A New Calibration Facility for Small Flow of Hydrocarbon Liquid

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Abstract: A new calibration facility for small flow of hydrocarbon liquid has been established at National Metrology Institute of Japan (NMIJ). At present, the facility provides calibration service for hydrocarbon flowmeters in the mass flow range between 10 kg/h to 100 kg/h. The new primary standard adopts gravimetric calibration method with standing-start-and-finish using static weighing. Light oil is used as the working fluid.

Keywords: Small hydrocarbon flow calibration facility, mass flow rate, light oil, gravimetric and static weighing, standing-start-and-finish

1. Introduction

A new calibration facility for small flow of hydrocarbon liquid has been established at National Metrology Institute of Japan (NMIJ) to further expand the current calibration flow range of 0.1 m^3/h ~ 300 m^3/h to below 0.1 m^3/h. Measurement accuracy in small flow range is becoming critical in industrial practices such as evaluation of automobile fuel efficiency, blending of bio-fuel and petrol, and metering of household fuel consumption. As a national primary standard, the new calibration facility is intended to contribute to the establishment of measurement traceability in such flow range.

The new calibration facility started its service from April 2010. At the current stage, the facility provides calibration service for hydrocarbon flowmeters in the mass flow range between 10 kg/h to 100 kg/h. The calibration service will be expanded in stages to cater for volumetric flow rate and wider flow range. The new primary standard adopts gravimetric calibration method with standing-start-and-finish using static weighing. Light oil is used as the working fluid.

In the present paper, a detailed description of the facility is given in the following section. Next, evaluation of the measurement uncertainty of the facility in accordance with the ISO/IEC Guide [1] is presented. Finally, the future challenges and plan drawn up for this facility is discussed.

2. Calibration Facility

2.1 Configuration

A schematic diagram of the facility is shown in Fig. 1. The facility comprises three main sections, namely (a) flow generation section, (b) test section and (c) weighing section. The flow generation section consists of a storage tank, a magnetic gear pump, a heat exchanger and a header tank. The working fluid, which is the light oil, is stored in the storage tank which has a capacity of 26 L. Fine mesh screen is mounted inside the storage tank at 30 ^{0} against the flow to remove any bubbles generated in the working fluid. The working fluid is delivered into the flow loop by the magnetic gear pump whose revolution speed is variable. The magnetic gear pump is capable of producing maximum flow rate of 11 L/min at pressure head of 0.87 MPa. Temperature of the working fluid in the flow loop is controlled by the heat exchanger. The heat exchanger has cooling power of 900 W and heating power of 2.5 kW. Temperature of the working fluid can be maintained at any value in the range of 15 ^{0}C ~35 ^{0}C. In the flow generation section, the flow circulates in such direction that the working fluid is sent by the pump from the storage tank through the heat exchanger before entering the header tank. From the header tank, a portion of the working fluid is released into the test line while the remaining is circulated back to the storage tank. The header tank is cylindrical in shape and has a capacity of 2 L. The header tank takes the role of stabilizing any pulsating flow as well as adjusting the fluid pressure before the working fluid is delivered into the test line.

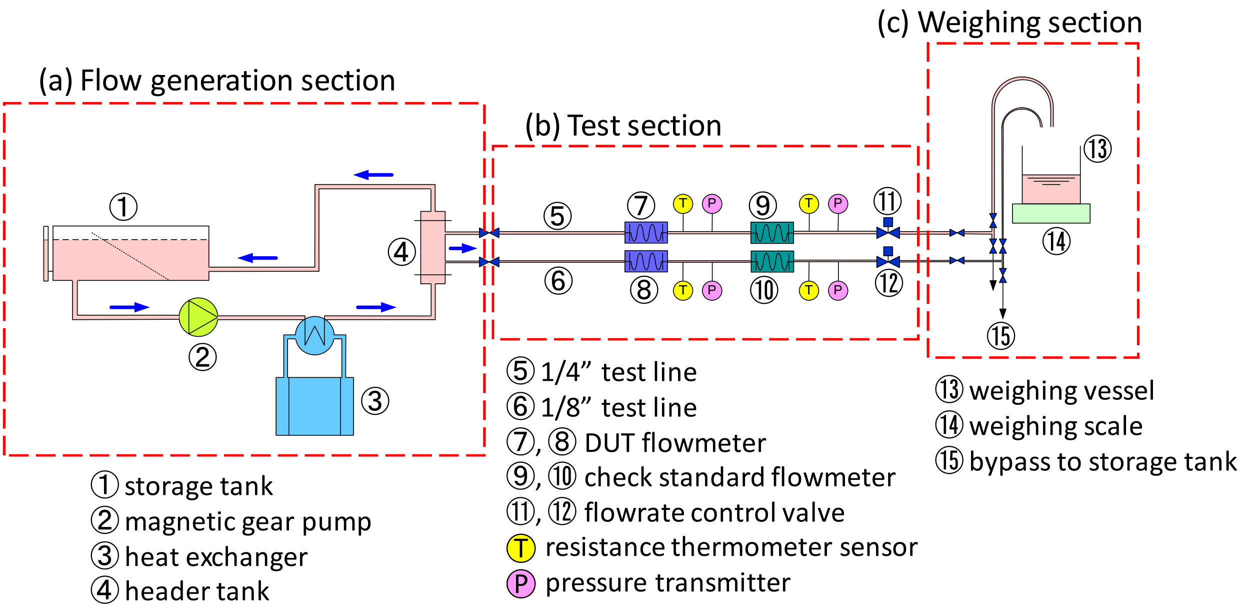

Fig. 1 Schematic of the calibration facility

In the test section, there are two test lines of which the outer diameters are 6.35 mm and 3.2 mm respectively. Flowmeters to be calibrated (identified as device under test (DUT) in Fig. 1) are mounted on the test lines at such a position that the upstream straight length is more than 100 times of the outer diameter of the test line. Flowmeters which act as the check standards are set up downstream of the DUTs. Since the facility only calibrates mass flow rate at the moment, Coriolis mass flowmeters are being used as the check standards. Meanwhile, thermometer sensor and pressure transmitter are being set up at downstream of each of the DUTs and check standards. The flowrate in the test line is regulated by the flowrate control valve mounted on each test line.

In the weighing section, working fluid is accumulated in a weighing vessel (beaker) being placed on a weighing scale. The weighing scale has a capacity of 6.2 kg, readability of 0.01 g and resolution of 1/620000. Switching of flow direction either to the weighing vessel or to the bypass to storage tank is controlled by air-actuated valves. To minimize any disturbances caused by air ventilation in the testing room, the weighing scale, with the weighing vessel on top of it, is placed inside an enclosed chamber. An actual picture of the calibration facility is shown in Fig. 2.

2.2 Calibration Procedure

As mentioned before, this calibration facility applies standing-start-and-finish gravimetric calibration method using static weighing. The flowmeters to be calibrated are restricted to pulse-output type, of which the pulse frequency generated is proportional to the flow rate. Data acquisition for calibration is shown in Fig. 3. Basically, the weight of the collected liquid in the weighing vessel shown by the weighing scale and the number of pulses obtained by the pulse counter over the duration of liquid collection are the two main quantities acquired for calibration of mass flow rate. The flowmeter to be calibrated and the check standard (reference flowmeter), namely the Coriolis mass flowmeter, can be simultaneously calibrated using the primary standard, in order to check the performance of the calibration system by comparing the K-factor of the check standard.

Fig. 2 Calibration facility

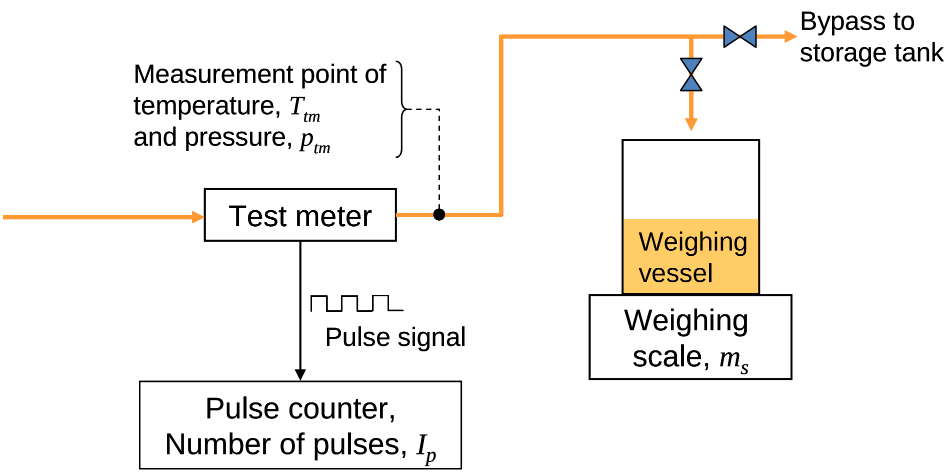

Fig. 3 Data acquisition for calibration

2.3 Safety Measures

Since the calibration facility involves the handling of inflammable liquid, certain safety measures were taken although the quantity of inflammable liquid does not reach the limit that requires compulsory fire safety measures. The testing room is designated as hazardous area due to the use of inflammable liquid. The room is being ventilated and humidified at all time. Lighting and electrical wiring in the room was also installed in accordance with explosion-proof measures. All the measurement devices such as thermometer sensors, pressure transmitters and weighing scale, as well as the check standard flowmeters are all explosion-proof.

3. Analysis of Measurement Uncertainty

Analysis of measurement uncertainty was performed under the condition that there is no leakage of liquid and no generation of bubbles between the flowmeter under calibration and the nozzle directing the liquid into the weighing vessel. Analysis of measurement uncertainty is summarized as follows.

The K-factor, K_{fm} (pulse/g) of the flowmeter is obtained by

$$K_{fm} = \frac{I_p}{k_s(M_e - M_i)}\left(1 - \frac{\rho_{air}}{\rho_L}\right) + \Delta K_{sd} \tag{1}$$

where I_p (pulse) is the number of pulses totalized by the pulse counter over the duration of liquid collection time. M_i (g) and M_e (g) are the readings of the weighing scale before and after the collection of liquid, respectively. k_s is the correction factor of the weighing scale. ρ_{air} (g/cm^3) and ρ_L (g/cm^3) are the air density surrounding the weighing scale and liquid density in the weighing vessel, respectively. ΔK_{sd} represents the error caused by the standing-start-and-finish method. Thus, the relative combined standard uncertainty of K-factor is expressed as follows.

$$\left\{\frac{u_c(K_{fm})}{K_{fm}}\right\}^2 = \left\{\frac{u(I_p)}{I_p}\right\}^2 + \left\{\frac{u(k_s)}{k_s}\right\}^2 + \left\{\frac{u(M_e - M_i)}{M_e - M_i}\right\}^2 + \left\{\frac{u(1-\rho_{air}/\rho_L)}{1-\rho_{air}/\rho_L}\right\}^2 + \left\{\frac{u(\Delta K_{sd})}{K_{fm}}\right\}^2 \tag{2}$$

The terms on the right side of the equation represent the uncertainties due to pulse count, correction factor of weighing scale, measurement of weighing scale, buoyancy effect correction and standing-start-and-finish method, respectively. Each uncertainty source is discussed as follows.

3.1 Pulse Count

The resolution of the pulse counter is assumed to be 1 and is subjected to the rectangular distribution of ± 0.5. Thus the pulse count corresponding to the time duration of liquid collection t is given by

$$t = I_p \pm \sqrt{\left(\frac{0.5}{\sqrt{3}}\right)^2 + \left(\frac{0.5}{\sqrt{3}}\right)^2} = I_p \pm 0.408 \text{ pulse} \tag{3}$$

Then the relative standard uncertainty is $u(I_p)/I_p$.

3.2 Correction Factor for Weighing Scale

The weighing scale was calibrated by standard weights in ambient air density of ρ_{air}. The correction factor for weighing scale, k_s is obtained by

$$k_s = \frac{M_{cal}}{M_s}(1 - \frac{\rho_{air}}{\rho_{cal}} + \delta a_s + \delta T_s + \delta E_s) + \frac{\delta m_r}{M_s} + \delta k_{rep} \tag{4}$$

where

M_{cal} : standard weight value

M_s : reading of weighing scale loaded with standard weight

ρ_{air} : air density = 0.0012 g/cm^3

ρ_{cal} : standard weight density = 8 g/cm^3

δa_s : linearity of weighing scale

δT_s : temperature effect on weighing scale

δE_s : off-center loading effect on weighing scale

δm_r : repeatability of weighing scale

δk_{rep} : reproducibility of weighing scale

As it can be assumed that $k_s \approx 1, M_s \approx M_{cal}$, the uncertainty of k_s is estimated as follows.

$$\begin{aligned}\{u(k_s)\}^2 = &\left\{\frac{u(M_{cal})}{M_{cal}}\right\}^2 + \left\{\frac{u(M_s)}{M_s}\right\}^2 + \left\{\frac{u(\rho_{air})}{\rho_{cal}}\right\}^2 \\ &+ \{u(\delta a_s)\}^2 + \{u(\delta T_s)\}^2 + \{u(\delta E_s)\}^2 + \left\{\frac{u(\delta m_r)}{M_s}\right\}^2 + \{u(\delta k_{rep})\}^2\end{aligned} \tag{5}$$

3.3 Reading of Weighing Scale

The weight of the liquid collected in the weighing vessel is obtained from the difference between the weighing scale readings before and after the liquid collection. The reading fluctuation is estimated to be similar to the readability of the weighing scale. Hence the uncertainty of the measurement reading during tare reset and rounding of the weight value is obtained as follows.

$$u(M_e - M_i) = \sqrt{u(M_e)^2 + u(M_i)^2} \tag{6}$$

3.4 Buoyancy Effect Correction

Buoyancy effect correction is performed based on the ambient air density surrounding the weighing scale, ρ_{air} (g/cm^3) and liquid density inside the weighing vessel, ρ_L (g/cm^3). The uncertainty due to the buoyancy effect correction is expressed as follows.

$$\left\{u\left(1 - \frac{\rho_{air}}{\rho_L}\right)\right\}^2 = \left\{\frac{u(\rho_{air})}{\rho_L}\right\}^2 + \left\{\frac{\rho_{air}}{\rho_L}\frac{u(\rho_L)}{\rho_L}\right\}^2 \tag{7}$$

3.5 Ultimate Uncertainty for Calibration of K-factor

Uncertainty sources owing to the calibration facility are discussed in sections 3.1~3.4. In this section, uncertainty of K-factor due to the randomness (dispersion in repeated calibrations) of flowmeter itself is discussed. The uncertainty for repeated calibrations of K-factor is defined as follows.

$$\overline{K_{fr}} = \frac{1}{n}\sum_{i=1}^{n} K_{fri} \quad (8), \qquad s^2(K_{fri}) = \frac{\sum_{i=1}^{n}(K_{fri} - \overline{K_{fr}})^2}{n-1} \quad (9), \qquad u(\overline{K_{fr}}) = \sqrt{\frac{s^2(K_{fri})}{n}} \quad (10)$$

n : number of repeated calibrations
K_{fri} : K-factor obtained from calibration no. i
$\overline{K_{fr}}$: averaged K-factor obtained from n calibrations
$s^2(K_{fri})$: variance (dispersion) of K-factor
$u(\overline{K_{fr}})$: standard uncertainty of averaged K-factor

The ultimate uncertainty of K-factor for flowmeter under calibration is a combination of uncertainty sources pertaining to the calibration facility and the flowmeter itself, which is given below.

$$\frac{u_c(K_f)}{|K_f|} = \sqrt{\left(\frac{u_c(K_{fm})}{|K_{fm}|}\right)^2 + \left(\frac{u(\overline{K_{fr}})}{|\overline{K_{fr}}|}\right)^2} \quad (11)$$

where

$\frac{u_c(K_f)}{|K_f|}$: combined ultimate uncertainty of K-factor for flowmeter under calibration

$\frac{u_c(K_{fm})}{|K_{fm}|}$: uncertainty due to calibration facility

$\frac{u_c(K_{fr})}{|K_{fr}|}$: uncertainty due to flowmeter itself

4. Future Challenges

The measurement uncertainty of the calibration facility will be improved in stages. The facility will also be upgraded to cater for other types of working liquid such as kerosene and to cover wider range of mass flow rate as well as volumetric flow rate. Other challenges include the automation of the facility and shifting to flying-start-and-finish method.

5. Conclusion

A new calibration facility for small flow of hydrocarbon liquid has been established at National Metrology Institute of Japan (NMIJ). At present, the facility provides calibration service for hydrocarbon flowmeters in the mass flow range between 10 kg/h to 100 kg/h by applying gravimetric calibration method with standing-start-and-finish using static weighing. Light oil is used as the working fluid.

6. Reference

[1] ISO/IEC Guide 98-3: 2008