Force Key Comparison APMP.M.F-K2.a and APMP.M.F-K2.b
(50 kN and 100 kN)

Final Report

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Pilot: KRISS, Republic of Korea

Yon-Kyu Park

Muktar Sawi (NMIM)

Seif M. Osman (NIS)

S.S.K.Titus (NPLI)

Shih Mean Lee (A*STAR)

Raymond Leung (SCL)

Pham Thanh Ha (VMI)

Sheng-Jui Chen (ITRI)

Kittipong Chaemthet (NIMT)

Hafid (RCM-LIPI)

Josephat O. Bangi (KEBS)

Zhimin Zhang(NIM)

Kazunaga Ueda (NMIJ/AIST)

1. Introduction

The APMP.M.F-K2 key comparison (KC) in the medium force range is initiated based on a decision of the APMP TCM meeting in October 2004 in Beijing, China. This comparison is planned to demonstrate the degree of equivalence between the national standards of force and to provide evidence for the calibration and measurement capability (CMC) claimed by participating national metrology institutes (NMIs) in the Asia-Pacific region, especially for those who did not participate in the global CCM.F-K2 KC. The APMP TCM approved that KRISS of Korea to serve as the pilot laboratory and NMIJ of Japan and NIM of China would be link laboratories.

The APMP.M.F-K2 KC has two schemes, which are APMP.M.F-K2.a (Scheme A) and APMP.M.F-K2.b (Scheme B).

This document describes the comparison scheme and reports the results of the comparison.

2. Participants in the comparison

There are 13 laboratories including the pilot. The participants are listed in Table 1.

Laboratory	Economy	Code	Scheme	Expanded relative uncertainty of force machine	Month	Remark
KRISS	Korea	1	A	2.00E-05	Pilot	Pilot, Link
			B	2.00E-05		
NMIM	Malaysia	2	B	4.00E-05	12 / 2007	
NIS	Egypt	3	B	2.00E-05	9 / 2008	
NPLI	India	4	A	2.00E-05	3 / 2011	
			B	2.00E-05		
A*STAR	Singapore	5	A	5.00E-05	7 / 2013	
			B	2.00E-04		
SCL	Hong Kong China	6	A	2.00E-05	5 / 2008	
			B	2.00E-04		
VMI	Viet Nam	7	A	5.00E-04	3 / 2009	
ITRI	Chinese Taipei	8	A	3.00E-04	7 / 2009	
NIMT	Thailand	9	A	2.00E-05	11 / 2009	
RCM-LIPI	Indonesia	10	A	1.00E-04	3 / 2010	
KEBS	Kenya	11	A	5.00E-04	10 / 2012	
NIM	China	12	A	2.00E-05	1 / 2014	k=3
		12.1	A	2.00E-05	1 / 2014	Link, k=3
NMIJ	Japan	13	A	2.00E-05	6 / 2014	
		13.1	B	2.00E-05	2 / 2008	Link

Table 1. Participating laboratories, indicating the code number used in the report

Laboratory 12 is NIM of China. NIM uses a 100 kN deadweight force machine in the APMP.M.F-K2 KC. However, NIM had used a 300 kN deadweight force machine in the previous CCM.F-K2 KC. In order to link the KCRV to this APMP KC, the pilot asked NIM to provide the measurement result using the 300 kN force machine. The result using the 100 kN machine was coded as number 12, while the result using the 300 kN machine was coded as number 12.1. The code 12.1 is used to link this APMP KC to KCRV and the code 12 used to represent the value of NIM.

Laboratory 13 is NMIJ of Japan. NMIJ participated in the KC using their 50 kN deadweight force machine in February 2008. While the measurement of the KC is running, NMIJ has modified the 50 kN force machine to a 100 kN one, and re-participated in the KC at June 2014. The measurement using the old force machine is coded as number 13.1 and is used only to link this KC to KCRV. Code 13 is used to represent the value of NMIJ.

3. Principles of the comparison

The APMP KC follows the protocol of its relevant CCM KC CCM.F-K2. The loading schemes are shown in Figure 1.

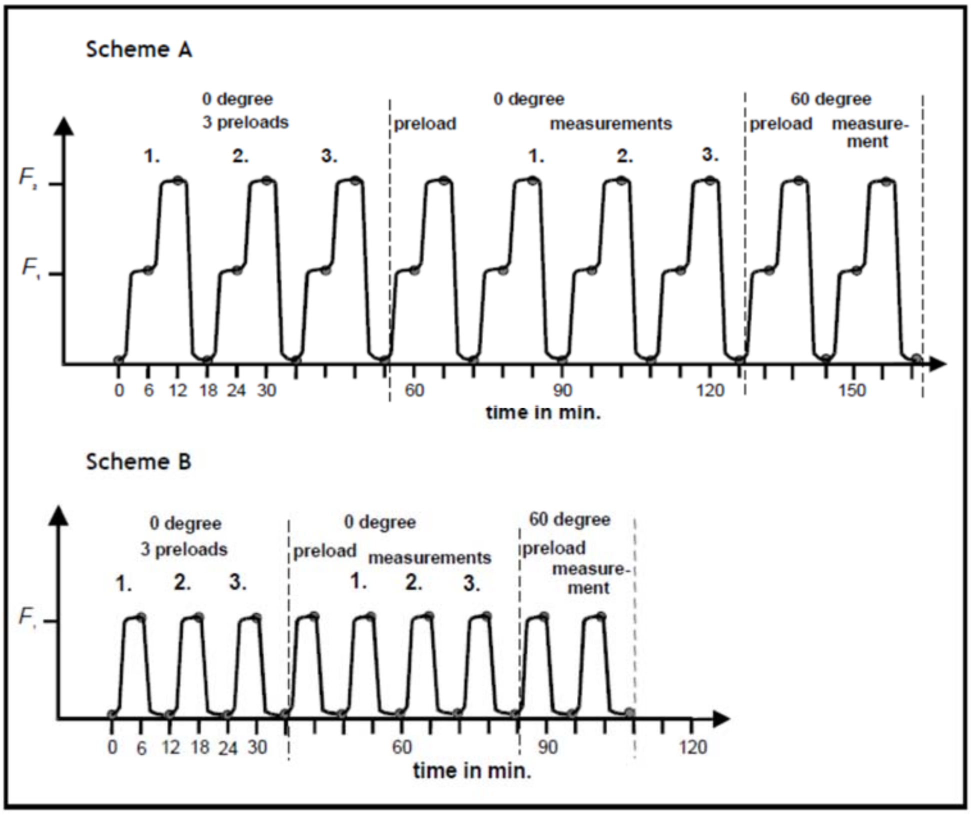

Figure 1. Loading scheme for both sets of transducers, at 50 kN and 100 kN (Scheme A) and at 50 kN (Scheme B).

The force transducer is rotated through a total of 720° in both schemes. One preload and one measurement (as at 60° in Figure 1) is carried out at 120°, 180°, 240°, 300°, 360°/0°, 60°, 120°, 180°, 240°, 300°, and 360°. The relatively long reading period of six minutes was selected to minimize the influence of creep.

The comparison was carried out using four transducers, two with nominal capacity 100 kN for Scheme A and two with nominal capacity 50 kN for Scheme B. The transducers used are detailed in Table 2.

Identification Code	Manufacturer	Serial Number	Capacity	Scheme
Tr1	HBM	H40377	50 kN	B
Tr2	GTM	48038	50 kN	B
Tr3	HBM	052230208	100 kN	A
Tr4	GTM	45851	100 kN	A

Table 2. Transducers used in the comparison

4. Format of the comparison

The comparison was made in a star format; the transducers came back to the pilot after each participating laboratory's measurements. One complete measurement cycle (pilot – participating laboratory – pilot) is called a loop. The pilot's first measurement is denoted the A-measurement and its second, after the participating laboratory, is called the B-measurement. The change at the pilot (B-measurement – A-measurement) is called the drift for that particular loop. The reference value for each loop is taken as the mean of the two pilot measurements – this is called the loop value.

5. Environmental conditions

Considering the climate in the Asia-Pacific region, the reference ambient temperature of this KC was chosen to be 23 °C instead of 20 °C of the CCM KCs. Temperature fluctuation exceeding ±0.2 °C, which is the limit in the CCM KCs, could be accepted in the APMP.M.F-K2 KC provided that the influence of temperature fluctuation on measurement results was properly taken into account. The reference ambient temperature and its allowance were the only departures from the conditions of the CCM KCs.

6. Reported results and uncertainties

Tables 3~8 represent chronological order of the measurement results which are deflection, corrected deflection, loop value, relative deviation from the pilot, and expanded relative uncertainty for different force steps and transducers.

The reported deflection from the participating laboratories are corrected in three ways, that means correction for the use of different DMP40, correction for the different ambient temperature, and the correction for the unit of force generation.

In the estimation of the uncertainty, uncertainty components due to force standard machine, repeatability, reproducibility, resolution of indicator, BN100 correction, temperature correction, and sensitivity drift in a loop were taken into account.

In each measurement at the pilot, output signals of the BN100A bridge calibration unit were monitored by the same DMP40 amplifier always kept in the laboratory environment. Considering the monitoring, an estimate of a relative standard uncertainty associated with the BN100 corrections of 5×10^{-6} would not seem unreasonable. The uncertainty associated with the temperature corrections is simply taken as the difference between calibration temperatures at the pilot and the participating laboratory multiplied by the standard uncertainty associated with the sensitivity value.

In the estimation of the uncertainty due to the sensitivity drift of the transducer in a loop, three alternative methods are possible:

1) Base the drift uncertainty contribution solely on the difference between the two pilot measurements, assuming a specific distribution. This has the disadvantage of basing the value on just two numbers – not a large sample. If the two pilot measurements are identical, this would lead to no contribution due to drift, even if the transducer displays significant values in other loops – it may just be chance that the two measurements are the same for one particular loop, and it does not mean that the transducer sensitivity is not different during the participant's measurements.

2) Take a standard deviation or average value of drift throughout the complete exercise as a common drift component. This has the disadvantage of possibly underestimating the contribution for some loops and overestimating it for others – it is possible that the stability of the transducer will vary throughout the comparison, particularly if significant environmental factors are present.

3) A combination of the above two approaches – using a rectangular distribution for the two pilot values for a specific loop together with a proportion of the mean absolute drift added as a second rectangular distribution.

Using approach 3, with 50 % of the mean absolute drift used as the half-width of the second rectangular distribution.

Code	Date	Deflection	Corrected deflection	Loop value	Relative deviation	Relative expanded uncertainty
Pilot	2007-11-07	2.000791	2.000779			2.27E-05
2	2007-12-19	1.956536	2.000718	2.000783	-3.26E-05	4.25E-05
Pilot	2008-01-22	2.000801	2.000787			2.28E-05
13.1	2008-02-07	1.962105	2.000772	2.000792	-1.01E-05	2.40E-05
Pilot	2008-02-26	2.000805	2.000797			2.25E-05
6	2008-05-15	2.000824	2.000866	2.000778	4.43E-05	4.50E-05
Pilot	2008-07-03	2.000763	2.000758			2.25E-05
3	2008-09-02	2.000203	2.000199	2.000767	-2.84E-04	2.52E-05
Pilot	2008-11-10	2.000787	2.000777			2.30E-05
Pilot	2010-06-01	2.000814	2.000801			2.26E-05
4	2011-03-21	2.000852	2.000853	2.000819	1.69E-05	2.60E-05
Pilot	2011-11-15	2.000850	2.000836			2.28E-05
Pilot	2013-03-25	2.000863	2.000864			2.27E-05
5	2013-07-05	2.000888	2.000951	2.000860	4.54E-05	6.54E-05
Pilot	2013-11-08	2.000860	2.000857			2.26E-05

Table 3. Chronological order of measurement for Tr1(HBM 50 kN)

Code	Date	Deflection	Corrected deflection	Loop value	Relative deviation	Relative expanded uncertainty
Pilot	2007-11-06	2.003077	2.003069			2.32E-05
2	2007-12-28	1.958749	2.002976	2.003061	-4.22E-05	4.51E-05
Pilot	2008-01-24	2.003060	2.003052			2.34E-05
13.1	2008-02-13	1.964264	2.002987	2.003077	-4.51E-05	3.15E-05
Pilot	2008-04-25	2.003109	2.003103			2.45E-05
6	2008-05-16	2.003023	2.002929	2.003090	-8.09E-05	5.70E-05
Pilot	2008-07-02	2.003082	2.003078			2.33E-05
3	2008-09-03	2.002975	2.003000	2.003075	-3.75E-05	2.88E-05
Pilot	2008-11-06	2.003072	2.003073			2.39E-05
Pilot	2010-05-28	2.002851	2.002848			2.44E-05
4	2011-03-18	2.002712	2.002693	2.002769	-3.82E-05	5.37E-05
Pilot	2011-10-27	2.002697	2.002691			3.11E-05
Pilot	2013-04-08	2.002520	2.002507			2.66E-05
5	2013-07-16	2.002192	2.002096	2.002478	-1.90E-04	7.57E-05
Pilot	2013-11-11	2.002462	2.002448			2.47E-05

Table 4. Chronological order of measurement for Tr2(GTM 50 kN)

Code	Date	Deflection	Corrected deflection	Loop value	Relative deviation	Relative expanded uncertainty
Pilot	2008-03-04	0.999603	0.999600			2.31E-05
6	2008-05-21	0.999040	0.999013	0.999587	-5.74E-04	2.11E-04
Pilot	2008-11-04	0.999571	0.999574			2.34E-05
7	2009-03-18	0.999222	0.999341	0.999590	-2.49E-04	5.03E-04
Pilot	2009-06-17	0.999604	0.999606			2.32E-05
8	2009-07-31	0.999555	0.999551	0.999598	-4.72E-05	3.08E-04
Pilot	2009-09-11	0.999590	0.999590			2.28E-05
9	2009-11-26	0.999583	0.999577	0.999605	-2.86E-05	4.18E-05
Pilot	2010-01-21	0.999621	0.999621			2.31E-05
10	2010-03-18	0.999594	0.999597	0.999616	-1.93E-05	1.03E-04
Pilot	2010-05-11	0.999611	0.999611			2.47E-05
4	2011-03-23	0.999608	0.999603	0.999611	-8.13E-06	2.68E-05
Pilot	2011-10-10	0.999604	0.999610			2.94E-05
11	2012-10-11	0.999852	0.999851	0.999633	2.18E-04	5.07E-04
Pilot	2013-03-05	0.999656	0.999656			2.32E-05
5	2013-07-13	0.999589	0.999570	0.999653	-8.30E-05	2.09E-04
Pilot	2013-11-07	0.999649	0.999650			2.38E-05
12.1	2014-01-09	0.999648	0.999647	0.999652	-5.30E-06	7.15E-05
12	2014-01-08	0.999641	0.999638	0.999652	-1.38E-05	3.81E-05
Pilot	2014-03-11	0.999656	0.999653			3.14E-05
13	2014-06-01	0.999636	0.999633	0.999657	-2.38E-05	3.72E-05
Pilot	2014-09-17	0.999655	0.999660			2.56E-05

Table 5. Chronological order of measurement for Tr3(HBM 100 kN) at 50 kN step

Code	Date	Deflection	Corrected deflection	Loop value	Relative deviation	Relative expanded uncertainty
Pilot	2008-03-03	0.999712	0.999708			2.58E-05
6	2008-05-23	0.999033	0.999057	0.999693	-6.36E-04	2.12E-04
Pilot	2008-11-05	0.999679	0.999677			2.56E-05
7	2009-03-19	0.999395	0.999403	0.999684	-2.81E-04	5.01E-04
Pilot	2009-06-16	0.999692	0.999691			2.66E-05
8	2009-07-29	0.999655	0.999654	0.999703	-4.87E-05	3.02E-04
Pilot	2009-09-24	0.999717	0.999715			2.69E-05
9	2009-11-24	0.999693	0.999683	0.999708	-2.50E-05	2.67E-05
Pilot	2010-01-19	0.999704	0.999701			2.58E-05
10	2010-03-24	0.999710	0.999708	0.999704	4.46E-06	1.01E-04
Pilot	2010-05-10	0.999712	0.999706			2.64E-05
4	2011-03-24	0.999653	0.999652	0.999697	-4.43E-05	2.89E-05
Pilot	2011-10-26	0.999687	0.999687			3.12E-05
11	2012-10-10	0.999892	0.999891	0.999688	2.02E-04	5.03E-04
Pilot	2013-03-06	0.999691	0.999690			2.79E-05
5	2013-06-20	0.999567	0.999597	0.999691	-9.40E-05	2.08E-04
Pilot	2013-11-14	0.999692	0.999693			2.85E-05
12.1	2014-01-10	0.999651	0.999647	0.999678	-3.11E-05	4.02E-05
12	2014-01-23	0.999647	0.999647	0.999678	-3.09E-05	3.85E-05
Pilot	2014-02-27	0.999661	0.999662			2.50E-05
13	2014-05-26	0.999686	0.999680	0.999674	6.23E-06	2.90E-05
Pilot	2014-09-23	0.999689	0.999686			2.32E-05

Table 6. Chronological order of measurement for Tr4(GTM 100 kN) at 50 kN step

Code	Date	Deflection	Corrected deflection	Loop value	Relative deviation	Relative expanded uncertainty
Pilot	2008-03-04	1.999494	1.999488			2.30E-05
6	2008-05-21	1.999043	1.998989	1.999470	-2.41E-04	2.09E-04
Pilot	2008-11-04	1.999450	1.999453			2.33E-05
7	2009-03-18	1.998729	1.998749	1.999477	-3.64E-04	5.04E-04
Pilot	2009-06-17	1.999501	1.999500			2.31E-05
8	2009-07-31	1.999433	1.999424	1.999481	-2.85E-05	3.05E-04
Pilot	2009-09-11	1.999468	1.999461			2.30E-05
9	2009-11-26	1.999502	1.999481	1.999495	-6.80E-06	3.92E-05
Pilot	2010-01-21	1.999535	1.999528			2.26E-05
10	2010-03-18	1.999404	1.999409	1.999517	-5.41E-05	1.02E-04
Pilot	2010-05-11	1.999511	1.999506			2.43E-05
4	2011-03-23	1.999519	1.999503	1.999501	1.16E-06	2.78E-05
Pilot	2011-10-10	1.999489	1.999496			2.91E-05
11	2012-10-11	1.999862	1.999856	1.999531	1.62E-04	5.07E-04
Pilot	2013-03-05	1.999578	1.999567			2.29E-05
5	2013-07-13	1.999333	1.999292	1.999573	-1.40E-04	2.08E-04
Pilot	2013-11-07	1.999586	1.999580			2.36E-05
12.1	2014-01-09	1.999583	1.999576	1.999580	-2.22E-06	5.88E-05
12	2014-01-08	1.999571	1.999563	1.999580	-8.52E-06	2.87E-05
Pilot	2014-03-11	1.999595	1.999581			2.66E-05
13	2014-06-01	1.999559	1.999549	1.999592	-2.19E-05	3.59E-05
Pilot	2014-09-17	1.999600	1.999604			2.84E-05

Table 7. Chronological order of measurement for Tr3(HBM 100 kN) at 100 kN step

Code	Date	Deflection	Corrected deflection	Loop value	Relative deviation	Relative expanded uncertainty
Pilot	2008-03-03	1.999579	1.999570			2.53E-05
6	2008-05-23	1.998964	1.999010	1.999546	-2.68E-04	2.09E-04
Pilot	2008-11-05	1.999528	1.999521			2.57E-05
7	2009-03-19	1.998922	1.998940	1.999536	-2.98E-04	5.01E-04
Pilot	2009-06-16	1.999557	1.999551			2.61E-05
8	2009-07-29	1.999479	1.999477	1.999568	-4.54E-05	3.01E-04
Pilot	2009-09-24	1.999592	1.999584			2.69E-05
9	2009-11-24	1.999536	1.999512	1.999574	-3.13E-05	2.66E-05
Pilot	2010-01-19	1.999571	1.999564			2.49E-05
10	2010-03-24	1.999507	1.999506	1.999567	-3.06E-05	1.01E-04
Pilot	2010-05-10	1.999586	1.999570			2.60E-05
4	2011-03-24	1.999434	1.999430	1.999544	-5.72E-05	2.94E-05
Pilot	2011-10-26	1.999525	1.999518			3.10E-05
11	2012-10-10	1.999895	1.999889	1.999515	1.87E-04	5.02E-04
Pilot	2013-03-06	1.999522	1.999512			2.62E-05
5	2013-06-20	1.999166	1.999219	1.999517	-1.49E-04	2.10E-04
Pilot	2013-11-14	1.999528	1.999522			2.67E-05
12.1	2014-01-10	1.999446	1.999434	1.999493	-2.95E-05	3.95E-05
12	2014-01-23	1.999420	1.999418	1.999493	-3.76E-05	3.61E-05
Pilot	2014-02-27	1.999473	1.999463			2.45E-05
13	2014-05-26	1.999503	1.999488	1.999481	3.37E-06	2.72E-05
Pilot	2014-09-23	1.999514	1.999499			2.40E-05

Table 8. Chronological order of measurement for Tr4(GTM 100 kN) at 100 kN step

7. Stability of transducer sensitivity

Figures 2~7 show stability of the traveling force transducers over the period of this KC. The figures indicate relative deviations of measurement results at the pilot with respect to an arithmetical mean value of them. The uncertainty bars represent relative expanded uncertainties of the measurements with the coverage factor k=2.

The stability of Tr2 is not sufficient to be used as a transfer standard for the KC. The low stability causes high measurement uncertainty for the participating laboratories. Because of the high uncertainty, the influence of the Tr2 might be reduced in estimating the weighted mean.

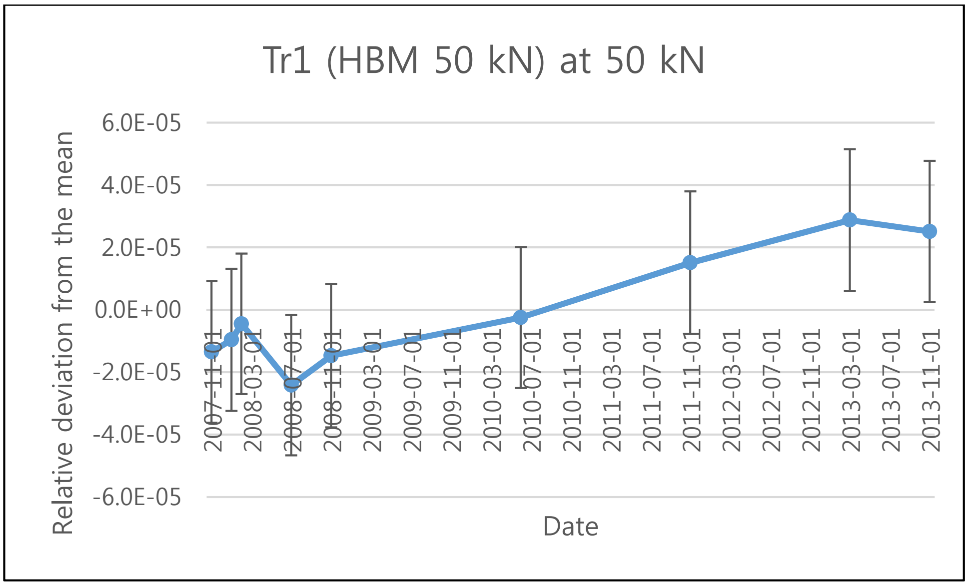

Figure 2. Stability of Tr1 at 50 kN throughout the comparison

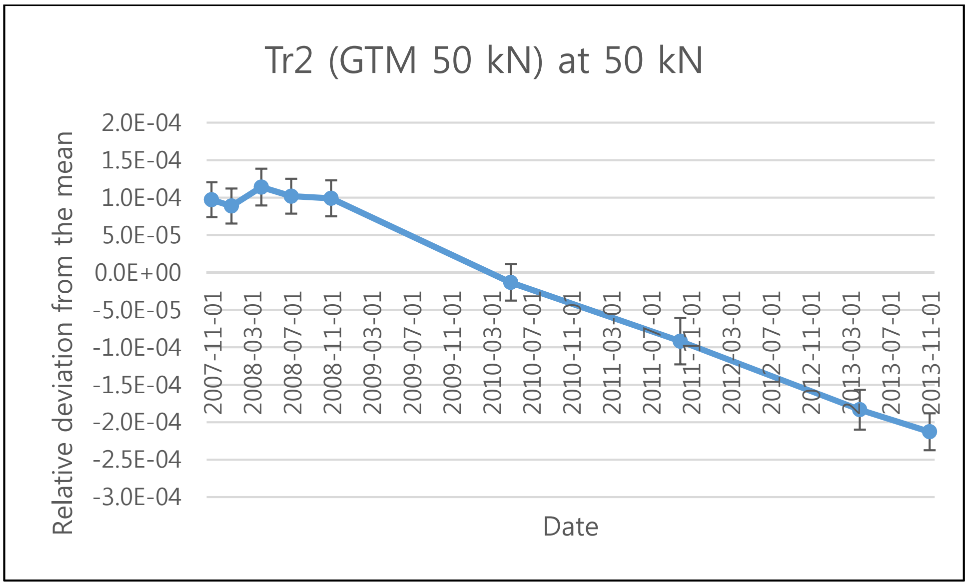

Figure 3. Stability of Tr2 at 50 kN throughout the comparison

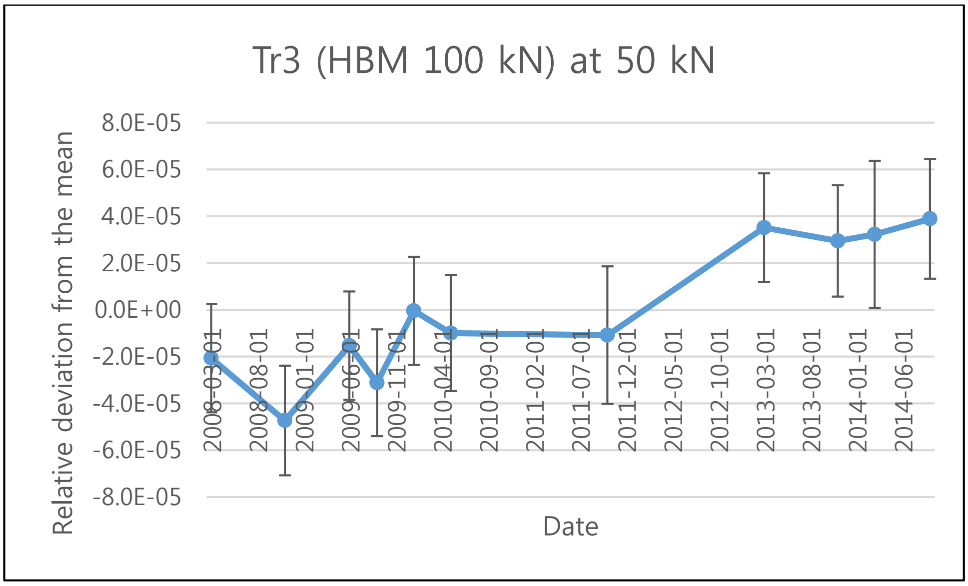

Figure 4. Stability of Tr3 at 50 kN throughout the comparison

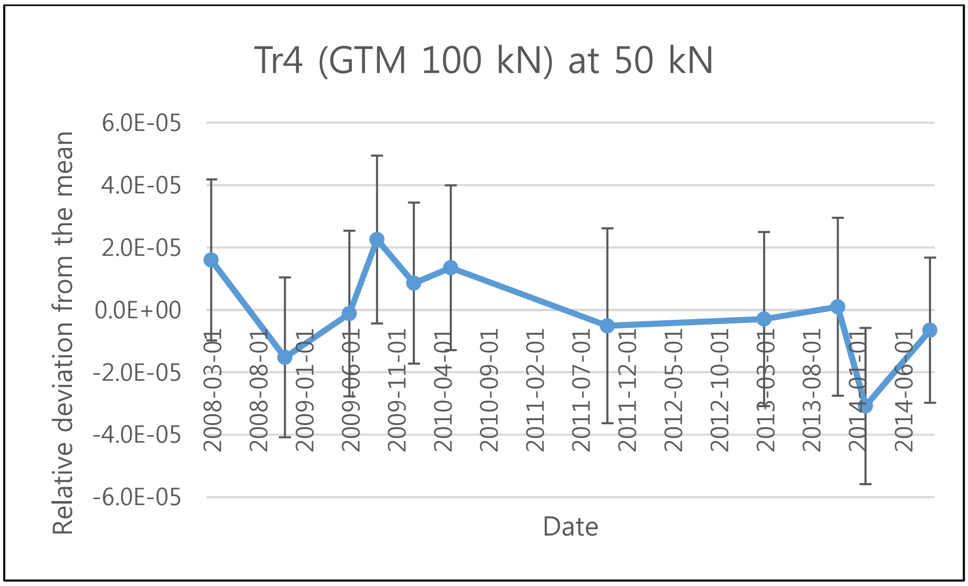

Figure 5. Stability of Tr4 at 50 kN throughout the comparison

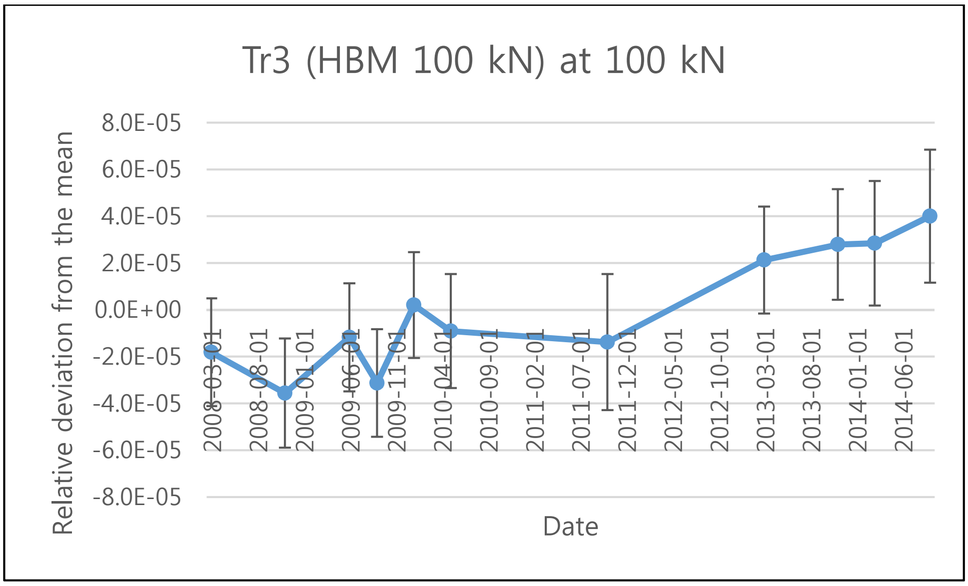

Figure 6. Stability of Tr3 at 100 kN throughout the comparison

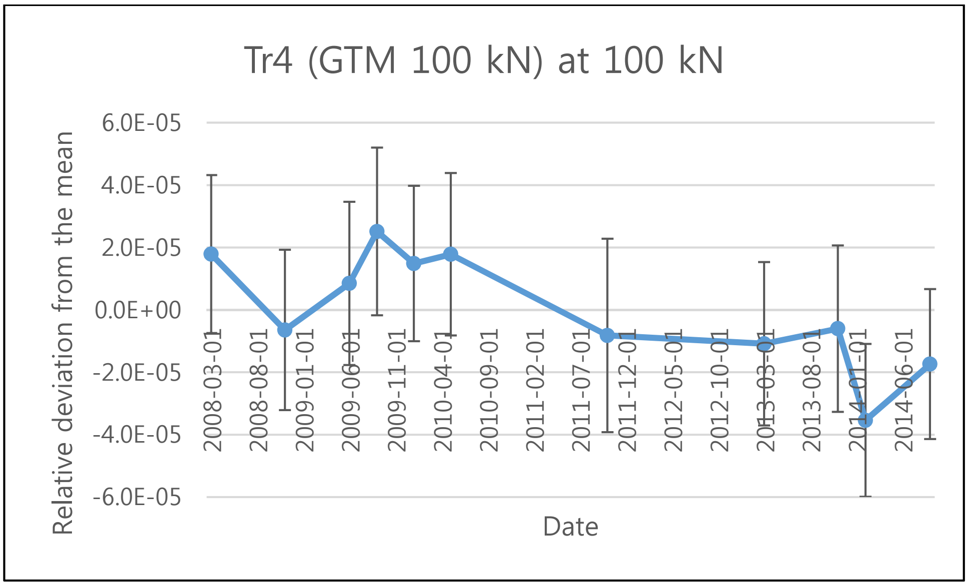

Figure 7. Stability of Tr4 at 100 kN throughout the comparison

8. Relative deviation of participating laboratories from the pilot

The relative overall deviation of a laboratory is estimated as a weighted mean of each relative deviations using the two force transducers. For participating laboratories in Scheme B, the weighted means of the results using Tr1 and Tr2 were estimated at 50 kN. For participating laboratories in Scheme A, the weighted means of the results using Tr3 and Tr4 were estimated at 50 kN and 100 kN. For the participating laboratories in A/B, the weighted means at 50 kN from Tr1-Tr2 set and Tr3-Tr4 set were merged again to deduce one value for a laboratory.

Relative overall deviation D_i of a laboratory *i* from the pilot is calculated by taking a weighted mean of relative deviations of measurements on Tr1 and Tr2 as follows. Its uncertainty $u(D_i)$ is evaluated with considering correlation between the relative deviations $d_{i,Tr1}$ of Tr1 and $d_{i,Tr2}$ of Tr2, because the two measurements were made by the same force standard machine of each participant and that of the pilot.

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

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

where, $r(d_{i,Tr1}, d_{i,Tr2})$ is the correlation coefficient between the measurements of Tr1 and Tr2.

The relative overall deviation from Tr3 and Tr4 is estimated as the same way.

Table 9 represents the relative overall deviations of all participating laboratories from the pilot and their uncertainties.

Code	50 kN		100 kN	
	Relative deviation (D_i)	Expanded relative uncertainty	Relative deviation (D_i)	Expanded relative uncertainty
1	0.00E+00	2.48E-05	0.00E+00	2.53E-05
2	-3.71E-05	3.70E-05		
3	-1.77E-04	2.27E-05		
4	-8.87E-06	2.18E-05	-2.63E-05	2.83E-05
5	-5.79E-05	6.08E-05	-1.45E-04	2.07E-04
6	-2.69E-05	4.34E-05	-2.54E-04	2.07E-04
7	-2.65E-04	5.01E-04	-3.31E-04	4.98E-04
8	-4.80E-05	3.05E-04	-3.70E-05	3.00E-04
9	-2.60E-05	3.11E-05	-2.36E-05	3.04E-05
10	-7.27E-06	1.02E-04	-4.22E-05	1.01E-04
11	2.10E-04	5.04E-04	1.75E-04	5.00E-04
12	-2.23E-05	3.83E-05	-1.98E-05	3.13E-05
12.1	-2.49E-05	4.76E-05	-2.10E-05	4.51E-05
13	-4.23E-06	3.07E-05	-5.88E-06	3.01E-05
13.1	-2.30E-05	2.27E-05		

Table 9. Relative overall deviation of participating laboratories from the pilot

9. Degree of equivalence to the KCRV

Mean value at 50 kN, $D_{Llink,50kN}$ of the relative deviations of the link laboratories 1, 12.1, and 13.1 from the pilot and its uncertainty $u(D_{Llink,50kN})$ are calculated as follows by taking a weighted mean.

$$D_{Link,50kN} = \frac{D_{1,50kN}/u(D_{1,50kN})^2 + D_{12.1,50kN}/u(D_{12.1,50kN})^2 + D_{13.1,50kN}/u(D_{13.1,50kN})^2}{1/u(D_{1,50kN})^2 + 1/u(D_{12.1,50kN})^2 + 1/u(D)^2} \quad (3)$$

$$u(D_{Link,50kN}) = \sqrt{\frac{1}{1/u(D_{1,50kN})^2 + 1/u(D_{12.1,50kN})^2 + 1/u(D_{13.1,50kN})^2}} \quad (4)$$

Mean value at 100 kN, $D_{Llink,100kN}$ of the relative deviations of the link laboratories 1 and 12.1 from the pilot and its uncertainty $u(D_{Llink,100kN})$ are calculated as follows by taking a weighted mean.

$$D_{Link,100kN} = \frac{D_{1,100kN}/u(D_{1,100kN})^2 + D_{12.1,100kN}/u(D_{12.1,100kN})^2}{1/u(D_{1,100kN})^2 + 1/u(D_{12.1,100kN})^2} \quad (5)$$

$$u(D_{Link,100kN}) = \sqrt{\frac{1}{1/u(D_{1,100kN})^2 + 1/u(D_{12.1,100kN})^2}} \tag{6}$$

Weighted means of the deviations of link laboratories and their expanded relative uncertainties are listed in Table 10.

50 kN		100 kN	
Relative deviation ($D_{Llink,50kN}$)	Expanded relative uncertainty	Relative deviation ($D_{Llink,100kN}$)	Expanded relative uncertainty
-1.38E-05	1.58E-05	-5.04E-06	2.21E-05

Table 10. Overall relative deviations of the link laboratories from the pilot

Table 11 shows the relative deviations $d_{i\text{-}KCRV}$ of the three link laboratories from the key comparison reference value (KCRV) and their expanded uncertainties $U(d_{i\text{-}KCRV})$. The last row of the Table 11 represents the weighted mean of the deviations $D_{Link\text{-}KCRV}$ and their relevant uncertainties $U(D_{Link\text{-}KCRV})$.

Link Laboratory	50 kN		100 kN	
	Relative deviation	Expanded relative uncertainty	Relative deviation	Expanded relative uncertainty
1	8.00E-06	2.40E-05	1.40E-05	2.70E-05
12.1	8.00E-06	2.40E-05	2.00E-06	2.30E-05
13.1	-1.70E-05	2.00E-05		
$D_{Link\text{-}KCRV}$	-2.47E-06	1.29E-05	7.05E-06	1.75E-05

Table 11. Relative deviations of the link laboratories from the KCRV and their uncertainties

For each of the participating institutes, the relative deviation to the KCRV, $D_{i\text{-}KCRV}$ and its expanded uncertainty $U(D_{i\text{-}KCRV})$ with the coverage factor k=2 are calculated in the following manner.

$$D_{i-KCRV} = D_i - (D_{Link} - D_{Link-KCRV}) \tag{7}$$

$$U(D_{i-KCRV}) = k\sqrt{u(D_i)^2 + u(D_{Link})^2 + u(D_{Link-KCRV})^2} \tag{8}$$

The relative deviation of participating laboratories to the KCRV and their expanded uncertainties are listed in Table 12.

Code	50 kN		100 kN	
	Relative deviation (Weighted mean)	Expanded relative uncertainty	Relative deviation (Weighted mean)	Expanded relative uncertainty
1	1.14E-05	3.21E-05	1.21E-05	3.79E-05
2	-2.57E-05	4.23E-05		
3	-1.66E-04	3.05E-05		
4	2.51E-06	2.99E-05	-1.42E-05	3.99E-05
5	-4.65E-05	6.41E-05	-1.33E-04	2.09E-04
6	-1.55E-05	4.80E-05	-2.42E-04	2.09E-04
7	-2.54E-04	5.01E-04	-3.19E-04	4.99E-04
8	-3.66E-05	3.05E-04	-2.49E-05	3.02E-04
9	-1.46E-05	3.72E-05	-1.15E-05	4.14E-05
10	4.11E-06	1.04E-04	-3.01E-05	1.05E-04
11	2.21E-04	5.05E-04	1.87E-04	5.01E-04
12	-1.09E-05	4.34E-05	-7.70E-06	4.21E-05
13	7.15E-06	3.69E-05	6.20E-06	4.13E-05

Table 12. Degree of equivalence to the KCRV and corresponding expanded uncertainty

Figures 8 and 9 represent the degree of equivalence to the KCRV at 50 kN and 100 kN respectively. In the graph, the error bar indicates expanded relative uncertainty.

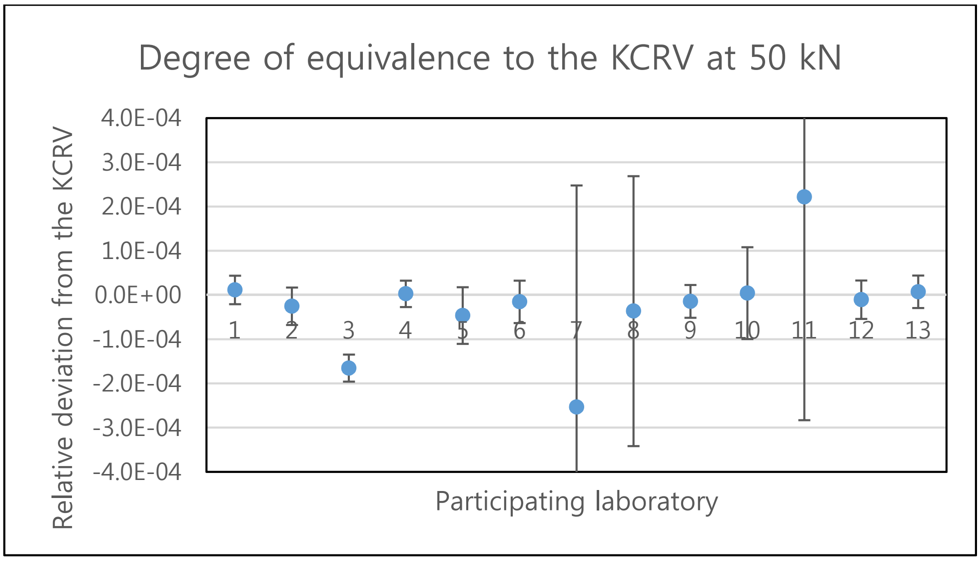

Figure 8. Degree of equivalence to the KCRV at 50 kN

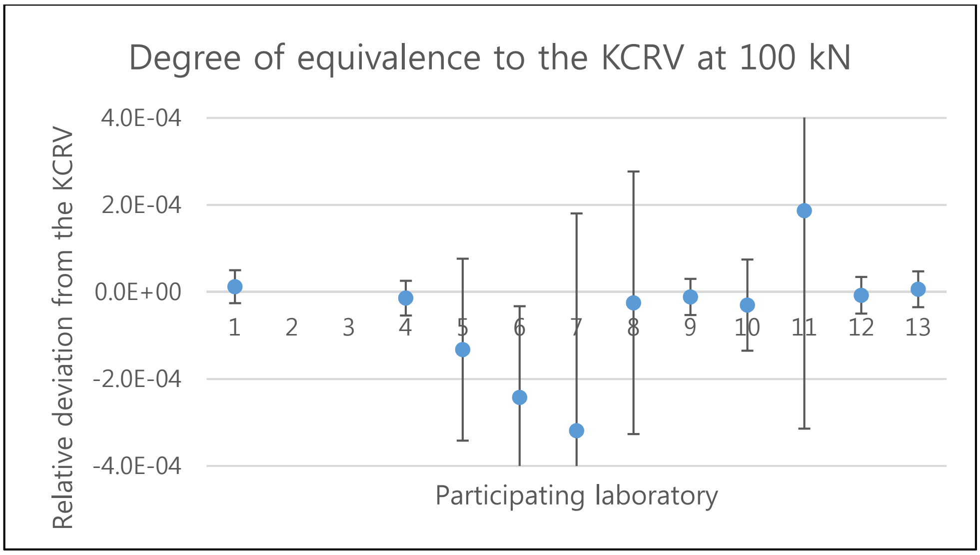

Figure 9. Degree of equivalence to the KCRV at 100 kN

10. Summary

The APMP.M.F-K2 key comparison in the 50 kN and 100 kN force range revealed that all results of the 13 participants are equivalent to the KCRV within their uncertainties except laboratory 3 at 50 kN, and laboratory 6 at 100 kN.

The measurement of the laboratory 3 was done in September 2008, hence there might be a possibility for the result of this report not to reflect present capability of the laboratory.

References

[1] Andy Knott et al., Final report on force key comparison CCM.F-K2.a and CCM.F-K2.b (50 kN and 100 kN), 2012, http://iopscience.iop.org/article/10.1088/0026-1394/49/1A/07002/meta

[2] Kazunaga Ueda et al., Final report on APMP.M.F-K4.b key Comparison for 2 MN force, 2012, http://iopscience.iop.org/article/10.1088/0026-1394/49/1A/07008/meta