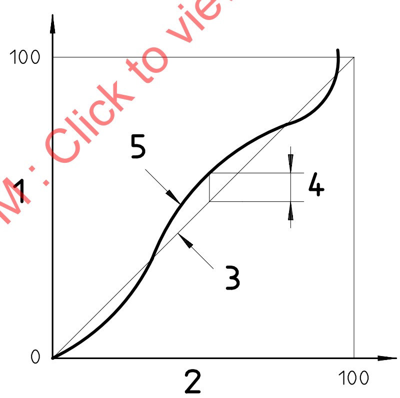
The forms of the graphs in Figure A.1 a), b) and c) are generalized to illustrate the three different expressions of linearity.



a) **Independent linearity**



b) **Terminal-based linearity**



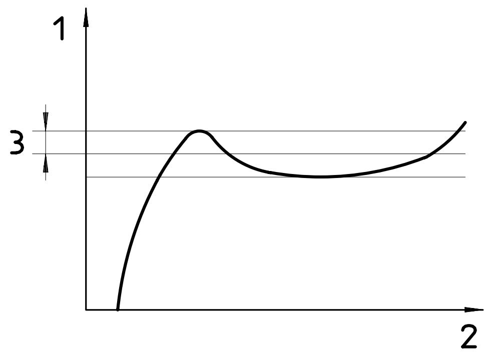
c) **Zero-based linearity**

Key

1 Response (% span)
2 Stimulus (% span)
3 Straight line
4 Maximum deviation
5 Actual result

Figure A.1 — Different expressions of linearity

Figure A.2 shows a typical turbine meter characteristic as an example of how linearity might be used in practice. This illustrates independent linearity in which the straight line has been positioned so as to minimize the deviation over a range and to give a constant K-factor.



Key

1 K-factor (pulses/unit volume)

2 Flowrate, Q (% span)

3 Maximum deviation

Figure A.2 — Typical application of independent linearity