Development of water flow standard system for calibrating water flow meters up to 2000 m^3/h in KRISS

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Abstract

There are a lot of needs for calibrating water flow meters with large-capacity in applications for steam turbine, chemical processing and water resource management industries. Accredited laboratories have equipped with gravimetric or master-meter flow calibration systems to calibrate water flow meters up to 5000 m^3/h – 12000 m^3/h. KRISS had its water flow standard system only up to 400 m^3/h. In this study, the water flow standard system (WFSS), of which measurement capacity was enlarged up to 2000 m^3/h, was recently developed. Toward its ends, four weighing tanks (0.1 t, 1 t, 5 t, 25 t) were integrated into one system with eight pipe lines (25A, 50A, 80A, 100A, 150A, 200A, 250A, 400A). Four pumps were applied to supply water to the head tank located at 20 m high. A mathematical model was revised in view of relative deviations according to the GUM. The BED (best existing device) uncertainty was also incorporated according to the WGFF resolutions. The measurement uncertainty of the WFSS was estimated to be less than 0.06 %. Some parts of the WFSS are involved in the CCM.FF-K1 KC and the APMP.M.FF-S1 SC. More details on the WFSS are described in this paper.

Keywords: buoyancy correction, calibration, gravimetric flow metering, measurement standard, uncertainty, water flow

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1. Introduction

It is necessary to monitor flow rate as well as pressure and temperature for safe operation of plants used in many industrial sectors such as water resource management, power plant, and custody transfer. For example, steam turbine efficiency is an important part of nuclear power engineering(1,2,3). The steam turbine efficiency can be increased by measurement uncertainty recapture (MUR)(2,3). This means that the steam turbine efficiency can be increased just below the restriction by safety code if a flow meter in the pipeline has good measurement uncertainty. It is possible because the steam turbine efficiency is determined by pressure and flow rate. The measurement uncertainty of the flow meter for the MUR is in order of 0.3 % ($k = 2$). Thus, a flow metering facility with good measurement uncertainty is required for testing such flow meters.

The water flow standard system (WFSS) at KRISS has been limited to 400 m^3/h. It is because the weighing tank with 5 t capacity can not measure flow rate more than 400 m^3/h. Recently, the WFSS was rebuilt by integrating the existing weighing tanks (0.1 t, 1 t, 5 t) and a new weighing tank (25 t) to measure flow rate up to 2000 m^3/h. The pipe lines (25A, 50A, 80A, 100A, 150A, 200A, 250A, 400A) were connected with each other so that the four weighing tanks can choose a pipe line to calibrate flow meters with wide flow ranges. In doing so, the performance of the WFSS was improved. And the operator's efficiency was also increased.

The measurement uncertainty of the WFSS was estimated to be less than 0.06 % ($k = 2$). This value is under review by participating in the two CCM KC (CCM.FF-K1.2015, CCM.FF-K2.2011) and a APMP SC (APMP.M.FF-S1)(4).

In this study, the WFSS is briefly explained. After that, the mathematical model to measure relative deviation is described. The relative deviation has been commonly used in the calibration certificates. The BED (best existing device) and the AI (associated instrument) uncertainties are considered as a part of relative uncertainty factors. This method corresponds with the WGFF resolutions(5).

2. Water Flow Standard System

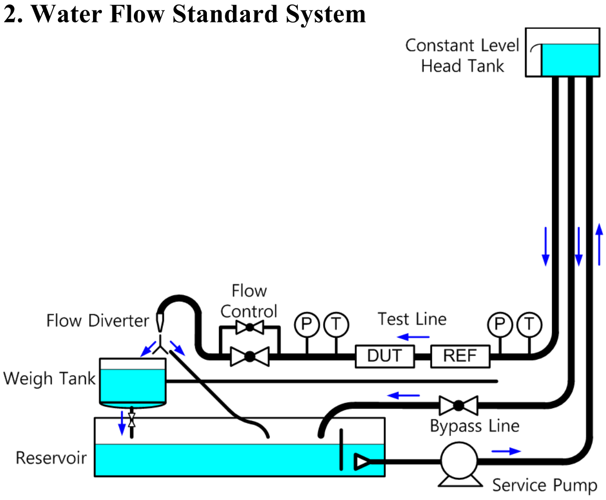

Figure 1: Schematic diagram of water flow standard system (WFSS).

The WFSS circulates water to generate flow rate in the pipe from 0.6 m^3/h to 2000 m^3/h. A reservoir can contain water up to 250 t. Four service pumps operate to induce water to a constant-level head tank at 20 m high from the ground. A bypass line is attached to the head tank to maintain the water head constantly. A reference flow meter (electro-magnetic or Coriolis flow meter) is installed upstream of a test flow meter (device under test, DUT) at each pipe line. Two pairs of pressure and temperature transmitters are installed upstream and downstream sides of the pipe line to correct dead volume. A set of glove valves are installed downstream of the DUT to adjust flow rate. The gravimetric flow measurement system is located downstream of the glove valves. Three of the weighing tanks are measured by load cells. And the weighing tank with smallest capacity (1 t) is measured by an electric balance. A linear type flow diverter is installed at the end of the pipe line.

3. Mathematical Model

The mathematical model is based on the relative deviation of mass flow rate between the DUT and the gravimetric flow system.

$$E = \frac{\dot{m}_{\mathrm{DUT}} - \dot{m}_{\mathrm{REF}}}{\dot{m}_{\mathrm{REF}}} \qquad (1)$$

Here, the locations of DUT and REF are shown in Fig. 2. Since mass flow rate consists of volume flow rate and density, Eq. (1) can be written as follows.

$$E = \frac{\rho_{\mathrm{DUT}}}{\rho_{\mathrm{REF}}}\frac{q_{\mathrm{DUT}}}{q_{\mathrm{REF}}} - 1 \qquad (2)$$

The volume flow rate of the WFSS is as follows.

$$q_{\mathrm{REF}} = \frac{\varepsilon W}{\rho_{\mathrm{REF}} t} \qquad (3)$$

If Eq. (3) is substituted into Eq. (1), E becomes as follows.

$$E = \frac{\rho_{\mathrm{DUT}} q_{\mathrm{DUT}} t}{\varepsilon W} - 1 \qquad (4)$$

The measurement uncertainty of E can be summarized after manipulating each uncertainty factor carefully.

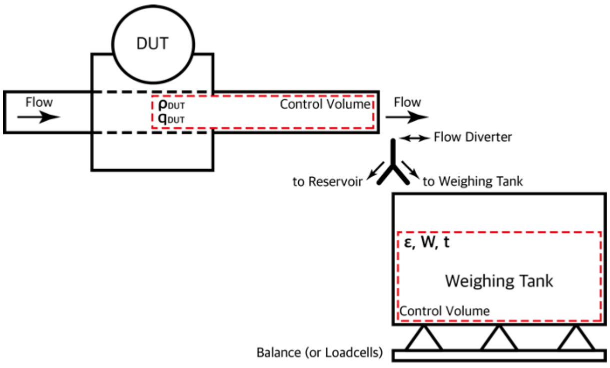

Figure 2: Control volume of the water flow standard system.

$$u(E) = \sqrt{\begin{array}{c} u(E_{\mathrm{A}})^2 \\ +\left(c_{\mathrm{r}\,\rho_{\mathrm{DUT}}} u_{\mathrm{r}}(\delta\rho_{\mathrm{DUT}})\right)^2 + \left(c_{\mathrm{r}\,q_{\mathrm{DUT}}} u_{\mathrm{r}}(\delta q_{\mathrm{DUT}})\right)^2 \\ +\left(c_{\mathrm{r}\,W} u_{\mathrm{r}}(\delta W)\right)^2 + \left(c_{\mathrm{r}\,t} u_{\mathrm{r}}(\delta t)\right)^2 + \left(c_{\mathrm{r}\,\varepsilon} u_{\mathrm{r}}(\delta\varepsilon)\right)^2 \end{array}} \qquad (5)$$

Here, $u(E_{\mathrm{A}})$ is the type A uncertainty of E.

$$u(E_{\mathrm{A}}) = \sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(E_i - \bar{E})^2} \qquad (6)$$

$\delta\rho_{\mathrm{DUT}}$, δq_{DUT}, δW, δt, and $\delta\varepsilon$ are corrections for each uncertainty factor. The sensitivity coefficients of relative uncertainties, $u_{\mathrm{r}}(\delta\rho_{\mathrm{DUT}})$, $u_{\mathrm{r}}(\delta q_{\mathrm{DUT}})$, $u_{\mathrm{r}}(\delta W)$, $u_{\mathrm{r}}(\delta t)$, and $u_{\mathrm{r}}(\delta\varepsilon)$, are found to be either $(E+1)$ or $-(E+1)$.

The relative uncertainties are denoted with percent unit (%). It is noteworthy that $u(E)$ is also denoted with percent unit (%), but it is not relative uncertainty. This is the reason why the sensitivity coefficients are not exactly 1. Relative uncertainties for corrections are the type B uncertainties, which are traceable to the SI units. Therefore, the calibration certificates or the long-term deviations are included in the type B uncertainties. On the contrary, $u(E_{\mathrm{A}})$ is the type A uncertainty, which considers repeatable measurements of all the uncertainty factors.

It is also notable that a pulse counter was used to read the output of the DUT. Thus, the pulse counter played a role as an associated instrument(5). The sensitivity coefficient of the relative uncertainty of the pulse counter was 1. Thus, the uncertainty of the associated instrument could be incorporated into $u(E)$ without difficulty.

4. Experimental Results

An electro-magnetic flow meter (E+H, 53W1H) was calibrated with the WFSS at 50 m^3/h. The calibration was done according to ISO 4185:1980 Annex A.1.2(5). Its purpose was twofold. The first purpose was to check the performance of a flow diverter by changing elapsed time as stated in the ISO 4185:1980(6). The second purpose was to evaluate the measurement uncertainty of flow rate with the normal elapsed time.

The uncertainty budget of this example is shown in Table 1. The subscript 1 indicates the relative uncertainty due to calibration certificate. The subscript 2 indicates the effect of long-term stability. In case of the elapsed time, there are two additional meanings. δt_{DIV1} indicates the effect of elapsed time on the performance of flow diverter. δt_{DIV2} means the effect of flow stability on the

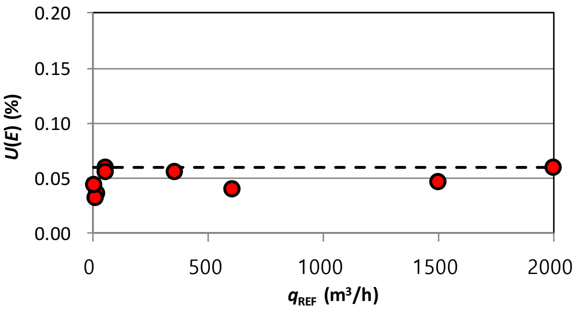

Figure 3: Distribution of the measurement uncertainty of the WFSS.

performance of the flow diverter. The flow stability is different from the repeatable measurements of E because the flow stability is based on the variation of flow rate of the gravimetric flow measurement system. On the contrary, the repeatable measurements are based on the comparison between the DUT and the gravimetric flow measurement system.

Finally, the distribution of measurement uncertainty of the WFSS is shown in Fig. 3. The measurement uncertainty is increased if the flow rate is decreased less than 50 m^3/h or increased more than 1500 m^3/h. Its main reason would be the characteristics of the flow diverter. Therefore, the flow diverter design would be an important part if the measurement uncertainty is to be improved further.

4. Conclusions

The water flow standard system (WFSS) at KRISS was rebuilt. This was an integrated flow meter calibration system by combining four weighing tanks and eight pipe lines. The flow range was from 0.6 m^3/h to 2000 m^3/h. And its measurement uncertainty was less than 0.06 % (k = 2). The mathematical model for the WFSS was based on the relative deviation between the gravimetric flow system (REF) and the test flow meter (DUT). This model incorporated the BED uncertainty because the repeatable measurements of the relative deviation should be considered. Relative notations of the uncertainty factors made the uncertainty budget better to read. The uncertainty evaluation procedure was correspondent with the WGFF resolutions.

Acknowledgement

This paper was supported by the Korea Research Institute of Standards and Science as “Measurement and Control Technology for Continuum Dynamics” (grant no. 16011010).

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Table 1: Uncertainty budget at 50 m^3/h with 5 t weighing tank.

X_i	x_i		$u(x_i)$		$p(x_i)$	$c(x_i)$	$c(x_i)\ u(x_i)$		ν_i
δW	0.0	kg	0.003	%	Gaussian	-1.0002	0.003	%	∞
δW_1	0.0	kg	0.002	%	Gaussian	1	0.002	%	∞
δW_2	0.0	kg	0.002	%	Rectangular	1	0.002	%	∞
δt	0.0	s	0.022	%	Student-*t*	1.0002	0.022	%	9
δt_{REF1}	0.0	s	0.001	%	Gaussian	1	0.001	%	∞
δt_{REF2}	0.0	s	0.001	%	Rectangular	1	0.001	%	∞
δt_{DIV1}	0.0	s	0.003	%	Student-*t*	1	0.003	%	39
δt_{DIV2}	0.0	s	0.022	%	Student-*t*	1	0.022	%	9
$\delta \rho_{\mathrm{DUT}}$	0.0	kg/m^3	0.017	%	Gaussian	1.0002	0.017	%	∞
$\delta \rho_{\mathrm{DUT1}}$	0.0	kg/m^3	0.017	%	Rectangular	1	0.017	%	∞
δT_{DUT1}	0.0	K	0.009	%	Gaussian	-0.049	0.000	%	∞
δT_{DUT2}	0.0	K	0.009	%	Rectangular	-0.049	0.000	%	∞
δq_{DUT}	0.0	m^3/h	0.000	%	Gaussian	1.0002	0.000	%	∞
δq_{DUT1}	0.0	m^3/h	0.000	%	Gaussian	1	0.000	%	∞
δf_{DUT1}	0.0	pulse	0.0000004	%	Gaussian	1	0.000	%	∞
δf_{DUT2}	0.0	pulse	0.0000004	%	Rectangular	1	0.000	%	∞
$\delta \varepsilon$	0.0		0.0004	%	Gaussian	-1.0002	0.0004	%	∞
E_{A}	0.02	%	0.010	%	Student-*t*	1	0.010	%	9
E	0.02	%					0.030	%	29
$u(E)$	0.02	%					0.060	%	