

Assessment of uncertainty in calibration and use of flow measurement devices

Part 1. Linear calibration relationships

ICS 17.120.01

National foreword

This British Standard reproduces verbatim ISO/TR 7066-1 : 1997 and implements it as the UK national standard. It supersedes BS 7118 : Part 1 : 1990 which is withdrawn.

The UK participation in its preparation was entrusted by Technical Committee CPI/30, Measurement of fluid flow in closed conduits, to Subcommittee CPI/30/9, General topics, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled 'International Standards Correspondence Index', or using the 'Find' facility of the BSI Standards Electronic Catalogue.

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Summary of pages

This document comprises a front cover, an inside front cover, the ISO/TR title page, pages ii to v, a blank page, pages 1 to 28, an inside back cover and a back cover.

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TECHNICAL REPORT

ISO/TR 7066-1

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Assessment of uncertainty in calibration and use of flow measurement devices —

Part 1: Linear calibration relationships

*Évaluation de l'incertitude dans l'étalonnage et l'utilisation des appareils de
mesure du débit —*

Partie 1: Relations d'étalonnage linéaires



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Descriptors: fluid flow, liquid flow, flow measurement, measuring instruments, calibration, error analysis, rules of calculation.

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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

- type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;
- type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;
- type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

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

ISO/TR 7066-1, which is a Technical Report of type 1, was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 9, *Uncertainties in flow measurement*.

This document is being issued as a type 1 Technical Report because no consensus could be reached between ISO TC 30/SC 9 and ISO TAG 4, *Metrology*, concerning the harmonization of this document with the *Guide to the expression of uncertainty in measurement*, which is a basic document in the ISO/IEC Directives. A future revision of this Technical Report will align it with the *Guide*.

This first edition as a Technical Report cancels and replaces the first edition as an International Standard (ISO 7066-1:1988), which has been technically revised.

ISO/TR 7066 consists of the following parts, under the general title *Assessment of uncertainty in calibration and use of flow measurement devices*:

- *Part 1: Linear calibration relationships*
- *Part 2: Non-linear calibration relationships*

Annex A forms an integral part of this part of ISO/TR 7066. Annexes B and C are for information only.

Introduction

One of the first International Standards to specifically address the subject of uncertainty in measurement was ISO 5168, *Measurement of fluid flow — Estimation of uncertainty of a flow-rate measurement*, published in 1978. The extensive use of ISO 5168 in practical applications identified many improvements to its methods; these were incorporated into a draft revision of this International Standard, which in 1990 received an overwhelming vote in favour of its publication. ISO 7066-1, *Assessment of uncertainty in the calibration and use of flow measurement devices — Part 1: Linear calibration relationships*, published in 1989, was drawn up according to the principles outlined in ISO 5168:1978. The draft revision of ISO 7066-1 is consistent with both the draft revision of ISO 5168 and with ISO 7066-2:1988.

However, the draft revisions of both ISO/TR 5168 and ISO/TR 7066-1 were withheld from publication for a number of years since, despite lengthy discussions, no consensus could be reached with the draft version of a document under development by a Working Group of ISO Technical Advisory Group 4, *Metrology* ISO TAG 4/WG 3). The TAG 4 document, *Guide to the expression of uncertainty in measurement* (GUM), was published in late 1993 as a basic document in the ISO/IEC Directives. At a meeting of the ISO Technical Management Board in May 1995 it was decided to publish the revisions of ISO 5168 and ISO 7066-1 as Technical Reports.

This document is published as a type 1 Technical Report instead of an International Standard because it is not consistent with the GUM. A future revision of this part of ISO/TR 7066 will align the two documents.

Assessment of uncertainty in calibration and use of flow measurement devices —

Part 1:

Linear calibration relationships

1 Scope

1.1 This part of ISO/TR 7066 describes the procedures to be used in deriving the calibration curve for any method of measuring flowrate in closed conduits or open channels, and of assessing the uncertainty associated with such calibrations. Procedures are also given for estimation of the uncertainty arising in measurements obtained with the use of the resultant graph, and for calculation of the uncertainty in the mean of a number of measurements of the same flowrate.

1.2 Only linear relationships are considered in this part of ISO/TR 7066; the uncertainty in non-linear relationships forms the subject of ISO/TR 7066-2. This part of ISO/TR 7066 is applicable, therefore, only if

a) the relationship between the two variables is itself linear,

or

one or both variables can be transformed in such a manner as to create a linear relationship between them, as, for instance by the use of logarithms,

or

the total range can be subdivided in such a way that within each subdivision the relationship between the two variables can be regarded as being linear; and if

b) systematic deviations from the fitted line are negligible compared with the uncertainty associated with the individual observations forming the graph.

NOTE — Examples of the application of the principles contained in this part of ISO/TR 7066 are given in annexes B and C.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO/TR 7066. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO/TR 7066 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 772:1996, *Hydrometric determinations — Vocabulary and symbols*.

ISO 1100-2:—¹⁾, *Liquid flow measurement in open channels — Part 2: Determination of the stage-discharge relationship*.

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

ISO/TR 5168:—²⁾ *Measurement of fluid flow — Evaluation of uncertainties*.

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

3 Definitions and symbols

For the purposes of this part of ISO/TR 7066, the definitions and symbols given in ISO 772 and ISO 4006 and the following definitions and symbols apply.

3.1 Definitions

3.1.1 calibration graph: Curve drawn through the points obtained by plotting some index of the response of a flow meter against some function of the flowrate.

3.1.2 confidence limits: Upper and lower limits about an observed or calculated value within which the true value is expected to lie with a specified probability, assuming a negligible uncorrected systematic error.

3.1.3 correlation coefficient: Indicator of the degree of relationship between two variables.

NOTE — Such a relationship may be causal or may operate through the agency of a third variable, but a decision on this point cannot be made on statistical grounds alone.

3.1.4 covariance: First product moment measured about the variate means, i.e.

$$\text{Cov}(x, y) = \left[\sum (x_i - \bar{x})(y_i - \bar{y}) \right] / (n - 1)$$

3.1.5 error of measurement: Collective term meaning the difference between the measured value and the true value.

It includes both systematic and random components.

3.1.6 error, random: That component of the error of measurement which varies unpredictably from measurement to measurement.

NOTE — No correction is possible for this type of error, the cause of which may be known or unknown.

3.1.7 error, systematic: That component of the error of measurement which remains constant or varies predictably from measurement to measurement.

NOTE — The cause of this type of error may be known or unknown.

1) To be published. (Revision of ISO 1100-2:1982)

2) To be published.

3.1.8 error, spurious: Error which invalidates a measurement.

Such errors generally have a single cause, such as instrument malfunction or the misrecording of one or more digits of the measurement value.

3.1.9 function: Mathematical formula expressing the relationship between two or more variables.

3.1.10 line of best fit: Line drawn through a series of points in such a way as to minimize the variance of the points about the line.

3.1.11 residual: Difference between an observed value and the corresponding value calculated from the regression equation.

3.1.12 sample [experimental] standard deviation: Measure of the dispersion about the mean of a series of n values of a measurand, defined by the formula:

$$s(x) = \left[\sum (x_i - \bar{x})^2 / (n - 1) \right]^{1/2}$$

NOTE — If the n measurements are regarded as a sample of the underlying population, then the formula below provides a sample estimate of the population standard deviation.

$$\sigma = \left[\sum (x_i - \mu)^2 / n \right]^{1/2}$$

3.1.13 systematic error limit: That component of the total uncertainty associated with the systematic error.

Its value cannot be reduced by taking many measurements.

3.1.14 uncertainty, random: Estimate characterizing the range of values within which it is asserted with a given degree of confidence that the true value of the measurand may be expected to lie.

Its magnitude in terms of mean values may be reduced by taking many measurements.

3.1.15 variance: Measure of dispersion based on the mean squared deviation from the arithmetic mean, defined as

$$\text{Var}(x) = \sum (x_i - \bar{x})^2 / (n - 1)$$

3.2 Symbols

NOTE — Symbols used in the open channel and closed conduit examples of annexes B and C where these differ from, or are in addition to, those listed below are included at the beginning of the respective annexes.

a	Intercept of the calibration curve on the ordinate
b	Gradient or slope of the calibration curve
c	Coefficient in a weighted least-squares equation
$\text{Cov}()$	Covariance of variables in brackets
$e_R()$	Random uncertainty of variable in brackets
$e_S()$	Systematic error limits of variable in brackets
$\ln$	Natural logarithm
n	Number of measurements used in deriving the calibration curve
Q	Flowrate
r	Correlation coefficient

$s()$	Experimental standard deviation of variable in brackets
s_R	Standard deviation (standard error) of points about best-fitting straight line
t	"Student's" t (as obtained from ISO 5168 or from any set of statistical tables)
w_i	i th weighting factor, in weighted least-squares
x	Independent variable; variable subject to the smallest error
y	Dependent variable; variable subject to the greatest error
U	Total or overall uncertainty
U_{ADD}	Uncertainty using the additive model; provides between approximately 95 % and 99 % coverage $U_{\text{ADD}} = e_S + e_R$
U_{RSS}	Uncertainty using the root-sum-square model; provides approximately 95 % coverage $U_{\text{RSS}} = (e_S^2 + e_R^2)^{1/2}$
γ	Ratio of the standard deviation of the independent, or x , variable to that of the dependent, or y , variable
Δ	Difference between an observed and a calculated value
μ	Population mean
σ	Population standard deviation
θ	Influence coefficient

NOTE — In a number of International Standards, the random uncertainty e_R and systematic error limits e_S are denoted by the symbols U_r and U_s or B respectively.

Subscripts and superscripts

NOTE — In the following, the summation sign $\sum$ is used to represent

$$\sum_{i=1}^n$$

unless otherwise noted; a bar above a symbol ($\bar{}$) denotes the mean value of that quantity; a circumflex ($\wedge$) denotes the value of the variable predicted by the equation of the fitted curve.

i i th value of a variable

ij i th value of the j th category

4 General

4.1 With the majority of calibrations considered in this part of ISO 7066, the relationship between the variables is of a functional nature and is defined by some form of mathematical expression. Any departure of the observed values from this relationship can then be attributed to errors of measurement of one kind or another, which may affect either or both variables and which may be random or systematic or a combination of the two.

4.2 The role of the calibration procedure is thus twofold: to assess the form of the underlying mathematical relationship and to provide an estimate of the uncertainty of the fitted line.