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testing for gas flowmeter**

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Contents

	Page
Introduction.....	1
1 Scope.....	1
2 Normative references	1
3 Terms and definitions	2
4 Equipment used for calibration and testing and its configuration	5
4.1 Configuration of test apparatus	5
4.2 Supplying system of test gas	6
4.3 Test apparatus	7
5 Method of calibration and testing	8
5.1 Calibration condition and testing condition	8
5.2 Calculation method of density of gas	12
5.3 Calculation method of deviation (instrumental error)	13
5.4 Calculation method of uncertainty factor	16
6 Calculation of uncertainty of correction factor of device under test and calculation of deviation (instrumental error) of flow rate	19
6.1 General	19
6.2 In the case of wet gas meter	21
6.3 In the case of flowmeter having pulsed output	23
6.4 In the case of critical flow nozzle (sonic nozzle)	25
6.5 In the case of restriction flowmeter	28
6.6 In the case of piston prover	31
6.7 In the case of bell prover	34
6.8 In the case of having voltage output and current output	36
6.9 When calibration and testing are performed based on visual observation	38
6.10 When calibration flow rate and testing flow rate are expanded using two or more reference standard flowmeters	41
6.11 In the case of calibration and testing with dry air and gases other than humid air	43
7 Report of results	44
7.1 In the case of calibration	44
7.2 In the case of testing	44
Annex A (informative) Budget table for uncertainty calculation of correction factor of device under test	45
Annex B (informative) Precautions when using a critical flow nozzle (sonic nozzle)	70

Annex C (informative)	Relation between correction factor of flowmeter and Reynolds number	73
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Foreword

This translation has been made based on the original Japanese Industrial Standard revised by the Minister of Economy, Trade and Industry, through deliberations at the Japanese Industrial Standards Committee as the result of proposal for revision of Japanese Industrial Standard submitted by Japan Measuring Instruments Federation (JMIF)/Japanese Standards Association (JSA) with the draft being attached, based on the provision of Article 12 Clause 1 of the Industrial Standardization Law applicable to the case of revision by the provision of Article 14.

Consequently **JIS B 7556**:2003 is replaced with this Standard.

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Procedures of calibration and testing for gas flowmeter

Introduction

This Japanese Industrial Standard aims to secure the reliability of a calibration result and a testing result also internationally by specifying the procedures of calibration and testing and the calculation method of uncertainty and deviation for a gas flowmeter.

1 Scope

This Standard specifies the procedures of calibration and testing and the calculation method of uncertainty and deviation for a gas flowmeter using the flowmeter (reference standard flowmeter) with ensured traceability as a reference standard.

The calibration and testing shall be performed under the environmental conditions of atmospheric pressure, normal temperature and normal humidity. Furthermore, a test gas shall be air with dry state at normal temperature and normal humidity.

In addition, this Standard does not specify the flow rate range in which calibration and test are performed and the pressure of the gas which flows into a device under test. Furthermore, when the pressure of the test gas supplied to the reference standard flowmeter exceeds the pressure described in a calibration certificate, this Standard does not apply.

NOTE 1 The flowmeter with ensured traceability refers to either of the following. In any case, the uncertainty of calibration is evaluated appropriately.

- a) The flowmeter with the calibration certificate published by the public institution or the JCSS calibration laboratories except the reference gas meter and the reference volume pipe which passed the reference equipment inspection based on the Measurement Law.
- b) The flowmeter calibrated based on this Standard using the above-mentioned flowmeter as the reference flowmeter.

NOTE 2 The gas flowmeter refers to the flowmeter for measuring the mass flow rate, volume flow rate or integrated volume of the gas flowing in pipelines and includes the flowmeters based on all the measurement principles in this Standard.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. The most recent editions of the standards (including amendments) indicated below shall be applied.

JIS Z 8103 *Glossary of terms used in measurement*

JIS Z 8762-1 *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full—Part 1: General principles and requirements*

- JIS Z 8762-2 *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full—Part 2: Orifice plates*
- JIS Z 8762-3 *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full—Part 3: Nozzles and Venturi nozzles*
- JIS Z 8762-4 *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full—Part 4: Venturi tubes*

3 Terms and definitions

For the purpose of this Standard, the terms and definitions given in **JIS Z 8103** and **VIM** and the following apply.

3.1 deviation

value expressed as a percentage (%) calculated by subtracting the indication value of a reference standard flowmeter from the indication value of a device under test and dividing the result by the indication value of the reference standard flowmeter

NOTE : In the edition published in 2003 (previous edition) of this Standard, the term “deviation” was not given. Instead, the term “instrumental error” was given and defined to be “the percentage calculated by subtracting the real quantity from the indication quantity of the equipment under test and dividing the result by the real quantity”. Since in International Vocabulary of basic and general terms in Metrology/VIM, the term “deviation” is given with the same definition as above but the term “instrumental error” is not given, in this Standard, the term adopted will be “deviation”, but attached with the term from the previous edition so as to read “deviation (instrumental error)”, where appropriate, in order to avoid the confusion.

3.2 uncertainty

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

It is an index which shows how reliable the measurement result is and also proves that traceability is securable.

3.3 traceability

property of the measurement result or the value of standard that can be related to a certain standard specified normally by National Standard or International Standard through an unbroken chain in which all of uncertainty is expressed

3.4 JCSS (Japan Calibration Service System)

calibration entrepreneur registration (accreditation) system based on the Measurement Law

The calibration here refers to the action which proves a connection to measurement hardware (traceability of measurement) by National Standard or by the chain of comparison with National Standard.

3.5 calibration

work to determine a correction factor newly in order to relate the flow rate of a reference standard flowmeter with the value which a device under test indicates

3.6 testing

work to determine how much deviation (instrumental error) exists between the flow rate of a reference standard flowmeter and the value which a device under test indicates, in which the deviation (instrumental error) can be corrected or not corrected

In the case where deviation is not corrected, it refers to the work to judge whether it is within a tolerance or not.

3.7 flow rate

In order to clarify the term “flow rate” in consideration of the characteristics of a measuring instrument called a flowmeter, it is used as follows.

- flow rate which a flowmeter indicates (or simply indication value): value before correction obtained by a flowmeter or indication value which a flowmeter indicates
- flow rate of a flowmeter: flow rate obtained by converting the flow rate which a flowmeter indicates into a certain state, etc.

3.8 reference standard flowmeter

flowmeter which is used as the reference standard which gives the standard value of flow rate in calibration and testing and equipped with the calibration certificate or the test report which clearly states the uncertainty of flow rate in calibration and testing

3.9 device under test

flowmeter targeted for calibration and testing, which is a measuring instrument giving a flow rate or a quantity related to it

3.10 mass flow rate

quantity of fluid moving per unit time expressed in mass

The volume of gas, even if the gas is of the same kind and mass, when the temperature or pressure of gas differs, the volume of gas at that time differs. Therefore, the value of mass flow rate can be indicated using the volume flow rate by specifying the conditions of gas (temperature and pressure). The volume flow rate indicated by specifying the conditions of gas in such a way is synonymous with mass flow rate.

3.11 volume flow rate

volume of gas flowing in pipelines per unit time

3.12 integrated volume

cumulative total value obtained by adding consecutively the volume of the passing fluid

3.13 standard condition

measurement condition used as a reference, which is specified in order to enable a comparison of the measurement results under different conditions as results under the same conditions

3.14 gas flow generator

device for generating the flow rate needed in test piping with a compressor, a vacuum pump, etc.

3.15 flow straightener

device for straightening the flow which is installed in the upstream side (inflow side) of a flowmeter in order to extinguish or decrease the swirl flow, drift and contraction of a fluid and lessen the adverse effect on characteristics of a flowmeter

There are a tubular type, a perforated-panel type, a Ben type, etc. as constructional examples.

3.16 flow rate regulator

instrument for regulating the flow rate of the flow in test piping

It has a function to regulate freely the flow rate of the flow in test piping and maintain it stably at a constant level by the ball valve, needle valve, etc. incorporated between the gas flow generator and the test apparatus.

3.17 pressure regulator

instrument for maintaining the pressure at a setting value given beforehand by suppressing the pressure fluctuation of test gas in pipelines in calibration and testing

3.18 temperature compensator for percent scale

mercury glass thermometer in which the temperature expansion correction factor of gas becomes 10 % at 27.3 °C when 0 °C is taken as a reference in the scale of a thermometer

3.19 correction coefficient

coefficient that relates the flow rate of a reference standard flowmeter to the indication value of a device under test, which is determined by calibration

3.20 discharge coefficient

ratio between the mass flow rate when actually passing through a critical flow nozzle (sonic nozzle) and the theoretical mass flow rate calculated from the condition of the throat part of a critical flow nozzle (sonic nozzle)

3.21 repeatability

dispersion of two or more flow rates obtained by fixing the conditions of calibration and testing and repeating measurements

In the case of a flowmeter, normally, the indication value fluctuates due to the effect of a flow field. Therefore, in this Standard, the average value of data obtained during measurement performed for a period of fixed time is taken as one measurement under that condition.

4 Equipment used for calibration and testing and its configuration

4.1 Configuration of test apparatus

The test apparatus consists of instruments such as a reference standard flowmeter, a gas flow generator, a device under test and piping connecting these, valves, and measuring instruments such as a thermometer, a hygrometer, a manometer, a barometer, and as necessary, a straightening part, a heat exchanger, etc. The material of piping used for connection shall not be deformed, and the shape of piping shall be such that resonance of piping is not generated by the flow and the flow does not stagnate.

4.1.1 Effect of straight pipe length

The piping which connects a reference standard flowmeter and a device under test requires the length which does not have the effect of the fluctuation of flow field by one flowmeter on that by another flowmeter. Since the drift, etc. of flow generated due to the measurement principle and structure directly affect the flow rate depending on the flowmeter, the velocity distribution is required to be uniform with respect to the piping cross section. For such a flowmeter, the recommended straight pipe length shall be secured for the upstream side and the downstream side of a flowmeter, respectively. When the straight pipe length is specified in other standards such as **JIS**, they shall be followed. Also in the cases other than that, the sufficient straight pipe length which does not have the effect of the flow field in the upstream side and the downstream side on the flow rate measurement shall be secured. When the sufficient straight pipe length cannot be secured, the flow field which flows into a flowmeter shall be made as uniform as possible using a straightening pipe, etc.

NOTE 1 Scientifically, for the straight pipe length needed to remove the strain of a flow field, the numbers of $50d$ and $100d$ are given, taking the piping inside diameter as d . Although they are required for the special apparatus specified in National Standard, etc., they are not actually significant.

NOTE 2 When the straight pipe length is not sufficient, since there may be a possibility that the effect of the flow field which flows into a flowmeter remains strong, the indication may not be right depending on the kind of flowmeter.

4.1.2 Effect of mounting posture of flowmeter

For the flowmeter in which gravity is related to the measurement of a flow rate, the mounting posture is restricted. Furthermore, also for the manometer, etc., since they are affected by gravity depending on the structure subjected to pressure, the mounting posture is restricted. Therefore, the test apparatus, including piping, a layout, etc. before and behind a reference standard flowmeter, shall be configured so that the stationary state of a flow field is maintainable and it is easy to exchange a device under test and it can be mounted with good reproducibility.

4.1.3 Mounting position of manometer, thermometer and hygrometer

Generally, the manometer and thermometer shall be mounted on the upstream piping of a standard flowmeter or a device under test. However, since the thermometer has a possibility of disturbing the flow, when turbulence of the flow affects the

flow rate of a flowmeter, they may be mounted on the downstream side of the flowmeter. When humidity is measured by inserting a hygrometer into the inside of piping, care shall be taken so that the sensor part does not form dew. In either case, when it is difficult to judge where to mount, the standard or the operation manual of each flowmeter shall be followed.

4.1.4 Mounting position of gas flow generator

A gas flow generator shall be used by connecting it to the most upstream side of a test apparatus when a test gas is supplied to the test apparatus using a blower, etc. and by connecting it to the most downstream side of the test apparatus when the test gas is sucked into the test apparatus by a suction pump, a vacuum pump, etc.

4.1.5 Effect of pipeline between reference standard flowmeter and device under test

The state of the flow in a reference standard flowmeter and a device under test mounted to a test apparatus is not the same, but always fluctuates. When the effect of fluctuation of a test gas which flows through the test apparatus is large, uncertainty may become large due to disagreement between the fluctuation of the flow which flows through the reference standard flowmeter and that of the flow which flows through the device under test. Therefore, unless two flowmeters affect each other, it is necessary to make the excessive piping length and the portion in which the flow stagnates, so-called dead space, as small as possible.

4.2 Supplying system of test gas

4.2.1 Push-in system

This system is the method of installing a blower, a compressor, a compressed-gas cylinder, etc. as a gas flow generator on the upper part of a test apparatus (see figure 1). Although this system is available for testing of all the flowmeters and used in general, it is easily affected by the pulsation from the gas flow generator. Furthermore, for this system, the temperature of test gas easily changes (rises). The test gas is supplied to the test apparatus through the pressure regulator for adjusting the pressure of test gas and the flow regulating valve for adjusting the flow rate, installed between the gas flow generator and the test apparatus. When the supplied test gas cannot obtain stability due to each factor such as the performance of the flow regulating valve in the piping system, or the test flow rate, a buffer tank should be provided between the flow regulating valve and the reference standard flowmeter.

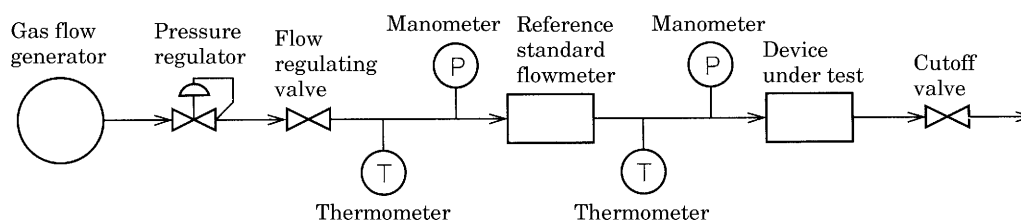


Figure 1 Supply method of test gas (push-in system)

4.2.2 Suction system

This system is the method in which a suction pump or a vacuum pump is used as a gas flow generator, and the pulsation, etc. of the gas flow generator are easily suppressed and the stabilized flow can be made by preparing a flow regulating valve between the gas flow generator and the test apparatus. This system is used for calibration and testing near at the atmospheric pressure. Furthermore, in this system, the temperature of test gas does not easily change. In this system, the downstream side of the device under test may be in a negative pressure state. This can be avoided by using the flow regulating valve, as shown in figure 2, which will ease the negative pressure state of the downstream side of the device under test.

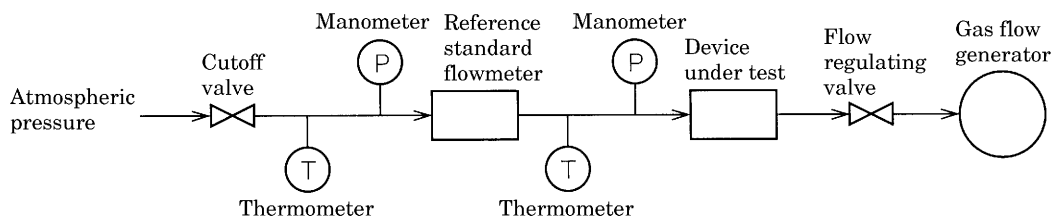


Figure 2 Supply method of test gas (suction system)

4.3 Test apparatus

4.3.1 Gas flow generator

A gas flow generator is a device which generates a flow rate in a test apparatus so as to enable it to generate stably a flow rate as steady as possible with a blower, a suction pump, a vacuum pump, etc. Furthermore, like a compressor, etc., when the gas flow generator is connected to the upstream side of the test apparatus, it is necessary to figure out a good way to make the temperature rise of the test gas by continuous running as small as possible.

4.3.2 Reference standard flowmeter

If the conditions in 3.8 are satisfied, any flowmeter can be used as a reference standard flowmeter.

4.3.3 Flow regulating valve

A flow regulating valve is for regulating the flow rate which flows through test piping, and it has the mechanism which is capable of regulating arbitrarily the flow rate which flows through test piping by incorporating a ball valve, a needle valve, etc. between the gas flow generator and the test apparatus to keep the flow rate stable and constant.

4.3.4 Pressure regulator

A pressure regulator is an instrument for maintaining at a predetermined setting value by suppressing the pressure fluctuation of a test gas in pipelines in calibration and testing. Furthermore, when the stability of pressure is not obtained by the ratio of supply pressure and working pressure or when the pressure is affected by the pulsation of a gas flow generator, the pressure is made to be in a stable state by using a buffer tank having sufficient capacity to a test flow rate between the gas flow generator and the test apparatus.

4.3.5 Thermometer

Although, for the thermometer used for calculation of the flow rate of a reference standard flowmeter and a device under test, the thermometer with ensured traceability calibrated by the JCSS calibration laboratories, etc. should be used, the thermometer of which the uncertainty is evaluated by performing calibration compared with the thermometer with ensured traceability may be used.

When the flow rate obtained by calibration and testing is corrected using a thermometer intended for environmental measurement, the thermometer used shall have an ensured traceability and clear uncertainty. However, if that value of flow rate is used and the correction of the flow rate is not performed, it is not necessary to use such a thermometer.

Since traceability is not ensured for the temperature compensator for percent scale which has been conventionally used and expresses the quantity of correction of flow rate as a percent from the indication value of temperature, uncertainty cannot be calculated. Therefore, when the temperature compensator for percent scale is used, the thermometer of which the traceability is ensured and uncertainty can be calculated shall be used simultaneously.

4.3.6 Manometer

The manometer to be installed in the upstream side of a reference standard flowmeter and the device under test, used for calculation of flow rate should be a manometer with ensured traceability calibrated by the JCSS calibration laboratory, etc. However, a manometer of which the uncertainty is evaluated by performing comparison calibration with the manometer with ensured traceability may also be used. The manometer may be an absolute pressure gauge, or may be a pressure gauge, and shall be selected according to the configuration of the test apparatus. Furthermore, a differential pressure gauge which obtains the differential pressure before and behind each of the reference standard flowmeter and the device under test, or the difference with atmospheric pressure may be used.

4.3.7 Barometer

Traceability need not be ensured when a barometer is used to specify the environmental condition and the value of the barometer is not used for correction of the flow rate. However, when the flow rate is corrected using the value, the barometer shall have the ensured traceability.

4.3.8 Hygrometer

Traceability need not be ensured when a hygrometer is used to specify the environmental condition and the value of the hygrometer is not used for correction of the flow rate. However, when the effect of the partial water vapour pressure of flow rate is calculated using the value, the hygrometer calibrated by the JCSS calibration laboratory, etc. of which the traceability is ensured and the uncertainty is clear shall be used.

5 Method of calibration and testing

5.1 Calibration condition and testing condition

The test apparatus and the handling of a reference standard flowmeter and a device under test in calibration and testing shall be as follows.

a) **Mounting method of reference standard flowmeter and device under test** When the mounting posture is indicated in the reference standard flowmeter and the device under test used as a reference, the test shall be performed according to the indicated mounting posture. However, when the mounting posture of the device under test has not the effect on the calibration result, testing may be performed by the mounting posture made suitable for the test apparatus. Furthermore, for the flowmeter with a rotary vane, since it is easily affected by swirl flow, it is necessary to prepare a straightening part as required before and behind it. Furthermore, since there are some flowmeters in which the flow direction is specified, that instruction shall be followed.

b) **Inspection of airtightness** The reference standard flowmeter, device under test and piping part mounted for calibration and testing shall maintain the airtightness evaluated beforehand with respect to test pressure. Although the inspection may be performed under either the reduced pressure condition or the pressurized condition, it shall be performed under the condition near that of the actual calibration and testing.

NOTE 1 In the airtightness test, since the effect of temperature fluctuation on pressure change is large, it is necessary to perform temperature control appropriately.

c) **Running-in** In order to stabilize the testing condition, running-in shall be performed until the temperature of a pipeline and a flowmeter reach equilibrium sufficiently by making the test gas flow at a flow rate near the maximum flow rate of the device under test (use the maximum flow rate of the reference standard flowmeter, if it is equal to or greater than that of the device under test), and for the flowmeter with a mechanical mechanism, until the mechanical mechanism conforms to the flow sufficiently.

NOTE 2 Since the time required for running-in differs according to the configuration of the test apparatus, the environmental condition and the kind of the device under test, it should be determined in consideration of the conditions of calibration and testing.

NOTE 3 When the time for running-in is not sufficient, since the indicated value of the flowmeter may change slowly during calibration and testing, there may be a possibility that the precise calibration and testing are not performed.

NOTE 4 In the case of the flowmeter with a mechanical mechanism, in order to obtain a result with sufficient reproducibility, the running-in not only in the low flow rate region but also in the maximum flow rate region of the flowmeter should be performed.

d) **Test flow rate** For the flow rate of calibration and testing, calibration and testing shall be performed at least at two points between the use flow rates of the device under test. When the use flow rate range is wide, the number of points of calibration and testing shall be increased according to the range.

The number of points of calibration and testing to perform shall be determined depending on the characteristics of the flowmeter and the uncertainty to be obtained.

- e) **Number of times of measurement of calibration and testing** In calibration, the measurement shall be repeatedly performed more than once under the same condition with respect to one flow rate, and repeatability shall be checked.

In testing, the measurement shall be repeatedly performed and repeatability shall be checked when there is no known data on repeatability, except when the characteristics of the device under test are known.

NOTE 5 Although when measurement is performed only once in a testing, etc., for the evaluation of repeatability of the flowmeter, known data is adopted, in that case, the evaluation of repeatability of the flowmeter may become worse than that which is actually performed.

- f) **Measurement of temperature** For the temperature measurement of gas passing through the reference standard flowmeter and the device under test, recording shall be continuously performed during calibration and testing at the predetermined location of each flowmeter in one testing for one flow rate. When this cannot be performed, the values shall be monitored during measurement, and the average value obtained based on the maximum and the minimum of the indicated value shall be adopted.

For the temperature measurement, although any of a resistance thermometer, a thermoelectric thermometer, a liquid-in-glass thermometer, etc. may be used, thermometers which are capable of ensuring traceability and calculating uncertainty shall be used.

- g) **Measurement of humidity** For the humidity of gas, although the measured value obtained before and after one testing for one flow rate may be used, the average value of measured values obtained before and after it should be used. Although any measuring instrument of humidity may be used, measuring instruments which are capable of ensuring traceability and calculating uncertainty shall be used except when there is no need to correct the measurement result obtained by using the measured values.

- h) **Measurement of pressure** For the pressure measurement of gas passing through the reference standard flowmeter and the device under test, recording shall be continuously performed during calibration and testing at the predetermined location of each flowmeter in one testing for one flow rate. When this cannot be performed, the values shall be monitored during measurement, and the average value obtained based on the maximum and the minimum of the indicated value shall be adopted.

The manometer which can ensure traceability and calculate uncertainty shall be used.

- i) **Measurement of differential pressure** The differential pressure at the upstream side and the downstream side of the reference standard flowmeter and the device under test shall be measured as necessary.

When these measured values are used as the testing result of the flowmeter, the flowmeter which can ensure traceability and calculate uncertainty shall be used except when there is no need to correct the measurement result obtained by using those values.

NOTE 6 The relation between the flow rate and the differential pressure of the gas flowmeter is useful in determining whether the operational condition is normal or not. This relation should be measured during testing.

- j) **Environmental condition under execution of calibration and testing** The degree of the effects of the environmental conditions (temperature, humidity and atmospheric pressure) of the location in which the test apparatus is installed on the calibration result and the testing result of the device under test shall be grasped and the control limits of the environmental conditions in calibration and testing shall be determined. The environmental conditions in calibration and testing shall be recorded and the result shall be described in the calibration certificate and the test report.

NOTE 7 It is important for confirming the reproducibility of calibration and testing to grasp the degree of the effects of the change in time of the environmental conditions (temperature, humidity and atmospheric pressure) on the calibration result and the testing result of the device under test and to determine the control limits of the environmental conditions in calibration and testing.

- k) **Check of pulsation in piping** Since a rotor type flowmeter, an eddy type flowmeter, an ultrasonic type flowmeter, etc. are subject to the effect of pulsating flow, the effect of the magnitude of pulsation of pressure generated in piping or the pulsation frequency on the device under test shall be evaluated beforehand. When the device under test is subject to the effect of pulsation, preventive measures shall be taken so that pulsation has no effect on the calibration result and the testing result.
- l) **Straightening device** It shall be checked that straightening is performed to such an extent that the velocity distribution in a pipeline does not affect the output of a flowmeter by giving each upstream straight pipe length of the reference standard flowmeter and the device under test sufficiently and if necessary by installing a straightening device.
- m) **Flow controller and pressure regulator** The installation location of a flow controller and a pressure regulator shall be selected so that it has a minimum effect on the reference standard flowmeter and the device under test.
- n) **Zero point check of manometer** The zero point check of a manometer which has an effect on the calibration result and the testing result shall be performed before measurement or as necessary.

NOTE 8 For the zero point of an absolute pressure gauge, the changed portion of the zero point should be corrected without performing the zero point adjustment.

NOTE 9 For the zero point of a pressure gauge and a differential pressure gauge, the zero point shall be checked in open atmospheric air, and the changed portion of the zero point shall be corrected, or the zero point shall be adjusted.

5.2 Calculation method of density of gas

5.2.1 General

In order to compare the volume flow rate or the integrated volume which a reference standard flowmeter and a device under test indicate, it is necessary to set them in the standard condition or the condition of any flowmeter. For that purpose, the value of density in each calibration condition and testing condition is required. The density of gas shall be calculated using the gas state equation from the measured values of pressure, temperature, and humidity.

When the value of density is required in this Standard, the formulae given in 5.2.2 and 5.2.3 shall be used.

5.2.2 In the case of air containing moisture

The density of humid air ρ_{wet} (unit: kg/m³) shall be calculated as follows using pressure P (unit: Pa), temperature T (unit: K) and relative humidity H (unit: %).

The molar fraction of water vapour χ shall be calculated according to the formula (1).

$$\chi = \frac{H}{100} \times f \times \frac{P_{\text{sv}}}{P} \dots\dots\dots (1)$$

where, f : partial pressure coefficient

$$f = 1.00062 + 3.14 \times 10^{-8} \times P + 5.6 \times 10^{-7} \times (T - 273.15)^2 \dots\dots\dots (2)$$

P_{sv} : saturated vapour pressure (unit: Pa)

$$\ln(P_{\text{sv}}) = 1.2811805 \times 10^{-5} \times T^2 - 0.019509874 \times T + 34.04926034 - \frac{6353.6311}{T} \dots\dots\dots (3)$$

The molar mass of air containing moisture $N_{\text{g wet}}$ using the molar fraction χ obtained by substituting the value calculated from the formulae (2) and (3) into the formula (1) shall be as follows.

$$N_{\text{g wet}} = N_{\text{g dry}} \times (1 - \chi) + N_{\text{g vap}} \times \chi \dots\dots\dots (4)$$

where, $N_{\text{g dry}}$: molar mass of dry air 0.0289634 (kg/mol)

$N_{\text{g vap}}$: molar mass of saturated vapour 0.018015 (kg/mol)

The density of humid air shall be calculated from the gas state equation using the formula (4) according to the formula (5).

$$\rho_{\text{wet}} = \frac{N_{\text{g wet}} \times P}{R \times T} \dots\dots\dots (5)$$

where, R : universal gas constant 8.31451 (J/K/mol)

The standard uncertainty $u(\rho_{\text{wet}})$ of ρ_{wet} shall be calculated according to the formula (6).

$$u(\rho_{\text{wet}}) = \sqrt{\left(\frac{N_{\text{g wet}} \times u(P)}{R \times T}\right)^2 + \left(\frac{N_{\text{g wet}} \times P \times u(T)}{R \times T^2}\right)^2} \dots\dots\dots (6)$$

Since the uncertainty of $N_{\text{g wet}}$ and P_{sv} is small enough here, it is not taken into consideration here. Furthermore, $u(P)$ and $u(T)$ are the standard uncertainty of the measured value of pressure and temperature, respectively.

5.2.3 In the case of dry air

Since the density of dry air ρ_{dry} (unit: kg/m³) is relative humidity $H=0$ (%), it is $\chi=0$. Therefore, the formula (5) is expressed by the formula (7).

$$\rho_{\text{dry}} = \frac{N_{\text{g dry}} \times P}{R \times T} \dots\dots\dots (7)$$

This uncertainty $u(\rho_{\text{dry}})$ shall be calculated according to the formula (8).

$$u(\rho_{\text{dry}}) = \sqrt{\left(\frac{N_{\text{g dry}} \times u(P)}{R \times T}\right)^2 + \left(\frac{N_{\text{g dry}} \times P \times u(T)}{R \times T^2}\right)^2} \dots\dots\dots (8)$$

NOTE 1 The formulae (7) and (8) are those in the special case of the formulae (5) and (6), respectively.

NOTE 2 Under the general condition in this Standard of $P=300$ (kPa), $T=298.15$ (K) and $H=50$ (%), when χ = approximately 0.03 is given, $u(\chi)$ = approximately 0.000 5 is obtained. Therefore, the uncertainty obtained by the humidity correction of $N_{\text{g wet}}$ is negligible since it is small enough.

NOTE 3 Since the saturated vapour pressure P_{sv} calculated under the condition of NOTE 2 is approximately 2 (kPa), the uncertainty $u(P_{\text{sv}})$ in that case is approximately 0.2 (kPa), which is small enough compared with the pressure measurement condition of 300 kPa and the contribution of P_{sv} to the uncertainty of density is small enough, the uncertainty $u(P_{\text{sv}})$ is negligible.

NOTE 4 The gas state equation is an equation which gives the relation between the density of gas and the pressure and temperature, which is given in the form of the formulae (5) and (7) in this Standard.

5.3 Calculation method of deviation (instrumental error)

5.3.1 In the case where flow rate is volume flow rate or integrated volume (calculation method by density correction)

The calculation method of deviation (instrumental error) can be used under any condition to which this Standard is applied. When the flow rate which a reference standard flowmeter indicates and the flow rate which a device under test indicates are volume flow rate or integrated volume, in order to calculate deviation (instrumental error), it is necessary to convert the flow rate which both flowmeters indicate into the flow rate in the same condition.

The density of gas in the state of the reference standard flowmeter is taken as ρ_{s} and the density of gas in the state of the device under test as ρ .

NOTE : The state of the device under test, the state of the reference standard flowmeter, etc. mean the state of the flow which flows into the device under test and the state of the flow which flows into the reference

standard flowmeter. The state of flow is determined by the values of pressure, temperature and humidity in that flow.

- a) **When set in the state of device under test** The integrated volume Q_{Sn} of the reference standard flowmeter in the state of the device under test shall be calculated according to the formula (9), taking the integrated volume which the device under test indicates as Q and the integrated volume which the reference standard flowmeter indicates as Q_S .

$$Q_{Sn} = Q_S \times \frac{\rho_S}{\rho} \dots\dots\dots (9)$$

At this time, the deviation (instrumental error) of the device under test shall be calculated according to the formula (10).

$$E = \frac{Q - Q_{Sn}}{Q_{Sn}} \times 100 (\%) \dots\dots\dots (10)$$

The volume flow rate Q_{vSn} of the reference standard flowmeter in the state of the device under test shall be calculated according to the formula (11), taking the volume flow rate which the device under test indicates as Q_V and the volume flow rate which the reference standard flowmeter indicates as Q_{VS} .

$$Q_{vSn} = Q_{VS} \times \frac{\rho_S}{\rho} \dots\dots\dots (11)$$

At this time, the deviation (instrumental error) of the device under test shall be calculated according to the formula (12).

$$E = \frac{Q_V - Q_{vSn}}{Q_{vSn}} \times 100 (\%) \dots\dots\dots (12)$$

- b) **When set in the state of reference standard flowmeter** The integrated volume Q_n of the device under test in the state of the reference standard flowmeter shall be calculated according to the formula (13), taking the integrated volume which the device under test indicates as Q and the integrated volume which the reference standard flowmeter indicates as Q_S .

$$Q_n = Q \times \frac{\rho}{\rho_S} \dots\dots\dots (13)$$

At this time, the deviation (instrumental error) of the device under test shall be calculated according to the formula (14).

$$E = \frac{Q_n - Q_S}{Q_S} \times 100 (\%) \dots\dots\dots (14)$$

The volume flow rate of the device under test Q_{vn} in the state of the reference standard flowmeter shall be calculated according to the formula (15), taking the volume flow rate which the device under test indicates as Q_V and the volume flow rate which the reference standard flowmeter indicates as Q_{VS} .

$$Q_{vn} = Q_V \times \frac{\rho}{\rho_S} \dots\dots\dots (15)$$

At this time, the deviation (instrumental error) of the device under test shall be calculated according to the formula (16).

$$E = \frac{Q_{vn} - Q_{vs}}{Q_{vs}} \times 100 (\%) \dots\dots\dots (16)$$

- c) **When output of reference standard flowmeter and device under test are set in the standard state** When the flow rate which the reference standard flowmeter and the device under test indicate is converted into that in a certain standard condition, the flow rate which both flowmeters indicate can be converted into the value in the standard state by substituting ρ in the formula (9) and ρ_s in the formula (11) into ρ_n , taking the density of the test gas in the standard state as ρ_n .

5.3.2 In the case where flow rate which flowmeter indicates is used as it is

Since this method used conventionally is a simple method, it is applicable to the calculation of deviation (instrumental error) at normal temperature and near at atmospheric pressure.

$$E = \frac{Q_v - Q_{vs}}{Q_{vs}} \times 100 + \frac{T_s - T}{2.73} + \frac{P - P_s}{1\,000} + \frac{P_{qs} - P_q}{1\,000} (\%) \dots\dots\dots (17)$$

where, Q_{vs} : flow rate of reference standard flowmeter

Q_v : flow rate which device under test indicates

P_s, T_s : upstream pressure and temperature of reference standard flowmeter (Pa), (K)

P, T : upstream pressure and temperature of device under test (Pa), (K)

P_{qs}, P_q : upstream water vapour pressure of device under test of reference standard flowmeter (Pa)

NOTE 1 Since it is assumed that the flow rate Q_{vs} of the reference standard flowmeter is the flow rate corrected using the correction factor, the deviation (instrumental error) of the reference standard flowmeter is zero. Therefore, the clause showing the deviation (instrumental error) of the reference standard flowmeter is not included in the formulae (10), (12), (14) and (16).

NOTE 2 Also in the case using the formula (17), if the flow rate Q_{vs} of the reference standard flowmeter of the 1st term uses the correction factor, it will be unnecessary to take the deviation (instrumental error) of the reference standard flowmeter into consideration as is the case with NOTE 1.

NOTE 3 When the flow rate Q_{vs} of the reference standard flowmeter is not corrected according to the formula (17), it is necessary to take the deviation (instrumental error) of the reference standard flowmeter into consideration. Usually, since the information for calculating deviation (instrumental error) is described in the calibration certificate, the deviation (instrumental error) shall be calculated based on them. Furthermore, when K factor or correction factor is only described and the deviation (instrumental error) as a flow rate is not described, it is necessary to

calculate the deviation (instrumental error) of the reference standard flowmeter based on the information on the calibration certificate again. In any case, it is necessary to add the obtained deviation (instrumental error) of the reference standard flowmeter to the result of the formula (17).

5.4 Calculation method of uncertainty factor

5.4.1 General

The factor and the calculation method of uncertainty of the flow rate which the device under test which is calibrated and tested indicates are largely dependent on the output form of the device under test. However, the measured values of pressure, temperature and humidity serve as a factor common to all.

Here, the view of the calculation method of the uncertainty on common items is shown.

5.4.2 Uncertainty of flow rate of reference standard flowmeter

As the uncertainty factor of the flow rate of a reference standard flowmeter, there are uncertainty described in the calibration certificate and dispersion of the indication value caused by change of a test gas. Furthermore, when a certain flow rate within the flow range described in the calibration certificate is used, the value interpolated from the flow rate described in the calibration certificate shall be used. Thus, when the value obtained by determining the interpolation function form with respect to two or more flow rates described in the calibration certificate is used, the difference between the flow rate described in the calibration certificate and the flow rate obtained from the interpolation function occurs. Although this is called residual, the standard deviation of this residual (square root of sum of squares of the difference of these) shall be calculated, and this value shall be added in the final calculation of the uncertainty of flow rate. Namely, when the expanded uncertainty (coverage factor k) of the reference standard flowmeter is taken as u_0 , the dispersion (standard deviation) of the indication value accompanied by change of flow as σ_1 and the standard deviation of the residual between the function form determined based on the value of the calibration certificate and the value described as σ_2 , the standard uncertainty of flow rate of the reference standard flowmeter u shall be calculated according to the formula (18).

$$u = \sqrt{\left(\frac{u_0}{k}\right)^2 + \sigma_1^2 + \sigma_2^2} \dots\dots\dots (18)$$

When the uncertainty described in the calibration certificate is used as it is, σ_2 of the 3rd term is unnecessary.

NOTE : When a polynomial is used as an interpolation function, although a residual becomes small by increasing the order, the order should not be increased until the function form becomes physically unnatural.

5.4.3 Uncertainty of value which device under test indicates

The uncertainty of the indication value of a device under test shall be calculated from the standard deviation of change of the indication value during calibration and testing. When the standard deviation cannot be calculated, the uncertainty of an indication value shall be calculated by using the following methods.

- a) **In the case of pulsed output** The minimum digit of the pulse obtained from a pulse counter shall be taken as uncertainty.
- b) **In the case of voltage output and current output** In the case of the digital output, the minimum digit of an indicated value shall be taken as uncertainty. When the voltage output and current output are measured using an external voltmeter and ammeter, these measuring instruments shall use those of which the traceability is ensured.
- c) **In the case of visual observation** When an indicated value like an analog output is obtained by visual observation, the minimum scale value of the object to observe visually shall be taken as uncertainty. When the indicated value fluctuates exceeding a minimum scale, the scale width which covers the range of fluctuation shall be taken as uncertainty.
- d) **In the case of time measurement** The minimum digit of measurement time obtained from timer equipment shall be taken as uncertainty.

5.4.4 Uncertainty of measured values of pressure, temperature, humidity, etc.

The factors of uncertainty of measurement of pressure, temperature, humidity, etc. when using a measuring instrument include the following two items.

- a) **Uncertainty of measurement which measuring instrument itself has** When the measuring instrument to be used has the calibration certificate, that value shall be used. When it has not the calibration certificate, $1/\sqrt{3}$ of the value described in a catalog, etc. shall be taken as the standard uncertainty of the measuring instrument. In this case, the traceability of the measuring instrument shall be able to be proved. Furthermore, when a certain guarantee period, points to be checked of reproducibility, etc. are described in a catalog, etc., the correction and periodic check shall be performed according to the description. Even when nothing is especially described with regard to these, the periodic check of values performed by a reliable method shall be required.
- b) **Effect of fluctuation of flow field at the time of calibration and testing** The effect of fluctuation of a flow field at the time of calibration and testing shall be evaluated as follows.
 - 1) The information on the upstream flow field during calibration and testing shall be recorded continuously, and that standard deviation shall be taken as fluctuation of a flow field.
 - 2) The maximum value and the minimum value of fluctuation of a flow field during calibration and testing shall be measured by visual observation, and the value obtained by multiplying the half width by $1/\sqrt{3}$ shall be taken as fluctuation of the flow field.

The standard uncertainty u of the measured value of pressure, temperature and humidity shall be given according to the formula (19), taking the expanded uncertainty (coverage factor k) of the measuring instrument to be used as u_0 and the uncertainty due to fluctuation of a flow field during measurement as σ .

$$u = \sqrt{\left(\frac{u_0}{k}\right)^2 + \sigma^2} \dots\dots\dots (19)$$

When the accuracy described in the catalog of the measuring instrument to be used is used as uncertainty, the formula (20) shall be used. Since a rectangle distribution is assumed here, $a = \sqrt{3}$ is applied.

$$u = \sqrt{\left(\frac{u_0}{a}\right)^2 + \sigma^2} \dots\dots\dots (20)$$

NOTE : The coverage factor k is usually $k=2$, which is equivalent to reliability 95 % in this case. Furthermore, in the formula (20), a is used in place of k since k is the divisor of probability distribution.

5.4.5 When repeat measurement is not performed

When the calibration of a device under test is performed, dispersion of the indication value in the repeat measurement of the device under test is an important factor in uncertainty evaluation. However, in the case of testing which examines the capability of the device under test instead of calibration, the repeat measurement [5.1 e)] need not be performed. In this case, for the repeatability of the device under test, the existing repeatability data of the same type shall be used as a representative value. However, when there is no repeatability data of the flowmeter of the same type, the repeat measurement shall be performed and repeatability shall be calculated.

5.4.6 Calculation method of uncertainty of deviation (instrumental error)

When deviation (instrumental error) is obtained, although the description of uncertainty in the report is not required, when the proof of traceability is requested from a client, it is necessary to calculate uncertainty to submit it. On that occasion, calculation shall be performed according to the following method.

- a) **Uncertainty of deviation (instrumental error) E** When the flow rate of a reference standard flowmeter is converted into the conditions of a device under test, deviation (instrumental error) E may be calculated according to the formula (10).

$$E = \frac{Q_V - Q_{VS_n}}{Q_{VS_n}} \times 100 (\%)$$

where, Q_V : flow rate which device under test indicates

Q_{VS_n} : flow rate when the flow rate of reference standard flowmeter is converted into the conditions of device under test

The standard uncertainty $u(E)$ of the deviation (instrumental error) E shall be calculated according to the formula (21).

$$u(E) = \sqrt{\left(\frac{u(Q_V)}{Q_{VS_n}}\right)^2 + \left(\frac{Q_V \times u(Q_{VS_n})}{Q_{VS_n}^2}\right)^2} \times 100 (\%) \dots\dots\dots (21)$$

where, $u(Q_V)$: standard uncertainty of flow rate which device under test indicates

$u(Q_{VSn})$: standard uncertainty of flow rate when flow rate of reference standard flowmeter is converted into the conditions of device under test

NOTE 1 It is also possible to calculate two or more E values by performing repeat measurement and take that standard deviation as uncertainty at that time, in which case, it is necessary to perform repeat measurement at least five times.

- b) **Uncertainty of flow rate Q_V which the device under test indicates in the case of correcting deviation (instrumental error) E** In calculation of deviation (instrumental error), since the flow rate of both the reference standard flowmeter and the device under test is used, both values of uncertainty are needed.

Standard uncertainty of flow rate of reference standard flowmeter u_c : formula (18) in 5.4.2

Standard uncertainty of indication value of device under test σ : see 5.4.3

The standard uncertainty u of the flow rate which the device under test indicates shall be calculated according to the formula (22).

$$u = \sqrt{u_c^2 + \sigma^2} \dots\dots\dots (22)$$

NOTE 2 The formula (22) is a general formula for calculating the standard uncertainty of the flow rate which the device under test indicates.

- c) **Uncertainty of flow rate Q_V which device under test indicates when deviation (instrumental error) E is not corrected** This is a case where the device under test is evaluated by judging whether deviation (instrumental error) E is within the predetermined tolerance or not. The standard uncertainty of the flow rate which the device under test indicates when deviation (instrumental error) E is within this tolerance $\pm b$ shall be calculated according to the formula (23).

$$u = \sqrt{u_c^2 + \sigma^2 + \left(\frac{b}{\sqrt{3}}\right)^2} \dots\dots\dots (23)$$

6 Calculation of uncertainty of correction factor of device under test and calculation of deviation (instrumental error) of flow rate

6.1 General

Precautions for performing calibration and testing of various flowmeters using a reference standard flowmeter and the calculation method of uncertainty and deviation (instrumental error) shall be as follows. For a device under test targeted for calibration and testing of which the output form is the same, uncertainty and deviation (instrumental error) can be calculated by the method which conforms to it.