INTERNATIONAL STANDARD

ISO 9368-1

First edition
1990-12-01

Measurement of liquid flow in closed conduits by the weighing method — Procedures for checking installations —

Part 1: Static weighing systems

Mesure de débit des liquides dans les conduites fermées par pesée — Contrôle des installations de mesure —
Partie 1: Installations statiques

Reference number
ISO 9368-1 : 1990 (E)

Contents

International Organization for Standardization
Case postale 56 • CH-1211 Genève 20 • Switzerland
Printed in Switzerland

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 9368-1 was prepared by Technical Committee ISO/TC 30, *Measurement of fluid flow in closed conduits*.

ISO 9368 will consist of the following parts, under the general title *Measurement of liquid flow in closed conduits by the weighing method — Procedures for checking installations*:

— *Part 1: Static weighing systems*

— *Part 2: Dynamic weighing systems*

Annexes A, B, C, D and E form an integral part of this part of ISO 9368. Annex F is for information only.

Introduction

The weighing method of liquid flowrate measurement, as described in ISO 4185, is one of the basic methods of measurement. It is widely used in hydraulic research, in the testing of pumps and turbines and for flowmeter calibration.

To obtain comparative results when such measurements are carried out in various installations, it is necessary to standardize the procedures for carrying out the measurements and the tests.

Measurement of liquid flow in closed conduits by the weighing method — Procedures for checking installations —

Part 1: Static weighing systems

1 Scope

This part of ISO 9368 specifies methods of testing installations for flowrate measurement by the static weighing method. Methods of testing by dynamic weighing are given in ISO 9368-2.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 9368. 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 9368 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 : —[1]), *Measurement of fluid flow in closed conduits — Vocabulary and symbols.*

ISO 4185 : 1980, *Measurement of liquid flow in closed conduits — Weighing method.*

ISO 5168 : 1978, *Measurement of fluid flow — Estimation of uncertainty of a flow-rate measurement.*

OIML — International Recommendation 33 : 1973, *Conventional values of the result of weighing in air.*

3 Definitions and symbols

3.1 Definitions

For the purposes of this part of ISO 9368, the definitions given in ISO 4006 apply.

3.2 Symbols

The symbols used in this part of ISO 9368 are given in table 1.

Table 1 — Symbols

Symbol	Quantity	Dimension[1])	SI unit
E_R	Random uncertainty, relative value	Dimensionless	—
e_R	Random uncertainty, absolute value	2)	2)
E_S	Systematic uncertainty, relative value	Dimensionless	—
e_S	Systematic uncertainty, absolute value	2)	2)
m	Mass	M	kg
q_V	Volumetric flowrate	$L^3 T^{-1}$	m^3/s
q_m	Mass flowrate	$M T^{-1}$	kg/s
S	Standard deviation, relative value	Dimensionless	—
s	Standard deviation, absolute value	2)	2)
t	Time	T	s
V	Volume	L^3	m^3
ϱ	Liquid density	$M L^{-3}$	kg/m^3

1) M = mass; L = length; T = time.

2) The dimensions and units are those of the quantity for which the uncertainty is stated.

4 Certification

If the installation for flowrate measurement by the weighing method is used for purposes of legal metrology, if shall be cer-

1) To be published. (Revision of ISO 4006 : 1977.)

tified and registered by the national metrology service. Such installations are then subject to periodic inspection at stated intervals. If a national metrology service does not exist, a certified record of the basic measurement standards (length, mass, time and temperature), and error analysis in accordance with this part of ISO 9368 and ISO 5168, may also constitute certification for legal metrology purposes.

The person responsible for carrying out the checks shall evaluate the results in accordance with this part of ISO 9368 and shall issue and sign a written report on the results.

5 General principles

5.1 Main items of installation

Static weighing installations generally comprise the following main items:

— sump,

— test section,

— diverter,

— weightank,

— weighing device,

— receiving tank,

— timer,

— one or more pumps.

The requirements for these main items are specified in ISO 4185.

5.2 Test liquid

Clean water is generally used as the test liquid when verifying installations for flowrate measurement by the weighing method.

Other liquids may be employed provided that the liquid vapour pressure is low enough to make vaporization effects negligible. For practical reasons (particularly to limit the drainage time of the weightank) it is recommended that the kinematic viscosity of the liquid does not exceed about 35×10^{-6} m^2/s.

5.3 Principle of verification

Following the construction of a system, tests are carried out to assess the systematic and random errors.

Further tests are conducted at regularly established intervals to determine the errors and to compare them with the previous results to determine the required intervals between successive checks.

The general principle of the verification of flow calibration systems is to check separately the errors for each item of the installation and to combine them to determine the overall uncertainty of the whole installation.

ISO 4185 : 1980, subclause 6.2, covers methods for assessing the weighing device and diverter errors.

This part of ISO 9368 amplifies certain aspects of verification and testing of the system. In particular, alternative procedures are given for checking the weighing device (see 6.1 and annex A), checking the diverter (see 6.2 and annex B), checking the timer (see 6.3), checking the density measurement system (see 6.4), assessment of flowrate stability (see 6.5 and annexes C and D), study of flow characteristics (see 6.6 and annex E), and calculating the overall measurement uncertainty (see clause 7).

5.4 Preliminary operations

Before undertaking the detailed checks the following preliminary operations shall be carried out:

a) examine the technical description and written procedures for operating the installation;

b) check the characteristics of the main and auxiliary instrumentation and equipment, and verify that it conforms with the characteristics given in the documentation;

c) check the operation of the hydraulic system in order to establish any additional sources of error;

d) determine the operational flow range of the installation.

The maximum operational flowrate of an installation shall be the lower of the following two values:

a) the maximum flowrate which can be produced by the flow supply system when operating in a flow circuit with minimum hydraulic resistance;

b) the flowrate corresponding to the minimum allowable time for filling the weightank up to its maximum level, the minimum time having to satisfy the requirements given in ISO 4185 : 1980, subclause 3.3, i.e. 30 s.

6 Procedures for checking operations

6.1 Checking the weighing device

The mass of liquid collected is determined by weighing the weightank before and after the diversion period (double weighing) and the tare is then subtracted from the gross weight.

Checking of the weighing device used with the double weighing method shall allow the determination of the corrections to be applied and the systematic and random uncertainties due to the weighing device. Procedures for assessing these uncertainties are given in detail in ISO 4185 and annex A of this part of ISO 9368.

6.1.1 Checking by means of standard weights

In order to check the weighing device, standard weights of a total mass not less than the maximum possible mass of liquid collected shall be used whenever possible. The maximum permissible error of the standard weights shall be 20 % or less of the expected uncertainty of the weighing device.

If the total mass of the standard weights used in the process of verification is less than the maximum possible mass of liquid collected, then a method of successive substitution may be used for checking the weighing device. In this case, the total of the standard weights shall not be less than 25 % of the maximum possible mass of liquid to be weighed. Nevertheless, this value of 25 % may be reduced provided that it is possible to determine experimentally, according to the repeated procedures of successive substitution, that the required accuracy is achieved.

When a high accuracy is required, the effects of aerostatic buoyancy on the standard weights and test liquid shall be taken into account in accordance with OIML Recommendation 33 and ISO 4185.

6.1.2 Checking by means of standard volumetric tanks

In certain cases, for instance for large capacity weightanks or when some structures are not completely immersed according to the amount of water stored in the weightank, it is better to check the weighing device by means of standard volumetric tanks, the volume of which shall be between 5 % and 10 % of the maximum volume stored in the weightank.

It is then necessary to known the density of the water for the measurement conditions with an uncertainty less than 0,01 %. This implies in particular the determination of the water temperature with an uncertainty less than 0,5 °C.

The checking procedure is identical to that used with standard weights (see 6.1.1).

6.2 Checking the diverter

Before starting testing, the diverter shall be checked at minimum and maximum flowrates to ensure that no splashing occurs when diverting the flow or measuring the flowrate. Splashing of liquid is not permitted. (Splashing of liquid to the non-operational channel of the diverter can cause unacceptably large errors.)

The proximity of the nozzle outlet to the splitter plate of the diverter can give rise to flowrate variations due to pressure fluctuations. This shall be determined by measuring any pressure variations in the pipeline at maximum flowrate with the diverter in a fixed position. Abnormal fluctuations of pressure in the pipeline shall not occur.

The diverter shall be visually inspected for effective sealing (leaktightness) at a pressure equal to the working pressure. In cases where a very small leakage can be tolerated, the leakage mass shall be collected and determined over a normal diversion period. Since the leakage mass may depend on flowrate, measurements shall be carried out at minimum, mid-range and maximum flowrates (see clause B.1 for details of the calculation procedure).

After these checks, systematic and random errors produced by the diverter shall be determined, employing methods described in ISO 4185 : 1980, subclauses 6.2.1.3 and 6.2.2.2, and annex A, or alternatively by the method given in annex B of this part of ISO 9368.

6.3 Checking the timer

Any error in calibrating the timer will give a systematic error in the measurement of the filling time of the weightank.

In order to ensure that the random error in the measurement of the filling time due to the timer may be neglected, the discrimination of the timer shall be such that the error is less than 0,01 % for the minimum filling time of the weightank (i.e. for instance 3 ms for a minimum filling time of 30 s). It is possible to obtain reading errors of less than 0,01 % using interpolation methods such as the so-called double chronometer method (see ISO 7278-3).

6.4 Checking the density measurement system

If volume flowrates corresponding to known mass flowrates are required, the density of the liquid shall be measured with the required accuracy. Such accuracy is difficult to achieve with liquids having a high thermal expansion coefficient. Techniques for measuring density and the method for calculating the corresponding errors are given in ISO 4185 : 1980, subclauses 3.5 and 6.2.1.4.

6.5 Assessment of flowrate stability

It is desirable to determine the stability of the flowrate in the test section for certain applications of weighing systems. The stability assessment will indicate the operational efficiency of any flowrate stabilization system, including devices for damping out flowrate instabilities, the spectrum of which may cover a wide frequency band.

Various techniques are available for evaluating flowrate stability. One method which gives successful results is to install a low inertia turbine flowmeter in the circuit, preferably one with an enhanced pulse output frequency to give improved discrimination. The turbine meter shall have an inherent stability better than the anticipated flowrate stability of the system.

Flowrate stability can be assessed either within the integration (or diversion) interval or between integration intervals. Different techniques are involved for the two applications, as detailed in 6.5.1 and 6.5.2.

6.5.1 Flowrate stability within the integration interval

A suitable turbine meter with frequency or pulse output is installed in the circuit to assess the flowrate stability within the integration interval. Alternatively, a different type of meter may be used provided that it has good short-term stability, reasonably fast response characteristics, and an output suitable for recording or reading over short intervals of time. The flowrate stability shall be determined at a number of flowrates over the operating range of the system.

Once the flowrate has stabilized, the diverter shall be actuated to start the chronometer. When the flowmeter output signal is representative of a flowrate, the signal shall be recorded at least once per second; 60 such recordings shall be taken over the integration interval.

This procedure shall be repeated at the other selected flowrates. The results obtained shall be analysed according to the method given in annex C, where a worked example is presented.

6.5.2 Flowrate stability between integration intervals

For certain applications, it may be necessary to determine the longer-term flowrate stability, in which case different techniques are required. A meter with a medium-term stability better than that expected for the system shall be installed in the test section. A good quality turbine meter or an electromagnetic flowmeter with good zero stability is suitable. The procedure is described in annex D, which also includes a worked example.

6.5.3 Application of flowrate stability assessments

The derived value for S_5 (the relative standard deviation of the random error component, as detailed in annex C) should only be used as a guide in assessing the overall random uncertainty of the system. For example, if the weighing method is used for calibrating flowmeters, then the contribution of the S_5 value to the overall random uncertainty depends on the type of flowmeter being calibrated and the method used for measuring its mean output over the weightank filling time.

If a turbine meter is being calibrated using the total number of pulses to integrate the flowrate, then the contribution of flowrate instability to the total measurement error may be considered to be negligible. Conversely, a differential pressure primary flow device with its output read as a single instantaneous reading may require the inclusion of the whole of the S_5 term.

The assessment of flowrate stability between integration intervals may be of interest for checking the long-term flowrate stability and for determining the effectiveness of any stabilizing devices in the system. It may be important if a stable flowrate is required over a long period of time such as for pump or water turbine testing.

Thus the necessity or not of taking into account any errors due to instability of the flowrate will depend on the device under test or the purpose of the installation.

Where flowrate instability is likely to affect seriously flowrate measurements, the analysis of errors shall include its effects.

6.6 Study of flow characteristics

If a weighing system is used for calibrating flowmeters it may be of importance to know the characteristics of the flow through the calibration test line.

Annex E gives details of various techniques for measuring the required flow characteristics.

7 Calculation of the overall uncertainty

The systematic and random components of uncertainty shall be determined in accordance with the procedures in clause 6 and annexes A to D of this part of ISO 9368.

Whenever possible, systematic errors shall be corrected before subsequent measurements are made. Any remaining systematic uncertainties shall be evaluated as described in ISO 4185 : 1980, subclause 6.2.1 and annex C.

The relative systematic uncertainty E_S is given by

$$E_S = (E_{S_1}^2 + E_{S_2}^2 + E_{S_3}^2 + E_{S_4}^2)^{1/2}$$

where

E_{S_1} is the relative systematic uncertainty of the weighing device (see 6.1 and annex A);

E_{S_2} is the relative systematic uncertainty of the diverter operation (see 6.2 and annex B);

E_{S_3} is the relative systematic uncertainty of the diverter leakage (see 6.2 and annex B);

E_{S_4} is the relative systematic uncertainty of the density determination (see 6.4).

It should be noted that E_{S_4} is only taken into consideration if the volume flowrate rather than the mass flowrate is being measured.

The relative random uncertainty E_R is given by

$$E_R = t^* (S_1^2 + S_2^2 + S_3^2 + S_4^2)^{1/2}$$

where

S_1 is the relative standard deviation of the random error of the weighing device (see 6.1 and annex A);

S_2 is the relative standard deviation of the random error of the diverter operation (see 6.2 and annex B);

S_3 is the relative standard deviation of the random error of the diverter leakage (see 6.2 and annex B);

S_4 is the relative standard deviation of the random error of the density determination (see 6.4);

t^* is Student's variable, given in table 2, for the appropriate number of degrees of freedom.

If the flowrate instability is liable to affect the test results, it may be necessary to take into account S_5 and possibly S_6 (see 6.5, and annexes C and D).

The overall uncertainties in the flowrate measurement should be quoted as two separate values:

— random uncertainty, E_R

— systematic uncertainty, E_S

Table 2 — Student's t^* distribution for various degrees of freedom and 95 % confidence level

Degrees of freedom	t^*_{95}
1	12,706
2	4,303
3	3,182
4	2,776
5	2,571
6	2,447
7	2,365
10	2,228
15	2,131
20	2,086
30	2,042
60	2,000
∞	1,960

Alternatively, the overall uncertainty can be expressed as a combination of uncertainties:

$$E = (E_R^2 + E_S^2)^{1/2}$$

where the random uncertainty has 95 % probability. The overall random uncertainty $(E_R)_{95}$ shall then be quoted separately, in accordance with the requirements of ISO 5168.

Annex A
(normative)

Estimation of systematic and random errors introduced by the weighing device

The most commonly used direct weighing system is the steelyard. ISO 4185 gives a method for determining the systematic and random errors of this type of weighing machine. The following method is an alternative technique which also covers other direct weighing systems.

A.1 Experimental procedure

The weighing device is successively loaded with standard test weights, then unloaded. The error values are determined at every loading and unloading at not less than 10 uniformly distributed load values beginning from zero up to the maximum load value (the maximum load value is equal to the difference between the maximum weighing limit of the weighing machine and the mass of the unloaded measuring tank).

Error values are determined from

$$\Delta m_i = R_{mi} - (m + \bar{R}_o) \qquad \ldots (1)$$

where

Δm_i is the error of the ith measurement at load $(m + \bar{R}_o)$;

R_{mi} is the reading of the weighing device at the ith measurement of standard weights of mass m;

m is the mass of the standard weights;

$\bar{R}_o$ is the mean of the R_{oi} values obtained, where R_{oi} is the reading of the weighing device at the ith measurement of the empty measuring tank.

A.2 Estimation of the uncertainty of a mass measurement carried out by double weighing

The arithmetical mean error value $\overline{\Delta m}$ and the standard deviation $s_{\Delta m}$ of the weighing device error are calculated for every load from

$$\overline{\Delta m} = \frac{1}{n} \sum_{i=1}^{n} \Delta m_i \qquad \ldots (2)$$

$$s_{\Delta m} = \left[\frac{\sum_{i=1}^{n} (\Delta m_i - \overline{\Delta m})^2}{(n-1)} \right]^{1/2} \qquad \ldots (3)$$

where n is typically 5 for values at maximum loading and with an empty measuring tank, and 10 for other load values.

The resulting values of $\overline{\Delta m}$ and $s_{\Delta m}$ for the expression $(m + \bar{R}_o)$ are used subsequently with interpolation. When the highest accuracy is required for the relationships between $\overline{\Delta m}$ and $(m + \bar{R}_o)$, and $s_{\Delta m}$ and $(m + \bar{R}_o)$, it is recommended that equations be calculated using the least squares method.

As the fluid mass M, collected in the tank (or discharged from the tank), is expressed by the difference between two weighings then

$$M = R_1 - R_2 \qquad \ldots (4)$$

where R_1 and R_2 are the readings of the weighing device.

Therefore the systematic error in the fluid mass determination is equal to $\overline{\Delta m_1} - \overline{\Delta m_2}$, where $\overline{\Delta m_1}$ and $\overline{\Delta m_2}$ are the values of $\overline{\Delta m}$ corresponding to R_1 and R_2. Subsequent weighing measurements shall be corrected by $(\overline{\Delta m_1} - \overline{\Delta m_2})$ to take account of the average systematic errors derived above.

The remaining systematic uncertainty during a subsequent measurement is due to the random component of the systematic error observed during the calibration procedure plus any uncertainty in the masses of the standard weights. When the uncertainty in the masses of the standard weights may be neglected, as is often the case, the systematic uncertainty in a single mass measurement is given by

$$e_S = t^* / \sqrt{n} \left(s^2_{\Delta m_1} + s^2_{\Delta m_2} \right)^{1/2} \qquad \ldots (5)$$

where

$s_{\Delta m_1}$ and $s_{\Delta m_2}$ are values of $s_{\Delta m}$ corresponding to R_1 and R_2;

t^* is Student's t for $n - 1$ degrees of freedom.

The standard deviation, s, of the random error in a single fluid mass measurement, M, may be assumed to be equal to the standard deviation of the readings at the same load during the calibration procedure:

$$s = \left(s^2_{\Delta m_1} + s^2_{\Delta m_2} \right)^{1/2} \qquad \ldots (6)$$

The relative values of the systematic uncertainty E_{S_1} and the standard deviation S_1 of the random error are obtained as follows:

$$E_{S_1} = \frac{e_S}{M} \qquad \ldots (7)$$

$$S_1 = \frac{s}{M} \qquad \ldots (8)$$

A.3 Worked example

A weighing device with a tare of 1 100 kg was tested with ten 1 000 kg weights over five loading and unloading cycles; the results obtained are shown in table A.2.

The values of $s_{\Delta m}$ as a function of $(m + \bar{R}_o)$ are obtained from equation (3) and are given in table A.1.

Table A.1 — Values of $s_{\Delta m}$ as a function of $(m + \bar{R}_o)$

$(m + \bar{R}_o)$ kg	$s_{\Delta m}$ kg
2 100	2,6
3 100	3,6
4 100	1,9
5 100	3,0
6 100	3,7
7 100	3,9
8 100	3,6
9 100	3,3
10 100	3,9
11 100	3,6

Assuming that the following weighing data were obtained

$R_1 = 8\,620$ kg

$R_2 = 3\,235$ kg

then

$M = 8\,620 - 3\,235 = 5\,385$ kg

Using interpolation for values of $\overline{\Delta m_1}$, $\overline{\Delta m_2}$, $s_{\Delta m_1}$ and $s_{\Delta m_2}$ corresponding to R_1 and R_2, the following results are obtained:

$$\overline{\Delta m_1} = 0,6 + \frac{1,2 - 0,6}{9\,100 - 8\,100} \times (8\,620 - 8\,100) \approx 0,9 \text{ kg}$$

$$\overline{\Delta m_2} = 3,1 + \frac{0,3 - 3,1}{4\,100 - 3\,100} \times (3\,235 - 3\,100) \approx 2,7 \text{ kg}$$

$$s_{\Delta m_1} = 3,6 + \frac{3,3 - 3,6}{9\,100 - 8\,100} \times (8\,620 - 8\,100) \approx 3,4 \text{ kg}$$

$$s_{\Delta m_2} = 3,6 + \frac{1,9 - 3,6}{4\,100 - 3\,100} \times (3\,235 - 3\,100) \approx 3,4 \text{ kg}$$

Correction to be applied to the fluid mass measurement:

$$-(0,9 - 2,7) = +1,8 \text{ kg}$$

Systematic uncertainty:

$$e_S = \frac{2,262}{\sqrt{10}} (3,4^2 + 3,4^2)^{1/2} = 3,4 \text{ kg}$$

(the error in the mass of the standard weights is taken as negligible), i.e.

$$E_{S_1} = \frac{3,4}{5\,386,8} = 0,000\,6 \text{ or } 0,06 \,\%$$

Standard deviation of the random error:

$$s = (3,4^2 + 3,4^2)^{1/2} = 4,8 \text{ kg}$$

i.e.

$$S_1 = \frac{4,8}{5\,386,8} = 0,000\,9 \text{ or } 0,09 \,\%$$