INTERNATIONAL STANDARD

ISO 5168

Second edition
2005-06-15

Measurement of fluid flow — Procedures for the evaluation of uncertainties

Mesure de débit des fluides — Procédures pour le calcul de l'incertitude

Reference number
ISO 5168:2005(E)

PDF disclaimer

This PDF file may contain embedded typefaces. In accordance with Adobe's licensing policy, this file may be printed or viewed but shall not be edited unless the typefaces which are embedded are licensed to and installed on the computer performing the editing. In downloading this file, parties accept therein the responsibility of not infringing Adobe's licensing policy. The ISO Central Secretariat accepts no liability in this area.

Adobe is a trademark of Adobe Systems Incorporated.

Details of the software products used to create this PDF file can be found in the General Info relative to the file; the PDF-creation parameters were optimized for printing. Every care has been taken to ensure that the file is suitable for use by ISO member bodies. In the unlikely event that a problem relating to it is found, please inform the Central Secretariat at the address given below.

iTeh STANDARD PREVIEW
(standards.iteh.ai)
ISO 5168:2005
https://standards.iteh.ai/catalog/standards/sist/d2d291ba-9c0f-4676-978f-8fc5130b963f/iso-5168-2005

© ISO 2005

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

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 2.

The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 5168 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*, Subcommittee SC 9, *General topics*.

This second edition of ISO 5168 cancels and replaces ISO/TR 5168:1998, which has been technically revised (see Annex I).

Introduction

Whenever a measurement of fluid flow (discharge) is made, the value obtained is simply the best estimate that can be obtained of the flow-rate or quantity. In practice, the flow-rate or quantity could be slightly greater or less than this value, the uncertainty characterizing the range of values within which the flow-rate or quantity is expected to lie, with a specified confidence level.

GUM is the authoritative document on all aspects of terminology and evaluation of uncertainty and should be referred to in any situation where this International Standard does not provide enough depth or detail. In particular, GUM (1995), Annex F, gives guidance on evaluating uncertainty components.

INTERNATIONAL STANDARD **ISO 5168:2005(E)**

Measurement of fluid flow — Procedures for the evaluation of uncertainties

1 Scope

This International Standard establishes general principles and describes procedures for evaluating the uncertainty of a fluid flow-rate or quantity.

A step-by-step procedure for calculating uncertainty is given in Annex A.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9300, *Measurement of gas flow by means of critical flow Venturi nozzles*

ISO Guide to the expression of uncertainty in measurement (*GUM*), 1995

International vocabulary of basic and general terms in metrology (*VIM*), 1993

3 Terms and definitions

For the purposes of this document, the terms and definitions given in VIM (1993), GUM (1995) and the following apply.

3.1
uncertainty
parameter, associated with the results of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

NOTE Uncertainties are expressed as an absolute value and do not take a positive or negative sign.

3.2
standard uncertainty
$u(x)$
uncertainty of the result of a measurement expressed as a standard deviation

3.3
relative uncertainty
$u^*(x)$
standard uncertainty divided by the best estimate

NOTE 1 $u^*(x) = u(x)/x$.

NOTE 2 $u^*(x)$ can be expressed either as a percentage or in parts per million.

NOTE 3 Relative uncertainty is sometimes referred to as dimensionless uncertainty.

NOTE 4 The best estimate is in most cases the arithmetic mean of the related uncertainty interval.

3.4
combined standard uncertainty

$u_c(y)$

standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or covariances of these other quantities weighted according to how the measurement result varies with changes in these quantities

3.5
relative combined uncertainty

$u_c^*(y)$

combined standard uncertainty divided by the best estimate

NOTE 1 $u_c^*(y)$ can be expressed as a percentage or parts per million.

NOTE 2 $u_c^*(y) = u_c(y)/y$.

NOTE 3 Relative combined uncertainty is sometimes referred to as dimensionless combined uncertainty.

NOTE 4 The best estimate is in most cases the arithmetic mean of the related uncertainty interval.

3.6
expanded uncertainty

U

quantity defining an interval about the result of a measurement that can be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand

NOTE 1 The fraction can be viewed as the coverage probability or the confidence level of the interval.

NOTE 2 $U = ku_c(y)$

3.7
relative expanded uncertainty

U^*

expanded uncertainty divided by the best estimate

NOTE 1 U^* can be expressed as a percentage or in parts per million.

NOTE 2 $U^* = ku_c^*(y)$.

NOTE 3 Relative expanded uncertainty is sometimes referred to as dimensionless expanded uncertainty.

NOTE 4 The best estimate is in most cases the arithmetic mean of the related uncertainty interval.

3.8
coverage factor

k

numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty

NOTE A coverage factor is typically in the range 2 to 3.

3.9
Type A evaluation

⟨uncertainty⟩ method of evaluation of uncertainty by the statistical analysis of a series of observations

3.10
Type B evaluation

⟨uncertainty⟩ method of evaluation of uncertainty by means other than the statistical analysis of a series of observations

3.11
sensitivity coefficient

c_i

change in the output estimate, y, divided by the corresponding change in the input estimate, x_i

3.12
relative sensitivity coefficient

c^*_i

relative change in the output estimate, y, divided by the corresponding relative change in the input estimate, x_i

4 Symbols and abbreviated terms

4.1 Symbols

a_i	estimated semi-range of a component of uncertainty associated with input estimate, x_i, as defined in Annex B
A_{t}	area of the throat
b_i	breadth associated with a vertical i
b'_i	upper bound of an asymmetric uncertainty distribution as defined in Annex B
c_i	sensitivity coefficient used to multiply the uncertainty in the input estimate, x_i, to obtain the effect of a change in the input quantity on the uncertainty of the output estimate, y
c^*_i	relative sensitivity coefficient used to multiply the relative uncertainty in input estimate, x_i, to obtain the effect of a relative change in the input quantity on the relative uncertainty of the output estimate, y
C_{c}	calibration coefficient
C	discharge coefficient
C_{V}	coefficient of variation
d_i	depth associated with a vertical i
d_{o}	orifice diameter
$d_{\mathrm{o},0}$	orifice diameter measured at temperature $T_{0,x}$
d_{p}	pipe diameter
$d_{\mathrm{p},0}$	pipe diameter measured at temperature $T_{0,x}$
$\overline{E}$	mean meter error, expressed as a fraction

E_j	jth meter error, expressed as a fraction
f	functional relationship between estimates of the measurand, y, and the input estimates, x_i, on which y depends
$\frac{\partial f}{\partial x_i}$	partial derivative with respect to input quantity, x_i, of the functional relationship, f, between the measurand and the input quantities
F	flow factor, equal to $\frac{q}{\sqrt{\Delta p_{\mathrm{r}}}}$
F_{exp}	flow factor for a new design
F_{Redp}	$\left(19\,000 \cdot \beta / \mathrm{Re}_{\mathrm{dp}}\right)^{0,8}$
F_{ref}	reference flow factor
F_{s}	factor, assumed to be unity, that relates the discrete sum over the finite number of verticals to the integral of the continuous function over the cross-section
k	coverage factor used to calculate the expanded uncertainty, U
k_{t}	coverage factor derived from a table; see D.12
K	meter factor
$\overline{K}$	mean meter factor
K_j	jth K-factor;
l_{b}	length of crest
l_{h}	gauged head
l_1	distance from the upstream tapping to the upstream face
L_1	l_1 divided by the pipe diameter, d_{p}
l'_2	distance from the downstream tapping to the downstream face
L'_2	l'_2 divided by the pipe diameter, d_{p}
m	particular item in a set of data
m'	number of data sets to be pooled
m''	number of verticals
M'_2	$2L'_2/(1-\beta)$
n	number of repeat readings or observations
n'	exponent of l_{h}, usually 1,5 for a rectangular weir and 2,5 for a V-notch

n''	number of depths in a vertical at which velocity measurements are made
N	number of input estimates, x_i, on which the measurand depends
p_0	upstream pressure
Δp_{mt}	pressure difference across the orifice meter
Δp_{r}	pressure difference across the radiator
$P(a_i)$	probability that an input estimate, x_i, has a value of a_i
q	volume flow-rate
q_{ma}	mass flow;
Q	flow, expressed in cubic metres per second, at flowing conditions
R	specific gas constant
$\mathrm{Re}_{\mathrm{dp}}$	Reynolds number related to d_{p} by the expression $Vd_{\mathrm{p}}\rho/\mu$
$s_{\mathrm{mt,po}}$	pooled experimental standard deviation of the orifice plate readings
s_{pe}	standard deviation of a larger set of data used with a smaller data set
s_{po}	standard deviation pooled from several sets of data
$s_{\mathrm{r,po}}$	pooled experimental standard deviation for the radiator readings
$s(x)$	experimental standard deviation of a random variable, x, determined from n repeated observations
$s(\bar{x})$	experimental standard deviation of the arithmetic mean, $\bar{x}$
t	Student's statistic
T_0	upstream absolute temperature
$T_{0,x}$	temperature at which measurement x is made
T_{op}	operating temperature
$u_{\mathrm{c,corr}}(y)$	combined uncertainty for those components for multiple meters that are correlated
$u_{\mathrm{c,uncorr}}(y)$	combined uncertainty for those components for multiple meters that are uncorrelated
u^*_{cal}	instrument calibration uncertainty from all sources, formerly called systematic errors or biases
$u^*_{\mathrm{cr}i}$	relative uncertainty in point velocity at a particular depth in vertical i due to the variable responsiveness of the current meter
u^*_{d}	relative standard uncertainty in the coefficient of discharge

$u^*_{\mathrm{e}i}$	relative uncertainty in point velocity at a particular depth in vertical i due to velocity fluctuations (pulsations) in the stream
u^*_{lb}	relative standard uncertainty in the measurement of the crest length
u^*_{lh}	relative standard uncertainty in the measurement of the gauged head
$u^*_{m''}$	relative uncertainty due to the limited number of verticals
$u^*_{\mathrm{p}i}$	relative uncertainty in mean velocity, V_i, due to the limited number of depths at which velocity measurements are made at vertical, i
$u^*(Q)$	combined relative standard uncertainty in the discharge;
u_{sm}	standard uncertainty of a single value based on past experience
$u(x_{i,\mathrm{corr}})$	correlated components of uncertainty in a single meter
$u(x_{i,\mathrm{uncorr}})$	uncorrelated components of uncertainty in a single meter
$u^*(x_i)$	standard uncertainty associated with the input estimate, x_i
$u^*_{\mathrm{c}}(y)$	combined standard uncertainty associated with the output estimate, y
$u^*(x_i)$	relative standard uncertainty associated with the input estimate x_i
$u^*_{\mathrm{c}}(y)$	combined relative standard uncertainty associated with the output estimate, y
$U^*(y)$	relative expanded uncertainty associated with the output estimate
$U(y)$	expanded uncertainty associated with the output estimate, y
U_{CMC}	combined uncertainty of the calibration rig
$U_{\text{AS-overall-}E}$	type A uncertainty in meter error
$U^*_{\text{AS-overall-}K}$	type A uncertainty in the K-factor
V	mean velocity in the pipe
V_i	mean velocity associated with a vertical i
x_i	estimate of the input quantity, X_i
x_m	mth observation of random quantity, x
x_0	dimension at temperature $T_{0,x}$
$\bar{x}$	arithmetic mean or average of n repeated observations, x_m, of randomly varying quantity, x
y	estimate of the measurand, Y
Δx_i	increment in x_i used for numerical determination of sensitivity coefficient

Δy	increment in y found in numerical determination of sensitivity coefficient
Z_n	Grubbs test statistic for outliers
β	orifice plate diameter ratio, equal to $d_\mathrm{o}/d_\mathrm{p}$
φ_cf	critical flow function
Φ_F	ratio of the factor F for a new design compared to the old design
λ	expansion coefficient
μ	dynamic fluid viscosity
ρ	fluid density
ν	degrees of freedom
ν_eff	effective degrees of freedom
ν_po	degrees of freedom associated with a pooled standard deviation

4.2 Subscripts

c	combined
corr	correlated
do	orifice diameter
dp	pipe diameter, effective
ex	external
i	of the ith input
j	of the jth set
$k = 2$	obtained with a coverage factor of 2
m	of the mth observation
n	of the nth observation
N	of the Nth input
nom	nominal value of
op	operating temperature
pe	from past experience
po	pooled
sm	based on a single measurement
t	tolerance interval

uncorr	uncorrelated
x	of x
$\bar{x}$	of the mean value of x
95	with a 95 % confidence level

5 Evaluation of the uncertainty in a measurement process

The first stage in an uncertainty evaluation is to define the measurement process. For the measurement of flow-rate, it will normally be necessary to combine the values of a number of input quantities to obtain a value for the output. The definition of the process should include the enumeration of all the relevant input quantities.

Annex E enumerates a number of categories of sources of uncertainty. This categorization can be of value when defining all of the sources of uncertainty in the process. It is assumed in the following sections that the sources of uncertainty are uncorrelated; correlated sources require different treatment (see Annex F).

Consideration should also be given to the time over which the measurement is to be made, taking into account that flow-rate will vary over any period of time and that the calibration can also change with time.

If the functional relationship between the input quantities X_1, X_2, ..., X_N, and output quantity Y in a flow measurement process is specified in Equation (1):

$$Y = f\left(X_1, X_2, \ldots, X_N\right) \tag{1}$$

then an estimate of Y, denoted by y, is obtained from Equation (1) using input estimates x_1, x_2, ... x_N, as shown in Equation (2):

$$y = f\left(x_1, x_2, \ldots, x_N\right) \tag{2}$$

Provided the input quantities, X_i, are uncorrelated, the total uncertainty of the process can be found by calculating and combining the uncertainty of each of the contributing factors in accordance with Equation (3):

$$u_\mathrm{c}\left(y\right) = \sqrt{\sum_{i=1}^{N}\left[c_i u\left(x_i\right)\right]^2} \tag{3}$$

Where the extent of interdependence is known to be small, Equation (3) may be applied even though some of the input quantities are correlated; ISO 5167-1:2003 [1] provides an example of this.

Each of the individual components of uncertainty, $u(x_i)$, is evaluated using one of the following methods:

- Type A evaluation: calculated from a series of readings using statistical methods, as described in Clause 6;
- Type B evaluation: calculated using other methods, such as engineering judgement, as described in Clause 7.

Uncertainty sources are sometimes classified as “random” or “systematic” and the relationship between these categorizations and Type A and Type B evaluations is given in Annex I.

The sensitivity coefficients, c_i, provide the links between uncertainty in each input and the resulting uncertainty in the output. The methods of calculating the individual sensitivity coefficients, c_i, are described in detail in Clause 8.

6 Type A evaluations of uncertainty

6.1 General considerations

Type A evaluations of uncertainty are those using statistical methods, specifically, those that use the spread of a number of measurements.

Whilst no correction can be made to remove random components of uncertainty, their associated uncertainty becomes progressively less as the number of measurements increases. In taking a series of measurements, it should be recognized that, as the purpose is to define the random fluctuations in the process, the timescale for the data collection should reflect the anticipated timescale for the fluctuations. Collecting readings at millisecond intervals for a process that fluctuates over several minutes will not characterize those fluctuations adequately.

In many measurement situations, it is not practical to make a large number of measurements. In this case, this component of uncertainty may have to be assigned on the basis of an earlier Type A evaluation, based on a larger number of readings carried out under similar conditions. Caution should be exercised in making these estimates (see Annex D), as there will always be some uncertainty associated with the assumption that the earlier measurements were taken under truly similar conditions.

The methods of calculating the uncertainty in a mean and in a single value reflect the reduction in uncertainty obtained by averaging several readings [Equations (4) to (8)] and are explained in more detail in D.4 to D.6.

6.2 Calculation procedure

Further explanation of the equations given below can be found in Annex D.

The standard uncertainty of a measured value, x_i, is calculated from a sample of measurements, $x_{i,m}$, in accordance with Equations (4) to (8):

a) Calculate the average value of the measurements in accordance with Equation (4); see D.1:

$$\bar{x}_i = \frac{1}{n}\sum_{m=1}^{n} x_{i,m} \tag{4}$$

b) Calculate the standard deviation of the sample in accordance with Equation (5); see D.2:

$$s\left(x_i\right) = \sqrt{\frac{1}{\left(n-1\right)}\sum_{m=1}^{n}\left(x_{i,m} - \bar{x}_i\right)^2} \tag{5}$$

The standard uncertainty of a single sample is the same as its standard deviation and is given by Equation (6):

$$u\left(x_i\right) = s\left(x_i\right) \tag{6}$$

c) Calculate the standard deviation of the mean value in accordance with Equation (7); see D.4:

$$s\left(\bar{x}_i\right) = \frac{s\left(x_i\right)}{\sqrt{n}} \tag{7}$$

The standard uncertainty of the mean value is then given by Equations (8):

$$u\left(\bar{x}_i\right) = s\left(\bar{x}_i\right) \tag{8}$$