Azbil Calibration Facility in Kyoto (ISO/IEC 17025)

-- JCSS, ISO/IEC 17025 Certification of Calibration System for Water Flowmeters --

Mr. Nobuyuki SUGIYAMA
Yamatake Corp.

Azbil Calibration Facility in Kyoto (ISO/IEC 17025)

JCSS, ISO/IEC 17025 Certification of Calibration System for Water Flowmeters

Summary:

Calibration facilities for water flowmeters consist of various measuring instruments, pipings, etc. The performance of calibration facility is determined by the sum of its uncertainties, as calculated based on factors such as the environmental sensitivity of each instrument. This paper describes our calibration facilities for water flowmeters, and the results of our collaborative research with the National Metrology Institute of Japan (hereinafter, "NMIJ"), which was undertaken to evaluate the uncertainty of our facility compared with that of NMIJ in advance of our application for ISO/IEC 17025 compliant JCSS certification as a calibration business. In addition, we describe how we calculate the uncertainty of our calibration system and how uncertainty is incorporated into the declaration of an instrument's conformity to standards.

1. Introduction

A water flowmeter calibration system consists of various types of measuring instruments and piping. In order to adjust/calibrate (i.e., assign values to) a flowmeter with a high degree of accuracy, it is essential to consider uncertainties as well as traceability and accuracy. This is because the reliability of the flowmeter calibration depends upon the sum of the respective uncertainties attributed to the measuring instruments and fluid used for calibration. Now that Yamatake has been registered as a JCSS-certified (Japan Calibration Service System) business operator as prescribed in the Measurement Act, we can demonstrate the permissible degree of uncertainty relative to the uncertainty of the specified standard maintained by NMIJ for ensuring the traceability of Yamatake's calibration system.

This paper gives an overview of our water flowmeter calibration system and describes the outcome of our joint research with NMIJ on calibration equipment for use by JCSS-certified calibration business operators as well as how to calculate uncertainties. In addition, the paper also explains the concept of declaration of conformity, which takes uncertainties into consideration.

2. Calibration system specifications

Yamatake's calibration system has been in service since April 2009. Figure 1 shows a schematic view of the calibration system. The calibration system is comprised of an underground cistern, lifting pumps, and an elevated cistern in addition to flowmeters for control, flow control valves, diverters, weighing tanks, weighers, and measuring systems. Water drawn by the lifting pumps is stored in the elevated cistern before being conveyed to the calibration equipment by using the head pressure on the elevated cistern. Flowmeters are located at the upstream ends of each measurement line to generate the valve travel control signals. The flow control valves automatically adjust their travel according to the calibrated flow to set the flow rate. Then, the diverters switch from the distributing pipe duct to the weighing tank duct in response to a system signal. After water has been poured into the tank for the predetermined period of time, the diverter returns to its original position. The weight of the water in the tank is measured with a weigher to calculate the standard flow rate value through buoyancy correction and density calculation. In synchronization with the pouring of water from the diverter to the tank, measurement of the current signal from the measuring instrument being calibrated (hereinafter, "MUT") as well as of the integral pulse is performed to compare the output of MUT with the reference flow rate in order to calculate instrumental error.

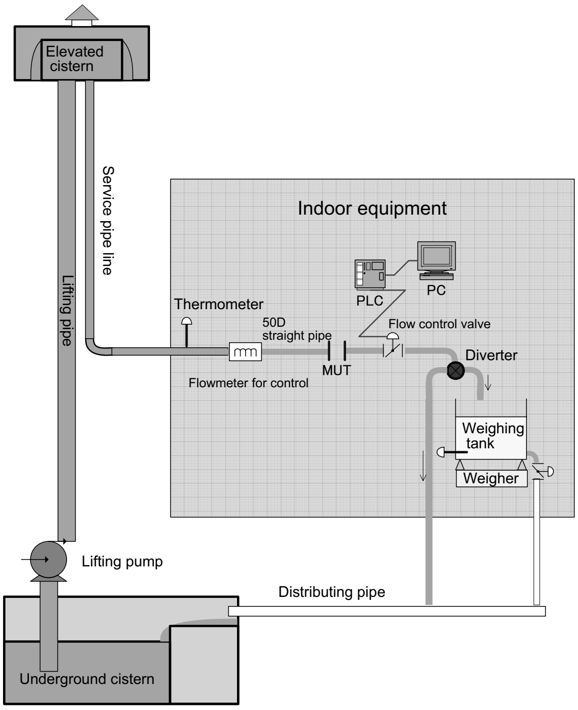

Figure 1. Calibration System Overview

2.1 Subsystem classification

The calibration system is divided into eight subsystems, each of which can operate independently. Yamatake was recently registered as a JCSS-certified calibration business operator for some of the lines included in those subsystems. The flow rates for such lines are within the range of 0.09 to 650 m^3/h.

2.2 Elevated and underground cisterns

The elevated cistern has an overflow structure such that the pressure does not fluctuate due to pump pulsation or water head changes. The elevated cistern is designed to keep the displacement of the surface of the water in the tank such that the fixed amount of displacement is never exceeded. As the lines from the service pipe to the respective lines are connected directly from the elevated cistern, they are unaffected by changes in the operating flow rates in the respective lines.

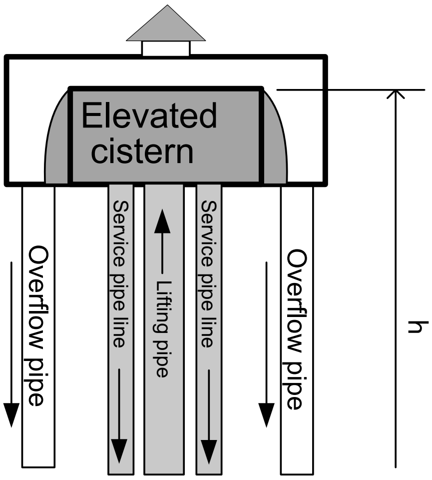

Figure 2. Overflow Structure

The elevated cistern is comprised of two tanks of different capacities arranged in a tier. The tank part from which water overflows is located at a height of 35 m for the smaller-capacity tank and 20 m for the larger-capacity tank. The smaller-capacity tank is used for smaller caliber lines while the larger-capacity tank is used for larger caliber lines. Larger caliber lines do not need to be fed with water from an elevated tank as the pressure loss in such lines is less than that of smaller caliber lines even when the flow velocity of both lines is identical.

Figure 3. External View of the Elevated Cistern

The underground cistern is located underground directly below the elevated cistern and pump chamber. The underground cistern, which always contains a fixed amount of water, is designed such that any air bubbles in the water therein can be completely removed.

2.3 Lifting pump

The calibration system is comprised of a total of eight lifting pumps, all or some of which are operated according to the calibrated flow in order to ensure that the system always maintains its overflow state.

2.4 Diverter, weigher, weighing tank

The calibration system is comprised of a total of 16 sets, each made up of a diverter, weigher, and weighing tank. The diverters accommodate flow rates of 0.0002 to 5,000 m^3/h. Diverters that accommodate a flow rate of 5,000 m^3/h are the largest in Japan.

The weighers can measure weight ranging from 600 g to 60 t. Weighers that accommodate weight of 6 t or less, which use an electromagnetic balance, have a resolution of 1/300,000 or higher. Weighers that accommodate weight exceeding 6 t, which use high-precision load cells, have a resolution of 1/10,000 or higher.

The weighing tanks are designed to have reduced weight so that they can be moved during calibration. Figure 4 shows a 60 t weigher being calibrated.

Figure 4. 60 t Weigher Being Calibrated

2.5 Measuring system

The equipment configuration on the operating panel is as shown in Figure 5. Two PCs are used per system.

PC1, which is intended for controlling devices via PLCs (Programmable Logic Controllers) as well as controlling sequences and man-machine interfaces, and PC2, which is intended for performing arithmetic operations such as calculating instrumental errors, are used as necessary depending on the objective to realize real-time processing.

PC1 uses Harmonas-FLeX™ controller technologies (Yamatake's harmonious controllers that have been well-received by customers and are intended to be deployed on-site for industrial automation) to realize reliable control and stability.

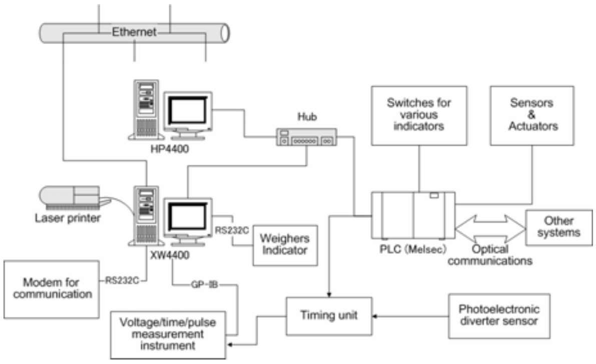

Figure 5. System Configuration Diagram

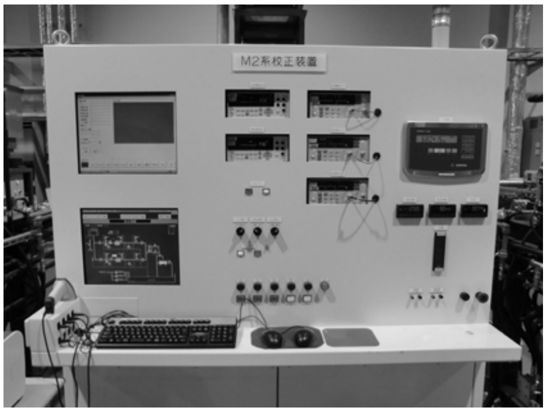

Figure 6. External View of the Operating Panel

2.6 **Piping**

The piping features contrivances for preventing air bubbles from accumulating. In addition, bubble detectors are installed in those areas where air bubbles easily accumulate to automatically discharge the air. Figure 7 shows part of the calibration system.

Figure 7. External View of the Calibration System

The straight pipe located upstream of MUT has a length at least 50 times that of its caliber so that the fluid under the test forms a perfectly axisymmetric flow. In addition, O-rings are used to seal the pipe joints so that use of gaskets does not result in the formation of steps. By employing the structure shown in Figure 8, the formation of steps on the inner surface of the piping can be prevented, thereby allowing for the realization of a stable state in which no eddies or similar phenomena are produced.

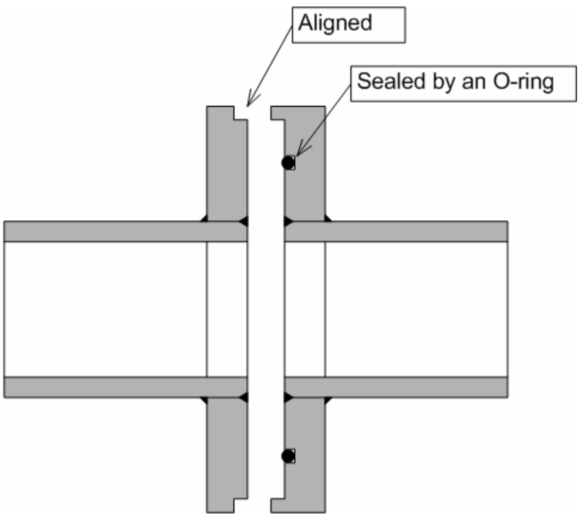

Figure 8. Pipe Connection Structure

In addition, fluid analysis to determine the optimal contours as shown in Figure 9 was conducted on the pipes laid upstream of the straight pipe's intake to prevent drifts or the generation of swirl flows. As shown in Figure 10, the pipeline is designed to reduce the turning component of the flow within it. Consequently, the flow velocity distribution on cross-sections of the pipes was also verified to be uniform.

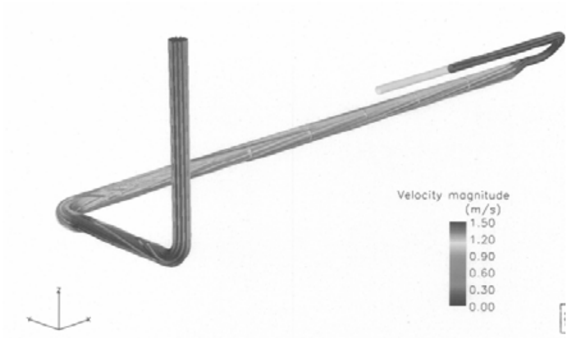

Figure 9. Pipe Layout

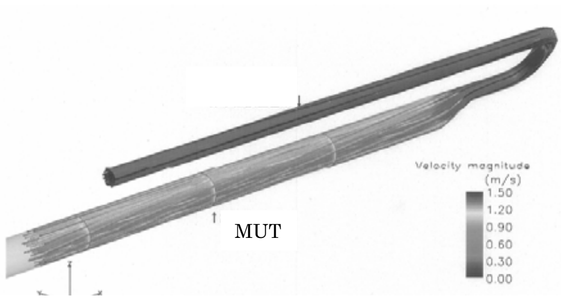

Figure 10. Diagram of the Streamline in which MUT is Installed

3. Calibration uncertainties

3.1 Joint research with NMIJ

Before filing an application to register as a JCSS-certified business operator, we conducted joint research with NMIJ. This section describes the outcome of that research.

Calibration was independently conducted using NMIJ's and Yamatake's calibration systems through the medium of a turbine flowmeter (of caliber 25A/50A/100A/200A). The joint research took approximately one year (October 2009 to October 2010). The research provided long-term evidence that the results of calibration using Yamatake's and

NMIJ's calibration systems (including reproducibility, which depends upon the installation and removal of the respective calibration systems) were consistent with each other.

Per-caliber measurement points are as shown in Table 1.

Table 1. List of Flow Rates Used in the Joint Research to Compare NMIJ's and Yamatake's Calibration Systems

Caliber of flowmeter	Caliber of piping	Range of flowmeter	Measurement point	Scales
25A	50A	1～18m^3/h	1.0 m^3/h	50 kg
			1.8 m^3/h	50 kg
			2.5 m^3/h	50 kg
			2.5 m^3/h	500 kg
			5.0 m^3/h	500 kg
			10 m^3/h	500 kg
50A	50A	10～58m^3/h	23 m^3/h	500 kg
			23 m^3/h	5000 kg
			35 m^3/h	5000 kg
			45 m^3/h	5000 kg
			55 m^3/h	5000 kg
100A	100A	40～300m^3/h	40 m^3/h	5000 kg
			90 m^3/h	5000 kg
			140 m^3/h	5000 kg
			140 m^3/h	22 t
			175 m^3/h	22 t
			225 m^3/h	22 t
200A	200A	80～660m^3/h	100 m^3/h	5000 kg
			140 m^3/h	5000 kg
			140 m^3/h	22 t
			200 m^3/h	22 t
			300 m^3/h	22 t
			400 m^3/h	22 t
			600 m^3/h	22 t
			650 m^3/h	22 t

Figures 11 to 14 show the results of calibration conducted using NMIJ's and Yamatake's calibration systems. The upper and lower markers on the Yamatake data represent the upper and lower limits (0.10%) of calibration measurement capability (hereinafter, "CMC").

As shown in Figure 11, for flowmeter caliber of 25A, unlike the horizontal axes of the graphs for other calibers, the horizontal axis of the graph represents a Reynolds number. This is because turbine flowmeters, which are characterized based on the Reynolds number, increasingly depend upon the same number as their caliber decreases.

As shown in Figures 12 to 14, for flowmeter calibers from 50A to 200A, the results of calibration conducted using Yamatake's calibration system are consistent with the results from NMIJ's calibration system as the data from both systems falls within the uncertainty ranges.

The aforementioned facts confirm consistency with the national standards for measurement points, 1 to 650 m^3/h.

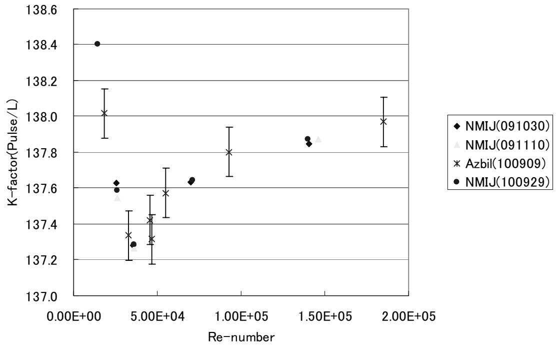

Figure 11. Calibration Results for 25A Caliber Flowmeter (the Horizontal Axis Represents a Reynolds Number)

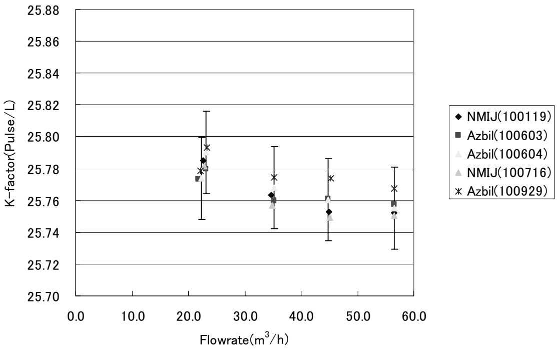

Figure 12. Calibration Results for 50A Caliber Flowmeter

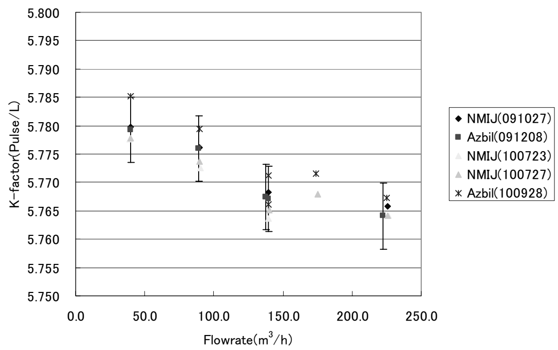

Figure 13. Calibration Results for 100A Caliber Flowmeter

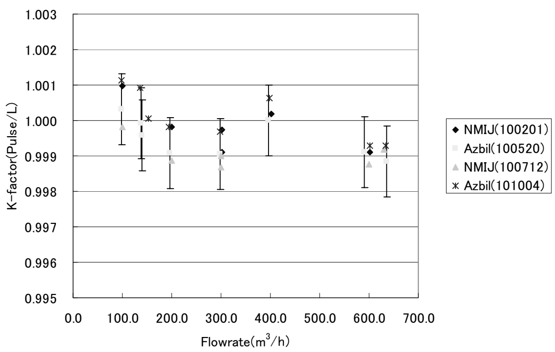

Figure 14. Calibration Results for 200A Caliber Flowmeter

3.2 **Uncertainties**

The data obtained from the calibration systems can be roughly divided into the following five categories:

(i) Data on weight measured upon starting measurement;

(ii) Data on weight measured upon finishing measurement;

(iii) Data on air density measured during measurement;

(iv) Data on water density; and

(v) Data on the length of time from starting until finishing measurement. First, the mass flow rate is derived from the mass of the material under measurement and time. Then, the volume flow rate is calculated from the mass flow rate and water density.

Therefore, a general formula to calculate the flow rate of a calibration system can be derived as follows:

$$q \equiv \frac{M}{t} \quad \text{Formula (1)}$$

q : Mass flow rate (kg/s)

M : Mass of water (kg)

t : Time (period of time in which water flows into the tank) (s)

If δq is the uncertainty component of q, the following formulae can be derived from formula (1):

$$q + \delta q = \frac{M + \delta M}{t + \delta t} \quad \text{Formula (2)}$$

$$q + \delta q = \frac{M\left(1 + \frac{\delta M}{M}\right)\left(1 - \frac{\delta t}{t}\right)}{t\left(1 + \frac{\delta t}{t}\right)\left(1 - \frac{\delta t}{t}\right)} \quad \text{Formula (3)}$$

By approximating the terms of formula (3) that represent the squared uncertainty components, the following formula can be derived from formula (3):

$$q + \delta q \approx \frac{M}{t}\left(1 + \frac{\delta M}{M} - \frac{\delta t}{t}\right) \quad \text{Formula (4)}$$

The following formula is then derived from formula (4):

$$\delta q \approx \frac{M}{t}\frac{\delta M}{M} - \frac{M}{t}\frac{\delta t}{t} \quad \text{Formula (5)}$$

Which leads to the following formula:

$$\frac{\delta q}{q} \approx \frac{\delta M}{M} - \frac{\delta t}{t} \quad \text{Formula (6)}$$

Formula (6) indicates that the value derived by synthesizing the relative uncertainties of the mass measurement and time measurement for each flow rate expresses the calibration uncertainty.

By substituting a formula that takes into consideration the data that would actually be obtained as well as the details pertaining to correction of such data into formula (1), formula (7) is derived:

$$q_m = \frac{\left(k_{\mathrm{f}} M_{\mathrm{f}} - k_{\mathrm{i}} M_{\mathrm{i}}\right) * \varepsilon}{t_{\mathrm{D}}} \quad \text{Formula (7)}$$

q_m : Mass flow rate indicated by the calibration system (kg/s)

k_{i} : Correction coefficient for the weigher to be applied upon starting measurement

M_{i} : Mass measured upon starting measurement (kg)

k_{f} : Correction coefficient for the weigher to be applied upon finishing measurement

M_{f} : Mass measured upon finishing measurement (kg)

ε : Buoyancy correction coefficient

t_{D} : Period of time in which water flows into the tank (s)

Note: As neither k_{i} nor k_{f} is corrected to be 1, these correction components are included in the uncertainties.

When formula (7) is used to calculate the volume flow rate, the mass flow rate is divided by ρ_{wD}, i.e., the density of water flowing through MUT (flowmeter), such that the volume flow rate can be expressed by the following formula:

$$Q_m = \frac{q_m}{\rho_{\mathrm{wD}}} \quad \text{Formula (8)}$$

The above formula enables calculation of the volume flow rate.
Just as formulae (1) to (7) have been derived sequentially, formula (9) can be derived from formula (8):

$$\frac{\delta Q_m}{Q_m} \approx \frac{\delta q_m}{q_m} - \frac{\delta \rho_{\mathrm{wD}}}{\rho_{\mathrm{wD}}} \quad \text{Formula (9)}$$

Q_m : Volume flow rate indicated by the calibration system (m^3/s)
ρ_{wD} : Density of water in the calibration system (kg/m3)

The relative uncertainty of the volume flow rate can be calculated by synthesizing the relative uncertainty of the mass flow rate and the relative uncertainty of ρ_{wD} (i.e., the density of water flowing through the flowmeter).
The uncertainty of the mass flow rate is expressed by the following formula:

$$\frac{\delta q_m}{q_m} = \sqrt{\left(\frac{\delta(M_{\mathrm{f}} - M_i)}{M_{\mathrm{f}} - M_i}\right)^2 + \left(\frac{\delta \varepsilon}{\varepsilon}\right)^2 + \left(\frac{\delta t_{\mathrm{D}}}{t_{\mathrm{D}}}\right)^2} \quad \text{Formula (10)}$$

The uncertainty of the volume flow rate is expressed by the following formula:

$$\frac{\delta Q_m}{Q_m} = \sqrt{\left(\frac{\delta(M_{\mathrm{f}} - M_i)}{M_{\mathrm{f}} - M_i}\right)^2 + \left(\frac{\delta \varepsilon}{\varepsilon}\right)^2 + \left(\frac{\delta t_{\mathrm{D}}}{t_{\mathrm{D}}}\right)^2 + \left(\frac{\delta \rho_{\mathrm{wD}}}{\rho_{\mathrm{wD}}}\right)^2} \quad \text{Formula (11)}$$

By contrast, formulae for calculating flow rate values from the output of MUT can be derived as follows.

■ For derivation from pulse output

$$q_u = \frac{I_{\mathrm{P}} \times P_{um}}{t_P} \quad \text{Formula (12)}$$

q_u :Mass flow rate indicated by MUT (kg/s)

I_{P} : Total number of pulses generated during one measurement session (as counted by the pulse counter during a single measurement session)
t_{P} : Time required for the pulse counter to capture a pulse (s)
P_{um} :Pulse weight set for MUT (kg/P)

$$Q_u = \frac{I_{\mathrm{P}} \times P_{uv}}{t_P \times 1000} \quad \text{Formula (13)}$$

Q_u :Volume flow rate indicated by MUT (m^3/s)

I_{P} : Total number of pulses generated during one measurement session (as counted by the pulse counter during a single measurement session)
P_{uv} :Pulse weight set for MUT (L/P)

If a pulse value is assigned as a K factor to MUT, the following formula is used to calculate the volume flow rate uncertainty:

$$Q_u = \frac{I_{\mathrm{P}}}{t_P \times 1000 K_u} \quad \text{Formula (14)}$$

K_u :K factor set by the manufacturer for MUT (P/L)

■ For derivation from current output

$$q_u = S_{um} \times \frac{I_{ave} - 0.004}{0.016} \quad \text{Formula (15)}$$

q_u :Mass flow rate indicated by MUT (kg/s)

I_{ave} :Average value (A) of the current output during the measurement period
S_{um} :Span set for MUT (kg/s)

$$Q_u = S_{uv} \times \frac{I_{ave} - 0.004}{0.016} \quad \text{Formula (16)}$$

Q_u :Volume flow rate indicated by MUT (m^3/s)

I_{ave} :Average value (A) of the current output during the measurement period
S_{uv} :Span set for MUT (m^3/s)

For derivation from pulse output, the uncertainty of

Q_u is expressed by the following formula:

$$\frac{\delta Q_u}{Q_u}=\sqrt{\left(\frac{\delta I_{\mathrm{P}}}{I_{\mathrm{P}}}\right)^2+\left(\frac{\delta t_P}{t_P}\right)^2}$$ Formula (17)

For derivation from current output, the uncertainty of Q_u is expressed by the following formula:

$$\frac{\delta Q_u}{Q_u}=\left(S_u\times\frac{\delta I_{ave}}{0.016}\right)\Big/Q_u=\frac{\delta I_{ave}}{I_{ave}-0.004}$$ Formula (18)

Deviation is calculated using the following formula:

$Er=Q_u-Q_m$ Formula (19)

The uncertainty component of deviation δEr can be calculated as follows:

$\delta Er=\delta Q_u-\delta Q_m$ Formula (20)

The ratio of deviation to Q_m, i.e., the volume flow rate indicated by the calibration system, is expressed as follows:

$$\frac{\delta Er}{Q_m}=\frac{\delta Q_u}{Q_u-Er}-\frac{\delta Q_m}{Q_m}$$ Formula (21)

As its value is much smaller than that of Q_u, Er can be approximated as follows:

$$\frac{\delta Er}{Q_m}\approx\frac{\delta Q_u}{Q_u}-\frac{\delta Q_m}{Q_m}$$ Formula (22)

For derivation from pulse output, the relative uncertainty of deviation is expressed by the following formula derived from formulae (11) and (17):

$$\frac{\delta Er}{Q_m}=\sqrt{\left(\frac{\delta I_{\mathrm{P}}}{I_{\mathrm{P}}}\right)^2+\left(\frac{\delta t_P}{t_P}\right)^2+\left(\frac{\delta(M_{\mathrm{f}}-M_i)}{M_{\mathrm{f}}-M_i}\right)^2+\left(\frac{\delta\varepsilon}{\varepsilon}\right)^2+\left(\frac{\delta t_D}{t_{\mathrm{D}}}\right)^2+\left(\frac{\delta\rho_{\mathrm{wD}}}{\rho_{\mathrm{wD}}}\right)^2}$$

Formula (23)

For derivation from current output, the relative uncertainty of deviation is expressed by the following formula derived from formulae (11) and (18):

$$\frac{\delta Er}{Q_m}=\sqrt{\left(\frac{\delta I_{ave}}{I-0.004}\right)^2+\left(\frac{\delta(M_{\mathrm{f}}-M_i)}{M_{\mathrm{f}}-M_i}\right)^2+\left(\frac{\delta\varepsilon}{\varepsilon}\right)^2+\left(\frac{\delta t_{\mathrm{D}}}{t_{\mathrm{D}}}\right)^2+\left(\frac{\delta\rho_{\mathrm{wD}}}{\rho_{\mathrm{wD}}}\right)^2}$$

Formula (24)

By calculating the respective uncertainty components as explained above, the uncertainty of deviation can be estimated.

Er :Deviation of the calibration value from the standard (m^3/s)

3.2.1 Uncertainties attributable to weighing

The uncertainty of values measured by weighers, which can be expressed as $(M_{\mathrm{f}}-M_i)$, are calculated by synthesizing the following:

1) Uncertainty of weigher calibration u_{m_cal}
2) Uncertainty attributable to linearity $u_{\mathrm{m\_line}}$
3) Uncertainty attributable to temperature characteristics $u_{\mathrm{m\_temp}}$
4) Uncertainty attributable to stability immediately after diverter switching $u_{\sigma\mathrm{m\_short}}$
5) Uncertainty attributable to output drifts occurring during the interval between weigher calibration and the subsequent calibration of the same weigher u_{m_drift}

(1) Uncertainty of weigher calibration u_{m_cal}

Weighers are subjected to JCSS calibration every two years. JCSS weigher calibration takes into consideration the uncertainty of the mass value of the weight used for calibration as well as uncertainties attributable to the resolution of the weigher, repeatability, and the position where the load of the aforementioned weight is applied. Accordingly, the uncertainty of weigher calibration can be calculated as follows by using the uncertainty values stated in the calibration certificate.

$$u_{\mathrm{m}\_cal}=\frac{\sqrt{u_c(M_f)^2+u_c(M_i)^2}}{k_{m\_cal}}$$ Formula (25)

$u_c(M_f),u_c(M_i)$:Uncertainties relative to the loads applied upon starting and finishing measurement stated in the calibration certificate

k_{m_cal} :Coverage factor for the weigher stated in the calibration certificate

(2) **Impact of weigher linearity** $u_{\mathrm{m\_line}}$

The maximum value of weigher linearity, θ , is set as follows:
θ = Maximum deviation value (absolute value) within the working range stated in the JCSS calibration certificate + slight margin The uncertainty attributable to linearity is calculated using the following formula:

$$u_{\mathrm{m\_line}} = \theta \Big/ \sqrt{3} \quad \text{Formula (26)}$$

θ : Maximum deviation value stated in the calibration certificate + α (kg)

(3) **Impact of weigher temperature characteristics** $u_{\mathrm{m\_temp}}$

The variation in the indication of weighers arising from temperature changes can be derived from the temperature characteristics of the respective weighers and the difference between the temperature upon calibrating those weighers and the temperature upon use of the same.

However, doing so requires the inclusion of all measurement points, thereby necessitating a complicated compensation formula. To avoid this, a temperature range of 5º to 35ºC is specified as the temperature range for calibration in order to estimate the worst value such that the estimated worst value may be included among the uncertainties. Temperature characteristics are calculated from the manufacturer's specifications using the following formula:

$$\frac{u_{\mathrm{m\_temp}}}{M_f - M_i} = \alpha \times \left(\left|t - t_0\right|\right) \Big/ \sqrt{3} \quad \text{Formula (27)}$$

α : Temperature coefficient for the weigher (%/ºC)
t :Temperature measured during calibration deviating the most from t_0 (5º or 35ºC)

t_0 :Reference temperature used to calibrate the balance (value stated in the calibration certificate) (ºC)

(4) **Impact observed immediately after diverter switching** $u_{\sigma\mathrm{m\_short}}$

After diverter switching occurs, variation in acquired data (short-term stability) may be observed.

For this reason, indicated values shall be read after ensuring that any deviation of data obtained from five measurement sessions does not exceed the minimum resolution. Thus the span of the minimum resolution can be considered to be distributed uniformly. Consequently, uncertainty can be derived as follows:

$$u_{\sigma\mathrm{m\_short}} = \omega \Big/ 2\sqrt{3} \quad \text{Formula (28)}$$

ω : Scale interval of the weigher (minimum resolution) (kg)

(5) Impact of weigher calibration intervals (drifts attributable to secular changes) u_{m_drift}

The amount of secular change in a weigher is to be verified using the results of the previous calibration of the weigher.
The amount of variation occurring during the interval between weigher calibration and subsequent calibration of the same weigher, which is expressed as $\Delta M_{\mathrm{drift}}$, is included in the uncertainties as the secular change of the weigher.

$$u_{m\_\mathrm{drift}} = \Delta M_{\mathrm{drift}} \Big/ \sqrt{3} \quad \text{Formula (29)}$$

$\Delta M_{\mathrm{drift}}$:Drift of the weigher (occurring over a two-year period) (kg)

(6) **Synthesis of uncertainties**

The uncertainty of values indicated by a weigher (that has not been subjected to buoyancy correction) is calculated using the following formula:

$$\delta(M_{\mathrm{f}} - M_i) = \sqrt{(u_{\mathrm{m\_}cal})^2 + (u_{\mathrm{m\_line}})^2 + (u_{\mathrm{m\_temp}})^2 + (u_{\sigma\mathrm{m\_short}})^2 + (u_{m\_\mathrm{drift}})^2}$$

Formula (30)

3.2.2 **Impact of the buoyancy correction coefficient**

Correction is necessary because atmospheric buoyancy acts on the water contained in the weighing tank.

The buoyancy correction coefficient ε can be expressed using the following formula:

$$\varepsilon = \frac{1 - \rho_{\mathrm{airC}} / \rho_{\mathrm{m}}}{1 - \rho_{\mathrm{airM}} / \rho_{\mathrm{wT}}} \quad \text{Formula (31)}$$

ρ_{airC} :Air density upon weigher calibration (kg/m^3)

$\rho_{\mathrm{air\,M}}$: Air density upon flow rate measurement (kg/m^3)

ρ_{m} : Density of the weight used to calibrate the weigher (kg/m^3)

ρ_{wT} : Density of water in the tank (kg/m^3)

The air densities ρ_{airC} and $\rho_{\mathrm{air\,M}}$ can be derived from the atmospheric temperature, atmospheric pressure, and humidity.

The aforementioned air density upon weigher calibration (ρ_{airC}) is corrected to match the agreed value. For this reason, it differs from the air density actually observed upon weigher calibration. Consequently, the difference between the aforementioned air density upon weigher calibration and the agreed value serves as an uncertainty. The air density $\rho_{\mathrm{air\,M}}$ is handled in a similar manner. Specifically, its value is not calculated each time flow rate measurement is conducted but rather it is treated as a fixed value. Consequently, the amount of variation in air density arising from environmental changes is calculated as an uncertainty.

<Scope of environmental control>

Atmospheric temperature: 20º ± 15ºC (5° to 35°C)

Atmospheric pressure: 100 ± 3 kPa (97 to 103 kPa)

Humidity (rh): 50% ± 40% (10% to 90%)

The minimum and maximum values of air density under these conditions are 1.0754 kg/m^3 and 1.2905 kg/m^3, respectively.

If the agreed value (1.2 kg/m^3) is used as a reference value, the maximum variation in air density is 0.1246 kg/m^3 (the agreed value minus the aforementioned minimum value). Accordingly, the ratio of maximum variation to the agreed value is 10.38%. An airborne weight of density 8,000 kg/m^3 has buoyancy of approximately 150 ppm. Accordingly, the relative variation represented by the numerator of formula (31) is approximately 15.6 ppm, which serves as the maximum value.

The denominator is calculated in the same manner. As water of temperature 20ºC (998 kg/m^3) has buoyancy of 1,202 ppm, 10.38% of the buoyancy, i.e., 125 ppm, is the maximum value of relative variation. Variation in the densities of the weight and water, which negligibly impact the correction coefficients used for calculation, is ignored. The air density upon weigher calibration（ρ_{airC}）and the air density upon flow rate measurement（$\rho_{\mathrm{air\,M}}$）can be handled separately as they are asynchronous. For this reason, the uncertainty arising from the impact of buoyancy（$\delta\varepsilon$）is calculated by dispersion synthesis of the values 15.6 ppm and 125 ppm. This calculation yields the maximum value, 126 ppm.

Consequently, the relative uncertainty of the buoyancy correction coefficient is expressed as follows:

$$\frac{\delta\varepsilon}{\varepsilon} \approx 126 / \left(\sqrt{3}\right) \ \text{ppm} = 0.007\ \% \quad \text{Formula (32)}$$

3.2.3 **Uncertainties attributable to time measurement**

The flow rate represents the amount of fluid flowing in unit time. Accordingly, such measurement involves time measurement.

This time measurement is performed by transmitting a diverter operation signal to the frequency counter upon starting and finishing measurement.

The period of time from start to finish of measurement in which water flows into the tank（t_{D}）can be expressed as follows:

$$t_{\mathrm{D}} = t_{\mathrm{Dm}} + t_{\mathrm{Dc}} \quad \text{Formula (33)}$$

t_{D} :Period of time in which water flows into the tank (s)

t_{Dm} :Time interval of diverter switching signal transmission (s)

t_{Dc} :Time measurement error (timing error) attributable to switching between diverter ducts (s)

By using the above formula, the relative uncertainty of the period of time in which water flows into the tank can be expressed as follows:

$$\frac{u_{t_{\mathrm{D}}}}{t_{\mathrm{D}}} = \sqrt{\left(\frac{u_{t_{\mathrm{Dm}}}}{t_{\mathrm{D}}}\right)^2 + \left(\frac{u_{t_{\mathrm{Dc}}}}{t_{\mathrm{D}}}\right)^2} \quad \text{Formula (34)}$$

In addition, $\frac{u_{t_{\mathrm{Dm}}}}{t_{\mathrm{D}}}$, i.e., the relative uncertainty of t_{Dm} (time interval of diverter switching signal transmission) on the right-hand side of the above formula can be expresses as follows:

$$\frac{ut_{\mathrm{Dm}}}{t_D} \approx \sqrt{\left(\frac{u_{t_{\mathrm{Hz\_cal}}}}{t_D}\right)^2 + \left(\frac{ut_{\mathrm{Hz\_drift}}}{t_D}\right)^2 + \left(\frac{u_{t_{\mathrm{Hz\_temp}}}}{t_D}\right)^2 + \left(\frac{ut_{\mathrm{Photoele\_sensor}}}{t_D}\right)^2}$$

Formula (35)

$u_{t_{\mathrm{Hz\_cal}}}$:Uncertainty of time counter (frequency counter) calibration counter (s)

$u_{t_{\mathrm{Hz\_drift}}}$:Impact of time counter (frequency counter) drifts (control span) (s)

$u_{t_{\mathrm{Hz\_temp}}}$:Impact of time counter (frequency counter) temperature (s)

$u_{t_{\mathrm{Photoele\_sensor}}}$:Impact of photoelectronic sensor response speed (s)

(1) **Impact of timing errors (time measurement errors attributable to switching between diverter ducts)**

Time measurement errors attributable to diverter switching (hereinafter, "timing errors") are measured using the method specified in Annex A of ISO 4185. By adjusting the position of the photoelectronic sensor, $t_{\mathrm{Dc}}/t_{\mathrm{D}}$ is controlled such that it remains within ± 0.008%. An example of timing error measurement results is shown in Figure 15.

The uncertainty attributable to timing errors is calculated as follows:

$$\frac{u_{t_{\mathrm{Dc}}}}{t_D} = \frac{t_{\mathrm{Dc\_MAX}}}{t_{\mathrm{D}}} \Big/ \sqrt{3} \quad \text{Formula (37)}$$

$\frac{t_{\mathrm{Dc\_MAX}}}{t_{\mathrm{D}}}$:This can be adjusted to a value of 0.008% or less. Note that the value is rounded up to 0.01% to allow for a margin.

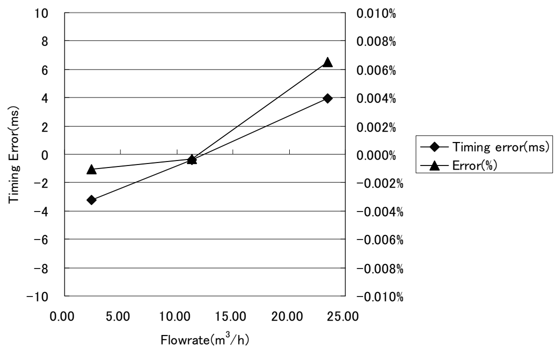

Figure 15. Timing Errors for a 500 kg Diverter

(2) **Uncertainty of time counter calibration** $u_{t_{\mathrm{Hz\_cal}}}$

The following value stated in the calibration certificate is assigned to the uncertainty of time counter calibration.

$$\frac{u_{t_{\mathrm{Hz\_cal}}}}{t_D} = 5\times10^{-7} \Big/ 2 \quad \text{Formula (38)}$$

(3) **Impact of time counter secular changes** $u_{t_{\mathrm{Hz\_drift}}}$

Since the time counter (frequency counter) is subjected to periodic maintenance such that its count remains within the control span (10.00000 ± 0.00003 MHz), the uncertainty attributable to time counter drifts is considered equivalent to 0.00003 MHz.

$$\frac{u_{t_{\mathrm{Hz\_drift}}}}{t_D} = \frac{0.00003}{10} \Big/ \sqrt{3} \quad \text{Formula (39)}$$

(4) **Impact of time counter temperature** $u_{t_{\mathrm{Hz\_temp}}}$

Based on the manufacturer's specifications (0º to 50ºC), a reference temperature of 25ºC is used to consider any impacts that may occur at temperatures near the reference temperature (25ºC) ± 15ºC and then calculate the values corresponding to those impacts. The manufacturer's specifications state that the aforementioned values must be 5 x 10-6 or less at temperatures between 0º and 50ºC (reference temperature: 25ºC).

In practical terms, however, the difference between actual operating temperatures (5º to 35ºC) and the calibration temperature (23ºC) can be taken into consideration to calculate the aforementioned values. From the range of actual operating temperatures and the calibration temperature noted above, a maximum temperature difference of 18ºC can be derived. For a 10 MHz frequency, for example, the variation is considered to be $5\times10^{-6}\times18/50$ MHz, i.e., 0.000018 MHz.

$$\frac{u_{t_{\mathrm{Hz\_temp}}}}{t_D}=\frac{0.000018}{10}\Big/\sqrt{3}$$ Formula (40)

(5) **Impact of photoelectronic sensor response speed** $u_{t_{\mathrm{Photoele\_sensor}}}$

According to the manufacturer's specifications, the response speed of the photoelectronic sensor is 1 ms. A measurement series consists of two operations, i.e., both measurement start and finish operations. However, for purposes of calculating the uncertainty, it is assumed that these operations have no correlations with each other. Thus, the uncertainty can be calculated as follows:

$$\frac{u_{t_{\mathrm{Photoele\_sensor}}}}{t_D}=\frac{\sqrt{\left(0.001^2+0.001^2\right)}}{\sqrt{3}}\Big/t_{\mathrm{D}}$$ Formula (41)

(6) **Synthesis of uncertainties**

With consideration given to the factors mentioned in Sections 3.2.3.(1) to 3.2.3.(5), the relative uncertainty of the period of time for which water flows into the tank (t_{D}),

i.e., $\frac{u_{t_{\mathrm{D}}}}{t_{\mathrm{D}}}$, can be expressed as follows:

$$\frac{u_{t_{\mathrm{D}}}}{t_{\mathrm{D}}}=\sqrt{\left(\frac{u_{t_{\mathrm{Dc}}}}{t_D}\right)^2+\left(\frac{u_{t_{\mathrm{Hz\_cal}}}}{t_D}\right)^2+\left(\frac{ut_{\mathrm{Hz\_drift}}}{t_D}\right)^2+\left(\frac{u_{t_{\mathrm{Hz\_temp}}}}{t_D}\right)^2+\left(\frac{ut_{\mathrm{Photoele\_sensor}}}{t_D}\right)^2}$$

Formula (42)

3.2.4 Uncertainties attributable to flow rate conversion

It is understood that the density of water used in the calibration system (ρ_{wD}) varies depending upon the temperature and pressure as well as the concentration of impurities within the water. Accordingly, the relative uncertainty given by the water density ($\frac{\delta\rho_{\mathrm{wD}}}{\rho_{\mathrm{wD}}}$) is derived from those three factors.

(1) **Impact of temperature on water density** $u_{\rho\_\mathrm{water\_t}}$

Assuming that the tolerance (control span) of the temperature transmitter is ± 0.6ºC and that the distribution of fluid temperature (at the temperature measurement points as well as within MUT and tank) is not more than 0.5ºC as well as on the grounds that the amount of water density variation per degree Celsius is not more than 0.38 kg/m^3 (such variation peaks at a temperature near 40°C), the following formula holds:

$$u_{\rho\_\mathrm{water\_t}}=0.38\times\sqrt{\left(0.6\big/\sqrt{3}\right)^2+\left(0.5\big/2\sqrt{3}\right)^2}\ \ \mathrm{kg/m^3}$$

Formula (43)

$u_{\rho\_\mathrm{water\_t}}=0.143$ kg/m^3

(2) **Impact of pressure on water density** $u_{\rho\_\mathrm{water\_P}}$

The compressibility of water is approximately 0.0045% per atm. The elevated cistern of the calibration system is at a height of 35 m and causes pressure variation of up to 3.5 atm. In view of this and the density determined using the density calculation formula, compression of 50% has been allowed for. The density correction uncertainty arising from compression is expressed as follows:

$$u_{\rho\_\mathrm{water\_P}}=1000\times0.000045\times3.5\big/2\sqrt{3}\ \ \mathrm{kg/m^3}$$

Formula (44)

$u_{\rho\_\mathrm{water\_P}} = 0.045$ kg/m^3 Formula (45)

(3) **Impact of impurities on water density** $u_{\rho\_\mathrm{water\_I}}$

Based on the results of the comparative calibration conducted by Yamatake and NMIJ in which pure water was used, the water density variation can be presumed to be no more than 0.03 kg/m^3 (k = 2).

In addition, consideration was given to the variation that occurred over the past two years. Consequently, the value of variation was increased by approximately 0.10 kg/m^3.

Based on the above, the variation in the density of water, which is replaced in two-year intervals, is corrected by including the variation that will occur in the upcoming year in advance, 0.05 kg/m^3. Consequently, the uncertainty of the water density ($u_{\rho\_\mathrm{water\_I}}$) can be expressed as follows:

$$u_{\rho\_\mathrm{water\_I}} = \sqrt{(0.03/2)^2 + (0.05/\sqrt{3})^2} \text{ kg/m}^3$$

Formula (46)

$u_{\rho\_\mathrm{water\_I}} = 0.033$ kg/m^3

(4) **Synthesis of uncertainties**

With consideration given to the factors mentioned in Sections 3.2.4. (1) to 3.2.4. (3), the uncertainty of the water density and the relative uncertainty given by the water density are derived as follows:

Uncertainty of the water density:

$$u_{\rho\_\mathrm{water}} = \sqrt{u_{\rho\_\mathrm{water\_t}}{}^2 + u_{\rho\_\mathrm{water\_P}}{}^2 + u_{\rho\_\mathrm{water\_I}}{}^2}$$

Formula (47)、

Relative uncertainty given by the water density:

$$\frac{\delta\rho_{\mathrm{wD}}}{\rho_{\mathrm{wD}}} \approx 0.015 \ \%$$

3.2.5 **Impact of capture of output by MUT**

Sections 3.2.1 to 3.2.4 describe the uncertainties attributable to the calibration system. With consideration given to these uncertainties, the uncertainties that occur when MUT captures output signals can be calculated.

Calibration data is input as pulses or electric current. For pulse input, the pulses are measured using a time counter. For current input, the amount of voltage drop in the current flowing through a fixed resistor of 250 Ω is measured.

For both types of measurement, the factors listed below related to uncertainties should be considered.

(1) **For pulse output**

Based on the assumptions that the difference among the measured pulse counts does not exceed 1 and that such pulse counts are uniformly distributed, the uncertainty of the total count of measured pulses (u_{Ip}) can be expressed as follows:

$u_{\mathrm{Ip}} = 1/\sqrt{3}$ Formula (48)

The uncertainty of the time required for the pulse counter to capture a pulse (t_{P}), which is expressed as u_{tP}, represents the time difference between the transmission of the trigger signal to the pulse counter and the gate signal to the time measurement counter. These two signals are branched from a switching signal from the diverter. Since the circuit is configured such that synchronicity is ensured, u_{tP} can be ignored.

$u_{\mathrm{tP}} = 0$ Formula (49)

(2) **For current output**

The uncertainty of current measurement is calculated with consideration given to the control span of the digital multimeter (as per the manufacturer's specifications), the control span of the 250 Ω standard resistor (as per the manufacturer's specifications), and the temperature coefficients for the respective devices. For current output, the amount of impact varies depending on the flow rate range even if the uncertainty of current measurement is the same. For this reason, a current-flow rate relational formula is derived from the flow rate range of MUT to calculate the amount of uncertainty impact. Since a standard resistor is used as mentioned above, the uncertainty of current measurement can be calculated in the following manner:

$$I = \frac{V}{R}$$ Formula (50)

Thus, the uncertainty of current can be expressed as follows:

$$u^2(I) = \left\{\frac{\partial I}{\partial V}u(V)\right\}^2 + \left\{\frac{\partial I}{\partial R}u(R)\right\}^2$$ Formula (51)

The sensitivity coefficient is as follows:

$$\frac{\partial I}{\partial V} = \frac{1}{R} \ , \ \frac{\partial I}{\partial R} = -\frac{V}{R^2}$$

From this, the following formula is derived:

$$u^2(I) = \left\{\frac{1}{R} * u(V)\right\}^2 + \left\{-\frac{V}{R^2} * u(R)\right\}^2$$

Formula (52)

The accuracy specifications for the digital multimeter shall fall within the respective values below, which show the precision valid for one year in accordance with the manufacturer’s written specifications.

Reading x 0.0030% + Range x 0.0005%

In addition, the temperature characteristics of the digital multimeter allow it to achieve the following accuracy at temperatures between 0º and 55ºC:

Reading x 0.0005% + Range x 0.0001%/ºC

As the digital multimeter is calibrated at 23ºC and operated at ambient temperatures from 5º to 35ºC, the difference between the calibration temperature and the temperature of the environment in which the digital multimeter is operated may be up to 18ºC. Accordingly, the uncertainty of the readings is expressed as follows:

$$u(V) = \frac{V \times (0.00003 + 0.000005 \times 18) + 10 \times (0.000005 + 0.000001 \times 18)}{\sqrt{3}}$$

Formula (53)

By contrast, the resistor for conversion from current to voltage (250 Ω) is controlled with an accuracy of ± 0.01% and its temperature coefficient is 10 ppm.

$$u(R) = \frac{R \times \left(\sqrt{0.0001^2 + (0.00001 \times 18)^2}\right)}{\sqrt{3}}$$ Formula (54)

By substituting formulae (53) and (54) into formula (52) and rearranging formula (52), the following formula is obtained:

$$u^2(I) = \frac{\left(I \times 1.2 \times 10^{-4} + \frac{2.3 \times 10^{-4}}{250}\right)^2 + \left(I \times 2.059 \times 10^{-4}\right)^2}{3}$$
$$= \frac{I^2 \times 5.68 \times 10^{-8} + I \times 2.208 \times 10^{-10} + 8.464 \times 10^{-13}}{3}$$

Formula (55)

The relationship between the uncertainty of the current measurement ($u(I)$) and the uncertainty of MUT output relative to the flow rate value ($\frac{u(Q_u)}{Q_u}$) is expressed as follows:

$$\frac{u(Q_u)}{Q_u} = \left(u(I) \middle/ (I - 0.004)\right)$$ Formula (56)

I :Actual current value (for output signals from 4 to 20 mA)

Figure 16 shows the variation in the relative uncertainty attributable to current output.

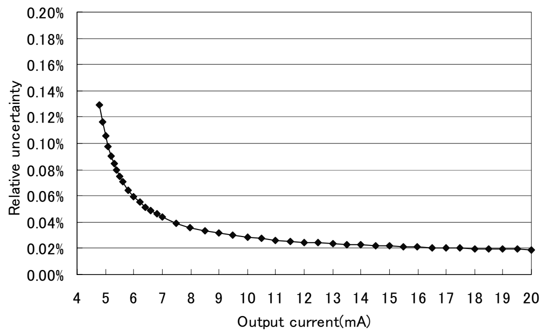

Figure 16. Relationship between Current Output and Relative Uncertainty

3.2.6 **Uncertainties attributable to MUT**

Uncertainties as described in the sections up to 3.2.5 can be calculated as uncertainties residing in the calibration system which do not depend on the type of calibrated instrument. For uncertainties attributable to MUT, the amount of impact varies depending on the type of calibrated instrument. For this reason, uncertainties are calculated separately for each of the following flowmeter types: electromagnetic, turbine, Coriolis, ultrasonic, volumetric, vortex, differential pressure-type, and other types of flowmeters. The following sections focus on turbine flowmeters, i.e., the type used in the joint research with NMIJ, in order to present the basis on which the uncertainties of such flowmeters are calculated.

(1) Impact of Repeatability

JCSS calibration generally uses the average of the measured values obtained from three measurement sessions as the calibration value.
The uncertainty of this average value (u_{x_σ}) is calculated from the results of three calibration sessions and the standard deviation.

$u_{x\_\sigma} = S/\sqrt{n}$ Formula (57)

S : Experimental standard deviation n : Number of calibration sessions

(2) **Impact of calibrated instrument temperature characteristics**

Turbine flowmeters incapable of 3α automatic correction are subjected to correction with reference to a fluid temperature of 20ºC. The uncertainty of the amount of this correction ($u_{q_{\text{temp\_slope}}}$) is derived by using the temperature characteristic (temperature coefficient) ($\alpha_{\text{temp\_eff}}$) as follows: Because of the uncertainty in the temperature measurement described in Section 3.2.4.1, the following formula holds:

$$u_{q_{\text{temp\_slope}}} = \alpha_{\text{temp\_eff}} \times \sqrt{\left(0.6/\sqrt{3}\right)^2 + \left(0.5/2\sqrt{3}\right)^2}$$

Formula (58)

$\alpha_{\text{temp\_eff}}$: 2βH + βR (βH: housing expansion coefficient; βR: rotor thermal expansion coefficient)

To calculate the uncertainty without performing temperature correction by using a reference temperature (e.g., 20ºC), the following formula can be derived from the fluid temperature during measurement.

$$u_{q_{\text{temp\_slope}}} = \alpha_{\text{temp\_eff}} \times \sqrt{\left((t_{\max} - 20)/\sqrt{3}\right)^2 + \left(0.6/\sqrt{3}\right)^2 + \left(0.5/2\sqrt{3}\right)^2}$$

Formula (59)

$t_{\max}$: The highest or lowest temperature of those measured during calibration, whichever is more distant from the reference temperature

If a reference temperature is specified case-by-case as a result of a customer's request, formula (59) is modified to calculate $u_{q_{\text{temp\_slope}}}$. However, such customer-specific reference temperatures must still remain within the operating temperature range.

(3) **Impact of swirl flows and drifts**

As mentioned in Chapter 2, due consideration has been given to the layout of the piping in the calibration systems in order to avoid the generation of swirl flows and occurrences of drifts. The impacts of fluid produced by these calibration systems on MUTs are minor and therefore included among the impacts described in Section 3.2.6.5 below.

(4) **Impact of air bubbles in the fluid**

Before calibration, the underground cistern is completely filled with water and all air bubbles are completely removed. If any bubble remains, the bubble detector signals to suspend calibration. This impact can be ignored.

(5) **Other impacts (including impact of installation status)**

This section considers the impact of reproducibility arising from installation or removal as well as the impacts of the calibration system (e.g., contours and lengths of piping) on MUT.

An uncertainty of no more than 0.1% is derived based on the outcome of the aforementioned joint research with NMIJ.

$u_{\Delta d} = 0.1/2\sqrt{3}$ % Formula (60)

$u_{\Delta d}$: Other uncertainties

3.2.7 **Budget sheet**

As an example, the uncertainties present during calibration of a 50A turbine flowmeter are shown below.
The measurement and environmental conditions are as follows:
Measurement point: 22.82 m^3/h
Measurement time: 53.5 s
Number of measurement sessions: 3
Pulse weight: 0.0294 L
Atmospheric temperature: 18.1 °C
Water temperature: 19.9 °C
Atmospheric pressure: 990.7 kPa
Humidity: 65.7 %RH

Table 2. Budget Sheet

No	Name	Type	Dist.	STD uncertainty	Relative uncertainty
				L/h	%
3.2.1	Uncertainties attributable to weighing				
3.2.1(1)	Temperature characteristics	B	Normal	2.85	0.012
3.2.1(2)	Weigher linearity	B	Rectangula	0.50	0.002
3.2.1(3)	Weigher temperature characteristics	B	Rectangula	0.40	0.002
3.2.1(4)	Impact after diverter switching	B	Rectangula	0.04	0.000
3.2.1(5)	Weigher calibration interval	B	Rectangula	4.34	0.019
3.2.2	Buoyancy correction coefficient	B	Rectangula	1.65	0.007
3.2.3	Uncertainties attributable to time measurement				
3.2.3(1)	Diverter timing errors	B	Rectangula	2.28	0.010
3.2.3(2)	Time counter calibration	B	Rectangula	0.01	0.000
3.2.3(3)	Time counter secular changes	B	Rectangula	0.04	0.000
3.2.3(4)	Time counter temperature characteristics	B	Rectangula	0.02	0.000
3.2.3(5)	Photoelectronic sensor response speed	B	Rectangula	0.35	0.002
3.2.4	Uncertainties attributable to flow rate conversion				
3.2.4(1)	Impact of temperature on water density	B	Rectangula	3.28	0.014
3.2.4(2)	Impact of pressure on water density	B	Rectangula	1.05	0.005
3.2.4(3)	Impact of impurities on water density	B	Rectangula	0.75	0.003
3.2.5	Impact of capture of output by the calibrated instrument				
3.2.5(1)	For pulse output	B	Rectangula	1.14	0.005
3.2.6	Uncertainties attributable to MUT				
3.2.6(1)	Repeatability	A	Normal	0.66	0.003
3.2.6(2)	MUT temperature characteristics	B	Rectangula	0.39	0.002
3.2.6(3)	Swirl flows and drifts	B	Rectangula	0.00	0.000
3.2.6(4)	Air bubbles in the fluid	B	Rectangula	0.00	0.000
3.2.6(5)	Other impacts	B	Rectangula	6.59	0.029

Combined standard uncertainty	9.65	0.042
Expanded uncertainty(k=1.96)	18.92	0.083

3.2.8 **Effective degrees of freedom and coverage factor**

Following the completion of the synthesis of standard uncertainties, the degrees of freedom of the synthesized standard uncertainty are calculated. The degrees of freedom of the synthesized standard uncertainty are calculated using the Satterthwaite method (when the number of Type A uncertainties is one) as follows:

$$v_{eff} = \frac{(u_c)^4}{\frac{(u_{x\_\sigma})^4}{n-1}} \quad \text{Formula (61)}$$

u_c :Synthesized standard uncertainty

v_{eff} :Degrees of freedom of u_c

For example, the budget sheet shown in Section 3.2.7 is used to calculate the degrees of freedom. If the values of the budget sheet in that section are used, the degrees of freedom can be calculated as follows:

$$v_{eff} = \frac{(9.65)^4}{\frac{(0.66)^4}{3-1}} = 91403 \quad \text{Formula (62)}$$

By calculating the value of t(v_{eff} ,0.05) using the t distribution table, the coverage factor k is found to be 1.96.

If the degrees of freedom number 10 or less due to the poor repeatability of the calibration result, measures to increase the degrees of freedom (e.g., by increasing the number of measurement sessions) should be considered.

In addition, if the expanded uncertainty is less than the CMC, the degrees of freedom must be recalculated to enter the CMC value in the Uncertainty column of the calibration certificate.

$$v_{eff} = \frac{\left(CMC/k\right)^4}{\frac{(u_{x\_\sigma})^4}{n-1}} = \frac{\left(22.82/1.96\right)^4}{\frac{(0.66)^4}{3-1}} = 193683$$

Formula (63)

In this example, there is no need for recalculation as the degrees of freedom are satisfactory as is. However, the above calculation formula is shown anyway to explain the calculation procedure.

3.2.9 **Summary of matters relating to uncertainties**

As the calibration result obtained by calibrating an instrument is derived from the combined performance of the calibration system and calibrated instrument, the reliability of calibration work can be verified by calculating the degrees of freedom based upon this result. Thus, the calibration result serves as an important point for confirmation.

This allowed us to verify that the performance of the calibration system and flowmeter (i.e., MUT) as well as our environmental control ability were sufficiently exercised to counter the estimated uncertainties in a variety of cases, including the aforementioned example.

4. Conclusion

First, we would like to express our gratitude to all of those involved from NMIJ, NITE, and Yamatake for their cooperation in Yamatake's registration to become a certified business operator for flowmeter calibration in April 2011.

Recently, an increasing number of business operators have registered as JCSS-certified business operators for water flowmeter calibration. In this environment, allowing such business operators to take advantage of being authorized to issue JCSS calibration certificates stating uncertainties whose traceability is ensured offers new values to the customers in the flowmeter market.

Yamatake has endeavored to make quality improvements for many years in its capacity as a manufacturer delivering flowmeters to customers. The company considers its recent registration as a JCSS-certified calibration business operator an opportunity to ensure higher reliability.

The company believes that flowmeters calibrated using the aforementioned techniques can be used by customers safely and comfortably.