< Final report >
Report on the APMP.M.F-S3 supplementary comparison for 1 kN force

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1. Introduction

This supplementary comparison, named APMP.M.F-S3, was carried out at small forces of 500 N and 1 kN. It was based on an international cooperation scheme for verifying degree of equivalence between 1 kN and 20 kN dead-weight type force standard machines (DWMs) of RCM-LIPI (Indonesia) and 3 kN DWM of NMIJ (Japan). It was also a challenge for both NMIJ and RCM-LIPI to make a comparison in small force range below 5 kN; that is, the comparison has no suitable corresponding international comparison for linkage. NMIJ organized the comparison as the pilot laboratory and RCM-LIPI participated in. This report describes scheme and results of the comparison.

2. Force standard machines participated in the comparison

2.1 General information

Force standard machines participated in this comparison are listed in Table 1.

Table 1. Force standard machines and participating laboratories.

Force standard machines			Institute
Capacity / kN	Type	Relative standard uncertainty of applied force	
3	Deadweight	5.4×10^{-6}	NMIJ (pilot lab)
1	Deadweight	2.0×10^{-5}	RCM-LIPI
20	Deadweight	1.5×10^{-5}	RCM-LIPI

2.2 Summary of the NMIJ's 3 kN DWM

The 3 kN DWM, as shown in Fig. 1, has a loading frame acting as a 100 N weight and two series of linkage weights. The upper series consists of ten 2 kN weights and the lower one has ten 1 kN weights. Both of the weight series are mounted on the supporting plates and the plates are driven independently by servomotors and screws. The loading table can be rotated by a motor with a compressive force measuring device mounted on it, and one calibration sequence including rotational position change of the device can be conducted automatically not only in ordinary calibrations according to ISO 376 but also in special cases such as one according to this comparison protocol.

Fig. 1. The NMIJ's 3 kN DWM (right half of the two machines).

2.3 Summary of the RCM-LIPI's 1 kN DWM

The 1 kN DWM, as shown in Fig. 2, is a manually operated machine. The weights used in this machine are in form of separated disk weights, not a linkage weights. This machine has a loading frame acting as 40 N weight and a set of disk weights with nominal of 10 N, 20 N, 50 N, 100 N and 200 N. For this comparison the used weights are 1 × 10 N, 1 × 50 N, 1 × 100 N and 4 × 200 N. Both loading and changing rotational positions of the force measuring device are operated manually.

Fig. 2. The RCM-LIPI's 1 kN DWM.

2.4 Summary of the RCM-LIPI's 20 kN DWM

The 20 kN DWM has a loading frame acting as a 200 N weight and one series of linkage weights consist of 4 × 100 N, 7 × 200 N, 6 × 500 N, 5 ×1000 N and 5 × 2000 N weights. For this comparison the used weights are 2 × 100 N and 3 × 200 N. The operation of this machine is automatic, but the rotation of the force measuring device is manual.

Fig. 3. The RCM-LIPI's 20 kN DWM.

3. Traveling artifacts and measuring amplifiers

3.1 Traveling artifacts

The following equipment was prepared by RCM-LIPI and was circulated as the traveling artifacts.

1) Force transducer

   Capacity: 1 kN (compressive force)

   Manufacturer: Hottinger Baldwin Messtechnik (HBM) GmbH

   Type: TOP-Z30A

   Serial number: 171113017

2) Bridge calibration unit

   Manufacturer: HBM GmbH

   Type: BN100A

   Serial number: 17152

3.2 Measuring amplifiers

Measuring amplifiers adopted for the comparison are listed in Table 2. The important settings applied for all measurements are the bridge excitation voltage of 5 V, the measuring range of 2.5 mV/V, the resolution of 0.000001 mV/V, and the cut-off frequency of low-pass filter of 0.1 Hz. Each measuring amplifier was checked just before and after the measurement by referring to the bridge calibration unit mentioned above at the settings of +0.0, +0.2, +1.0, +1.2, +2.0, and +2.2 mV/V and also at the amplifier's internal calibration signal of 2.5 mV/V. Readings of the measuring amplifier connected with the force transducer were corrected based on the check results before calculating the deflections.

Table 2. Measuring amplifiers used for the comparison.

Institute	Measuring amplifier		
	Manufacturer	Type	Serial number
RCM-LIPI	HBM GmbH	DMP40	123120093
NMIJ	HBM GmbH	DMP40S2	021420022

4. Comparison scheme and measurement procedures

The comparison scheme is based on other forgoing bilateral comparisons between force standard machines [1–4]. The first group of measurements was carried out at RCM-LIPI, and the intermediate and last groups were performed by NMIJ and RCM-LIPI, respectively. The first and last groups of measurements was carried out at RCM-LIPI respectively using the 1 kN and 20 kN DWMs, and the intermediate measurements was performed by NMIJ using the 3 kN DWM. The date and conditions of each measurement were listed in Table 3. The stability of sensitivity was estimated by difference between the first and last measurements executed by RCM-LIPI.

Loading procedure is depicted as Fig. 4. Following to three preloads between 0 N and 1 kN, three repetitious measurement cycles at 0 N, 500 N, and 1 kN were performed in the first force transducer's orientation of 0° in order to check simple repeatability of the measurement in the same orientation. After that, four sets each consisted of a preloading and a measurement cycle at 0 N, 500 N, and 1 kN were carried out to evaluate reproducibility in four different orientations of 90°, 180°, 270°, and 360°. All readings were noted in 3 minutes time intervals; hence, the total time for one measurement sequence was 117 minutes.

The all measurements were carried out at room temperature of (20.0 ± 0.5) °C. The force transducer was regarded to be insensitive to fluctuations of ambient pressure and humidity.

Table 3. Date and conditions of each measurement.

Identification	Date	Force standard machine	Ambient conditions
R1	6 Jan. 2017	1 kN DWM of RCM-LIPI	19.9 °C to 20.2 °C, 61 % to 65 % 99.6 kPa to 99.7 kPa
R2	3 Feb. 2017	20 kN DWM of RCM-LIPI	20.0 °C to 20.2 °C, 56 % 100.2 kPa
N	16 Feb. 2017	3 kN DWM of NMIJ	20.0 °C to 20.1 °C, 41 % 102.0 kPa to 102.1 kPa
R3	2 Mar. 2017	1 kN DWM of RCM-LIPI	19.8 °C to 20.2 °C, 61 % to 65 % 99.8 kPa to 99.9 kPa
R4	2 Mar. 2017	20 kN DWM of RCM-LIPI	19.9 °C to 20.2 °C, 60 % to 63 % 100.2 kPa to 100.3 kPa

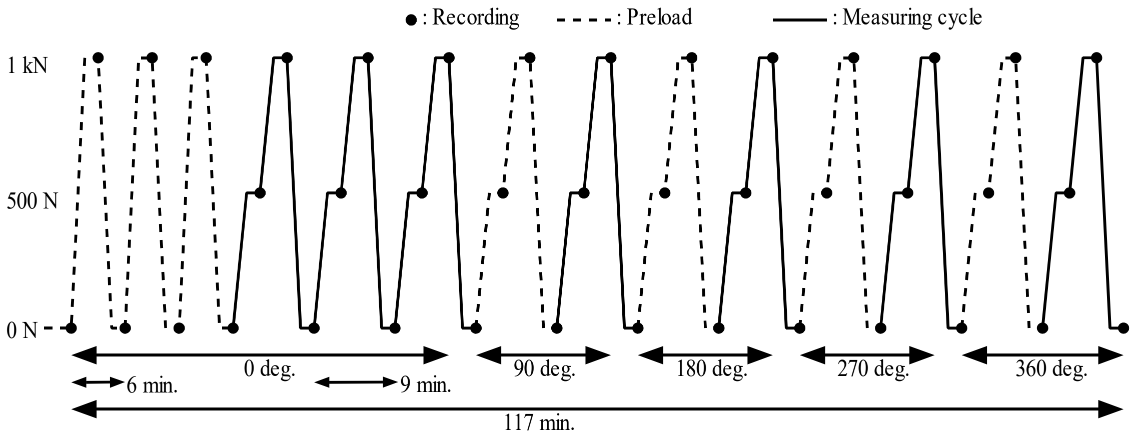

Fig. 4. Loading chart for the comparison.

5. Results

5.1 Stability of the traveling artifacts

Stability in sensitivity of the traveling artifacts consisting of the force transducer and the bridge calibration unit was estimated by the difference between the first and last measurements at RCM-LIPI. The force transducer was measured using the 1 kN and 20 kN DWMs; that means two values of sensitivity drift were evaluated between R1 and R3, and between R2 and R4, for each. These values of the sensitivity drift were taken into account when estimating uncertainty of the comparison; however, the sensitivity drifts of the force transducer did not exceed 6 nV/V even in the worst case. This sufficiently stable force transducer made the comparison meaningful, although it was the first challenge for the both institutes to carry out a comparison in such a small force range,

The bridge calibration unit was also monitored using the same measuring amplifier of RCM-LIPI. It also demonstrated sufficient stability, since changes in indications of the same measuring amplifier were 7 nV/V at the largest during the comparison. The value was also taken into account in the uncertainty estimation.

5.2 Uncertainty evaluation of each measurement

Following uncertainty sources are taken into account for each measurement tabulated in Table 3.

1) Uncertainty arisen from the applied force, w_{fsm}

2) Uncertainty arisen from the reproducibility among four orientations of 90°, 180°, 270°, and 360°, w_{rot}

3) Uncertainty arisen from the resolution of the measuring amplifier, w_{res}

4) Uncertainty arisen from the temperature fluctuation of the artifacts during the measurement, w_{temp}

5) Uncertainty arisen from the DMP40 correction, w_{dmp}

6) Uncertainty arisen from the sensitivity drift of the force transducer (only for RCM-LIPI), w_{drift}

Here, uncertainty sources of w_{rot}, w_{res}, w_{temp}, and w_{dmp} are regarded as uncorrelated, and combined using propagation law of uncertainty when weighted means are calculated as mentioned below. Other uncertainty sources are treated as correlated ones and combined by taking square root of sum of squares of these uncertainties, after calculation of weighted mean values. Uncertainty arisen from the DMP40 correction was estimated using the maximum change in the amount of corrections referring to the same BN100A between the first and the last measurement groups. Uncertainties arisen from the ambient condition differences of the two institutes were not considered because maximum temperature and pressure differences among all of the measurements were only 0.2 °C and 2.5 kPa, respectively, and were regarded as negligible against the comparison uncertainty.

Mean deflections and uncertainties of each measurement are listed in Table 4 and depicted in Fig. 5. The mean deflection at each force step of each measurement was an average of four values measured in four orientations of 90°, 180°, 270°, and 360°. In this phase, relative expanded uncertainty was calculated with considering only the uncertainty sources of w_{fsm}, w_{rot}, w_{res}, w_{temp}, and w_{dmp}. Note that all of the expanded uncertainties given in this report correspond to the level of confidence of approximately 95 % with coverage factors of $k = 2$.

Table 4. Mean deflection and uncertainty of each measurement.

ID	Institute	Force standard machine	500 N		1 kN	
			Deflection X / (mV/V)	Relative expanded uncertainty $W(X)$ / 10^{-6}	Deflection X / (mV/V)	Relative expanded uncertainty $W(X)$ / 10^{-6}
R1	RCM-LIPI	1 kN DWM	1.000187	41	2.000328	43
R2	RCM-LIPI	20 kN DWM	1.000197	31	2.000340	30
N	NMIJ	3 kN DWM	1.000193	12	2.000332	11
R3	RCM-LIPI	1 kN DWM	1.000188	41	2.000321	43
R4	RCM-LIPI	20 kN DWM	1.000197	31	2.000343	30

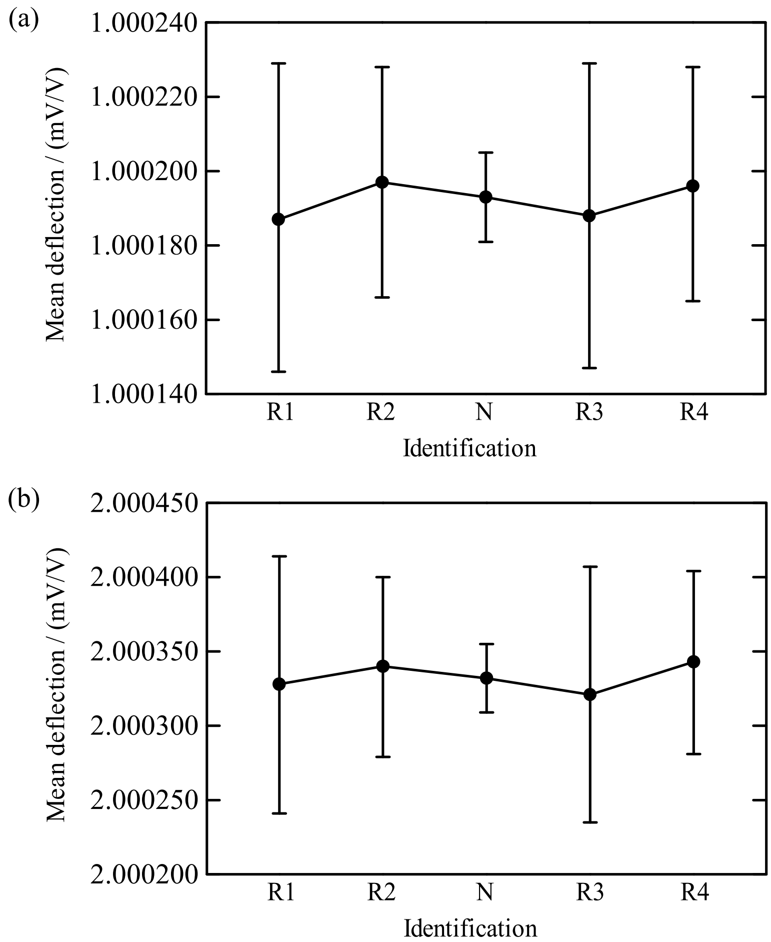

Fig. 5. Mean deflections and uncertainties of each measurement (a) at 500 N and (b) at 1 kN.

5.3 Weighted mean of the first and last measurements at RCM-LIPI

Weighted mean deflection of X_{R13} was calculated from two deflections of X_{R1} and X_{R3} to cancel influence of the sensitivity drift of the force transducer as eq. (1). Here, $w(X)$ means relative combined standard uncertainty of the deflection X. X_{R24} was computed from X_{R2} and X_{R4} in the same manner.

$$X_{\mathrm{R13}} = \frac{\dfrac{X_{\mathrm{R1}}}{w^2\left(X_{\mathrm{R1}}\right)} + \dfrac{X_{\mathrm{R3}}}{w^2\left(X_{\mathrm{R3}}\right)}}{\dfrac{1}{w^2\left(X_{\mathrm{R1}}\right)} + \dfrac{1}{w^2\left(X_{\mathrm{R3}}\right)}} \tag{1}$$

Because two deflections of X_{R1} and X_{R3} were obtained by using the same 1 kN DWM of RCM-LIPI, these two values were considered to be correlated and relative uncertainty w_{R13} was calculated as eq. (2). Here, $w(X_{\_\mathrm{uncorr}})$ means combined uncertainty arisen from uncorrelated sources; that is, combination of w_{rot}, w_{res}, w_{temp}, and w_{dmp}.

$$
\begin{aligned}
w\left(X_{\mathrm{R13}}\right) &= \sqrt{\left\{\left(\frac{\partial X_{\mathrm{R13}}}{\partial X_{\mathrm{R1}}}\right)^2 w^2\left(X_{\mathrm{R1}}\right)+\left(\frac{\partial X_{\mathrm{R13}}}{\partial X_{\mathrm{R3}}}\right)^2 w^2\left(X_{\mathrm{R3}}\right)+2\frac{\partial X_{\mathrm{R13}}}{\partial X \partial_{\mathrm{R1}}}\frac{\partial X_{\mathrm{R13}}}{\partial X_{\mathrm{R3}}} w\left(X_{\mathrm{R1}}, X_{\mathrm{R3}}\right)\right\}+w_{\mathrm{drift}}^2} \\
&= \sqrt{\left[\frac{\dfrac{w^2\left(X_{\mathrm{R1\_uncorr}}\right)}{w^4\left(X_{\mathrm{R1}}\right)}+\dfrac{w^2\left(X_{\mathrm{R3\_uncorr}}\right)}{w^4\left(X_{\mathrm{R3}}\right)}}{\left\{\dfrac{1}{w^2\left(X_{\mathrm{R1}}\right)}+\dfrac{1}{w^2\left(X_{\mathrm{R3}}\right)}\right\}^2}+w_{\mathrm{fsm}}^2\right]+w_{\mathrm{drift}}^2}
\end{aligned}
\tag{2}
$$

The mean deflections and relative uncertainties are listed in Table 5.

Table 5. Weighted mean deflections of the first and last measurements and their uncertainties.

ID	Force standard machine	500 N		1 kN	
		Deflection X / (mV/V)	Relative expanded uncertainty $W(X)$ / 10^{-6}	Deflection X / (mV/V)	Relative expanded uncertainty $W(X)$ / 10^{-6}
R13	1 kN DWM	1.000188	41	2.000324	42
R24	20 kN DWM	1.000197	31	2.000341	30

5.4 Equivalence between the force standard machines

Equivalence between forces realized by the DWMs are evaluated using relative deviation and comparison uncertainties as listed in Table 6. Relative expanded uncertainty of the comparison W_{comp} was calculated by taking square root of the sum of square of the two relative uncertainties $W(X)$ of the two related measurements.

All absolute values of the relative deviations in the table are within the respective relative expanded uncertainty of the comparison. Thus, it has been demonstrated that forces realized by the 1 kN and 20 kN DWMs of RCM-LIPI are equivalent to those by the 3 kN DWM of NMIJ at 500 N and 1 kN. The comparison results also suggests that, through the future work, it would be possible for RCM-LIPI to claim its improved calibration capability relevant to these two DWMs.

Table 6. Relative deviations and comparison uncertainties between the DWMs.

Force	ID	Force standard machine	Deflection X / (mV/V)	Relative expanded uncertainty $W(X)$ / 10^{-6}	Deviation / (mV/V)	Relative expanded uncertainty of comparison W_{comp} / 10^{-6}	Normalized error E_{n}
500 N	R13	1 kN DWM	1.000188	41	−0.000005	43	0.12
	N	3 kN DWM	1.000193	12			
	R24	20 kN DWM	1.000197	31	0.000004	33	0.12
	N	3 kN DWM	1.000193	12			
1 kN	R13	1 kN DWM	2.000324	42	−0.000008	43	0.09
	N	3 kN DWM	2.000332	11			
	R24	20 kN DWM	2.000341	30	0.000009	32	0.14
	N	3 kN DWM	2.000332	11			

6. Summary

The APMP.M.F-S3 supplementary comparison has been conducted between RCM-LIPI (Indonesia) and NMIJ (Japan) at small forces of 500 N and 1 kN. The comparison results revealed the equivalence of forces realized by the 1 kN and 20 kN DWMs of RCM-LIPI to those by the 3 kN DWM of NMIJ within their claimed uncertainties.

References

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