Force Key Comparison APMP.M.F-K2.1

Measurand Force:
50 kN, 100 kN

Final Report

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Participating Institutes: Vietnam Metrology Institute, Vietnam
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1. Introduction

KRISS (Korea Research Institute of Standards and Science) piloted the APMP comparison in the medium force range coded as APMP.M.F-K2, in which 13 laboratories in the Asia-Pacific region participated. The final report of the comparison was published [1]. VMI (Vietnam Metrology Institute) joined this comparison, however, using a force machine of a lever-amplification type with a relative uncertainty of 0.05% and in the range of 50 kN (scheme B). A new force machine with two ranges of 100 kN for deadweight forces and 1000 kN for lever-amplified forces was introduced to VMI after the comparison. Therefore, VMI needs to validate and update the CMCs (calibration and measurement capabilities) of the new force standard through a subsequent key comparison.

Recently, SASO-NMCC (Saudi Standards, Metrology and Quality Organization of the Kingdom of Saudi Arabia) set up a new 100 kN-capacity deadweight force machine and requested a comparison for the CMC registration. From these reasons, KRISS organized the subsequent key comparison coded as APMP.M.F-K2.1.

2. Comparison on measurand force at 50 kN and 100 kN

2.1 Participants' details

The participating laboratories are KRISS (Korea), VMI (Vietnam) and SASO-NMCC (Saudi Arabia). Their force standard machines (FSMs) and contact details are listed in Table 1 and 2, respectively.

Table 1: Participated institutes and torque standard machines

Institute	Force Standard Machine			Note
	Capacity in kN	Type	Relative expanded uncertainty of applied force in %	
KRISS	100	Deadweight	0.002	Pilot, Link Lab.
VMI	100	Deadweight	0.002	
SASO-NMCC	100	Deadweight	0.002	

Table 2: Contact details

KRISS	VMI	SASO-NMCC
Min-Seok Kim	Pham Thanh Ha	Abdulelah Bin Awn and Hamad A. Al Gamdi
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2.2 Measurement Details

The protocol was the same as one used in APMP.M.F-K2 except the reference temperature, which had been changed from 23 °C to 20 °C with consensus among participants. It should be noted that KRISS 100 kN deadweight machine was moved to the new mechanical metrology building in 2015. From this reason, we suspected that the reference values at KRISS could have changed from the ones measured during the campaign of the APMP.M.F-K2 conducted from 2008 to 2014, though internal checks through comparisons on forces at the overlapped ranges among KRISS force standard machines and a measurement of acceleration of gravity at new site revealed that difference of the reference values between before and after move could be negligible.

2.3 Traveling standard

The details of travelling standards and a bridge calibration unit used for this comparison are tabulated in Table 3. The GTM transducer coded as Tr1 had been used for APMP.M.F-K2 while the HBM transducer coded as Tr2 has been replaced with the old one.

Table 3: Transducers and a bridge calibration unit used in the comparison

Type	Identification Code	Manufacturer	Serial Number	Model
Transducer	Tr1	GTM	45851	KTN-D
Transducer	Tr2	HBM	100230021	Z4A
Bridge Calibration		HBM	07106	BN100A

2.4 Sensitivity coefficient of transducers

The temperature sensitivity coefficient for each transducer was evaluated for temperature correction using the Monte-Carlo method in [2]. The determined values are tabulated in Table 4.

Table 4: Temperature coefficients of transducers used for travelling standards

Identification Code	Force kN	Sensitivity Coefficient (mV/V)/K	Uncertainty (mV/V)/K
Tr1	50	3.3E-05	4E-06
	100	8.4E-05	3E-05
Tr2	50	1.1E-05	5E-06
	100	2.8E-05	9E-06

2.5 Measurement results

The measurement results from the pilot and participants are chronologically displayed in the Table 5 and 6 using Tr1 and Tr2, respectively. The deflections were corrected for the amplifier (DMP40) and temperature effect by the pilot. Pilot laboratory calculated each of the relative expanded uncertainties of deflections by combining the standard uncertainties due to the force generation, repeatability, reproducibility, resolution of the indicator and temperature correction [3]. The loop values were determined as weighted means of two neighboring pilot results, and their relative uncertainties include drift of two neighboring pilot results and uncertainties of the weighted means. The relative uncertainty of the relative deviation was estimated as a root of squared sum of relative uncertainty of a loop value and a corresponding result of a participating laboratory.

It is clearly seen that the relative deviations of SASO-NMCC with Tr2 transducer show large relative deviations compared with their uncertainties. It should be noted that SASO-NMCC reported an electrical potential difference between the force machine and the Tr2 (HBM) transducer during measurements. That potential difference was large enough to generate electrical spike when a metal rod touched the machine and a load button together, suggesting that electrical grounds have not been sufficiently provided to the machine or the DMP40 amplifier. The return measurements at KRISS with Tr2 transducer after SASO-NMCC measurements revealed that the deflections had been changed permanently by approximately 0.01% due to the effect of such electrical potential difference. Such large drifts in two neighboring pilot results of Tr2 increase uncertainties of the loop values for SASO-NMCC.

Table 5: Measured deflections of the Tr1 force transfer standard in chronological order.

Lab	Date (YYMMDD)	Deflection (mV/V)	Average Temp (°C)	Corrected deflection (mV/V)	Relative expanded uncertainty	Loop value (mV/V)	Relative expanded uncertainty of the loop value	Relative deviation	Relative uncertainty of the relative deviation
	50 kN								
Pilot	180918	0.999 544	20.1	0.999 526	2.8E-05				
VMI	181107	0.999 472	20.0	0.999 516	4.2E-05	0.999 527	2.3E-05	-1.1E-05	4.8E-05
Pilot	190108	0.999 533	20.1	0.999 528	2.3E-05				
NMCC	190528	0.999 543	20.3	0.999 536	2.9E-05	0.999 527	2.1E-05	8.9E-06	3.6E-05
Pilot	191120	0.999 533	20.2	0.999 526	2.2E-05				
	100 kN								
Pilot	180918	1.999 214	20.1	1.999 184	3.8E-05				
VMI	181107	1.999 068	20.0	1.999 157	4.8E-05	1.999 174	2.5E-05	-8.6E-06	5.4E-05
Pilot	190108	1.999 180	20.1	1.999 170	2.5E-05				
NMCC	190528	1.999 186	20.3	1.999 167	3.0E-05	1.999 170	2.2E-05	-1.5E-06	3.7E-05
Pilot	191120	1.999 187	20.2	1.999 170	2.3E-0.5				

Table 6: Measured deflections of the Tr2 force transfer standard in chronological order.

Lab	Date (YYMMDD)	Deflection (mV/V)	Average Temp (°C)	Corrected deflection (mV/V)	Relative expanded uncertainty	Loop value (mV/V)	Relative expanded uncertainty of the loop value	Relative deviation	Relative uncertainty of the relative deviation
	50 kN								
Pilot	180920	0.999 621	20.0	0.999 613	2.1E-05				
VMI	181108	0.999 568	20.0	0.999 612	3.5E-05	0.999 607	2.2E-05	5.0E-06	4.1E-05
Pilot	190110	0.999 619	20.1	0.999 601	2.1E-05				
NMCC	190530	0.999 674	19.5	0.999 745	3.0E-05	0.999 649	6.0E-05	9.6E-05	6.7E-05
Pilot	191121	0.999 700	20.2	0.999 698	2.1E-05				
	100 kN								
Pilot	180920	1.999 428	20.0	1.999 421	2.2E-05				
VMI	181108	1.999 311	20.0	1.999 398	4.1E-05	1.999 408	2.1E-05	-5.2E-06	4.6E-05
Pilot	190110	1.999 425	20.1	1.999 398	2.0E-05				
NMCC	190528	1.999 483	19.5	1.999 620	3.0E-05	1.999 479	5.3E-05	7.1E-05	6.1E-05
Pilot	191121	1.999 572	20.2	1.999 566	2.1E-05				

2.6 Linking comparison results to APMP.M.F-K2

2.6.1 Relative overall deviations of participating laboratories

In order to link the results of APMP.M.F-K2.1 to those of APMP.M.F-K2, the comparison results obtained from two transfer standards should be combined for each force first. It seems reasonable that this could be done by taking a weighted mean of relative deviations of Tr1 ($d_{i,Tr1}$) and Tr2 ($d_{i,Tr2}$) measurements [4]. The overall relative deviation D_i between the ith participant and the pilot and its corresponding relative expanded uncertainty $W(D_i)$ can be calculated using Equation (1) and (2), respectively.

$$D_i = \frac{d_{i,Tr1}/W(d_{i,Tr1})^2 + d_{i,Tr2}/W(d_{i,Tr2})^2}{1/W(d_{i,Tr1})^2 + 1/W(d_{i,Tr2})^2} \quad (1)$$

$$W(D_i) = \frac{W(d_{i,Tr1}) * W(d_{i,Tr1})}{W(d_{i,Tr1})^2 + W(d_{i,Tr2})^2} \times \sqrt{W(d_{i,Tr1})^2 + W(d_{i,Tr2})^2 + 2r(d_{i,Tr1}, d_{i,Tr2})W(d_{i,Tr1})W(d_{i,Tr1})} \quad (2)$$

where, $r(d_{i,Tr1}, d_{i,Tr2})$ is a correlation coefficient between two measurements using Tr1 and Tr2. They are correlated each other because the same force machine of each participant and that of pilot was used to obtain them. The calculated overall relative deviations and the corresponding uncertainties are given in Table 7.

Table 7: Overall relative deviation of each participant to pilot and corresponding relative expanded uncertainty.

Lab	50 kN		100 kN	
	Overall relative deviation	Relative expanded uncertainty	Overall relative deviation	Relative expanded uncertainty
KRISS	0.0E+00	2.0E-05	0.0E+00	2.1E-05
VMI	-1.9E-06	3.4E-05	-6.6E-06	3.8E-05
NMCC	2.8E-05	3.4E-05	1.8E-05	3.4E-05

2.6.2 Calculation of degree of equivalence

The degree of equivalence (DoE) of each participant's result can be estimated by linking it to KCRV. The relative deviation of each participant to the KCRV, $D_{i\text{-KCRV}}$ and the corresponding relative uncertainty can be calculated using Equation (3) and (4), respectively.

$$D_{i-KCRV} = D_i + D_{KR-KCRV} \quad (3)$$

$$W(D_{i-KCRV}) = \sqrt{W^2(D_i) + W^2(D_{KR-KCRV})} \quad (4)$$

where, $D_{KR\text{-}KCRV}$ is the deviation of the KRISS value to the KCRV reported in [1]. The DoEs of each participant for 50 kN and 100 kN are tabulated in Table 8 and graphically shown in Figure 1 and 2, respectively.

Table 8: DoEs of participants for 50 kN and 100 kN forces.

Lab	50 kN		100 kN	
	Overall relative deviation	Relative expanded uncertainty	Overall relative deviation	Relative expanded uncertainty
KRISS	1.1E-05	3.2E-05	1.2E-05	3.8E-05
VMI	9.5E-06	4.7E-05	5.5E-06	5.4E-05
NMCC	4.0E-05	4.7E-05	3.0E-05	5.1E-05

All results show their equivalence. It is worth noting that the error bars of SASO-NMCC barely cross the zero lines. This is due to the abnormal measurement results of SASO-NMCC with the Tr2 artifact. The relative deviations between SASO-NMCC and KRISS obtained using Tr1 are lower than 9 ppm as shown in Table 5, but as mentioned previously, the sensitivity of Tr2 artifact had increased permanently after SASO-NMCC measurements by approximately 0.01%. We confirmed such permanent shift in sensitivity of the Tr2 transducer by conducting repetitive measurements at KRISS after return from SASO-NMCC and comparing their results. They matched each other within their uncertainties, suggesting that the sensitivity itself is stable after the permanent shift. The mechanism of the shift in sensitivity is still unclear, but the sensitivity was definitely affected by a high electrical potential difference between the SASO-NMCC machine and the Tr2 transducer. SASO-NMCC investigated the cause of such electrical potential difference after reporting measurement results and revealed that this is due to malfunction of the power extension cord, such that it didn't provide a proper ground to the amplifier.

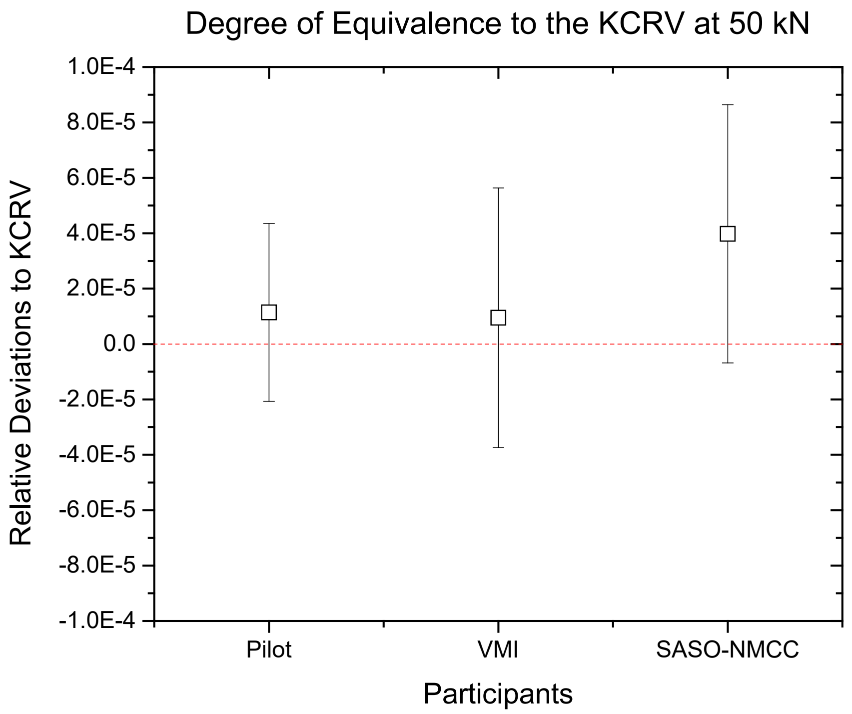

Figure 1: DoEs of participants at 50 kN force.

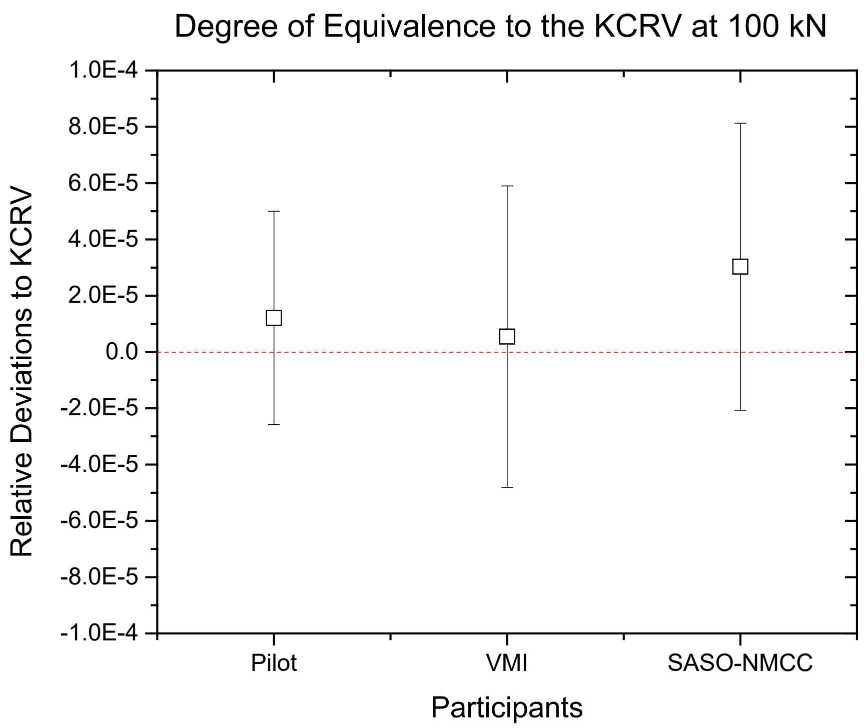

Figure 2: DoEs of participants at 100 kN force.

2.7 Summary

The subsequent key comparison on forces at 50 kN and 100 kN coded as APMP.M.F-K2.1 has been conducted to provide links for VMI and SASO-NMCC to APMP.M.F-K2. The DoEs of VMI and SASO-NMCC have been determined through comparisons with KRISS; those of VMI and SASO-NMCC show equivalence, though a loop measurement for SASO-NMCC using the Tr2 artifact exhibited high uncertainty due to a large drift in sensitivity. We suspect the high electrical potential difference, which happened during Tr2 measurements at SASO-NMCC, cause such a drift.

3. References

[1] Y.-K. Park et. al, "Force Key Comparison APMP.M.F-K2.a and APMP.M.F-K2.b (50 kN and 100 kN)," Metrologia Tech. Suppl., Vol. 56, pp. 07003, 2019.

[2] M.D. Damtew and M.-S. Kim, "Determination of temperature and humidity sensitivity coefficients of torque transducers and estimation of their uncertainties based on a Monte Carlo method," Metrologia, Vol. 57, 025011 (2020).

[3] A. Knott et al., "Final report on force key comparison CCM.F-K2.a and CCM.F-K2.b (50 kN and 100 kN)," Metrologia Tech. Suppl., Vol. 49, pp. 07002, 2012.

[4] K. Ueda et al., Final report on APMP.M.F-K4.b key Comparison for 2 MN force," Metrologia Tech. Suppl., Vol. 49, pp. 07008, 2012.