Force Key Comparison CCM.F-K2.a.1

(50 kN and 100 kN)

Final Report

1 December 2015

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Contents

1 Foreword

This report describes CIPM Key Comparison CCM.F-K2.a.1, for force values of 50 kN and 100 kN.

2 Background to the comparison

The CCM Force Working Group met in October 1998 in Sydney and made decisions about CIPM Key Comparisons for the unit of force. These were to cover four force ranges, with four different pilot laboratories:

i) 5 kN – 10 kN	Pilot: MIKES-Raute, Finland
ii) 50 kN – 100 kN	Pilot: NPL, United Kingdom
iii) 500 kN – 1 MN	Pilot: PTB, Germany
iv) 2 MN – 4 MN	Pilot: NIST, USA

Key Comparison ii), piloted by NPL, was officially designated CCM.F-K2.a (Scheme A) and CCM.F-K2.b (Scheme B) by BIPM. CCM.F-K2.a.1 is a pair of subsequent bilateral key comparisons conducted to tie INTI and CEM into the results of CCM.F-K2.a and, as such, it was also piloted by NPL using similar equipment and protocols.

This report gives the results for CCM.F-K2.a.1.

3 Participants in the comparison

The three participants in the comparison were NPL (United Kingdom), who acted as the pilot, INTI (Argentina), and CEM (Spain). The work at NPL was performed in November 2010, March/April 2011, November 2011, and January 2012, the work at INTI in January 2011, and the work at CEM in December 2011.

4 Principles of the comparison

The purpose of Key Comparisons is to compare the units of measurement as realised throughout the world. In the area of force, the way this is done is by the use of high quality force transducers subjected to similar loading profiles in national force standard machines, following a strict measurement protocol and using similar instrumentation.

The loading scheme shown in Figure 1 was proposed by the CCM Force Working Group and used in both CCM.F-K2.a and CCM.F-K2.a.1.

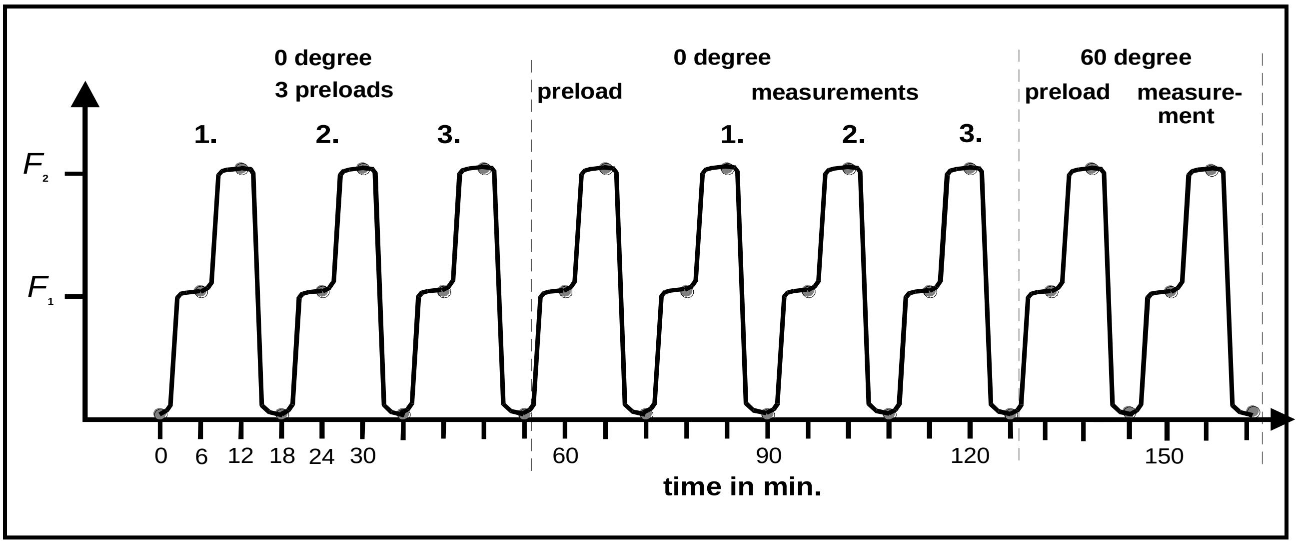

Figure 1. Loading scheme with F_1 = 50 kN and F_2 = 100 kN

The force transducer is rotated through a total of 720°. 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 minimise the influence of creep.

The comparison was carried out using two transducers, both with nominal capacity 100 kN. The transducers are detailed in Table 1.

Identification Code	Manufacturer	Serial Number	Capacity	Scheme
TrA	GTM	42793	100 kN	A
TrB	Sensy	19994730004	100 kN	A

Table 1. Transducers used in the comparison

Prior to the comparison, the temperature sensitivities of the two transducers had been determined, to enable corrections to be made for the effect of calibration temperatures differing from the nominal value of 20 °C. The results of these temperature tests are shown in Figures 2 and 3, and the assumption is made that the temperature sensitivity determined will be valid at any applied force.

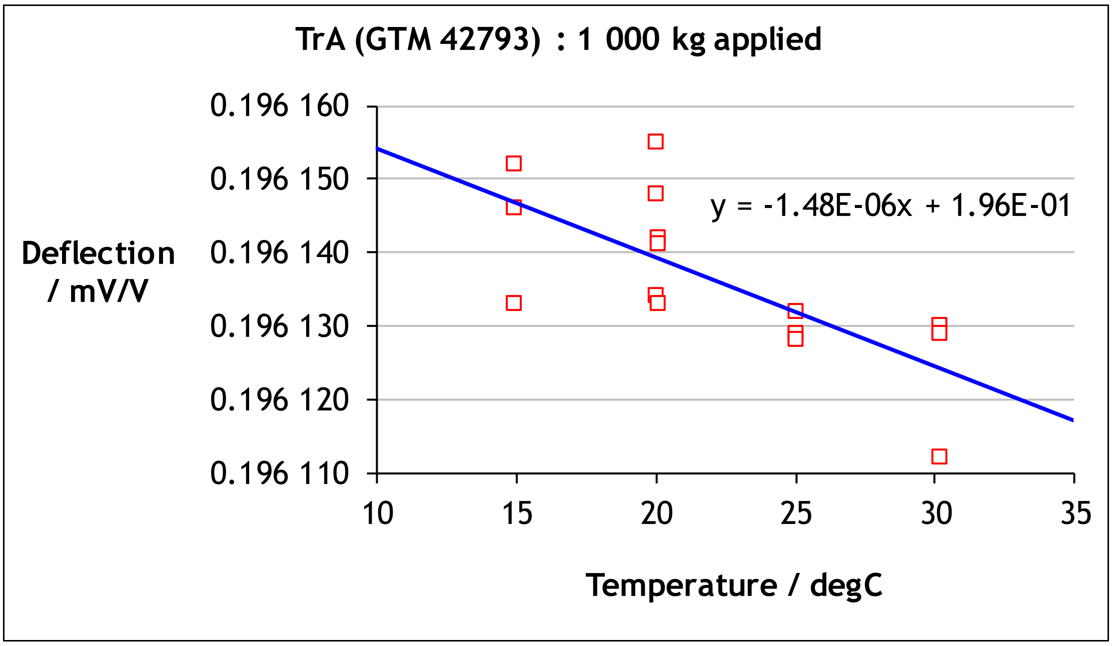

Figure 2. Temperature sensitivity results for TrA at an applied load of 1 000 kg

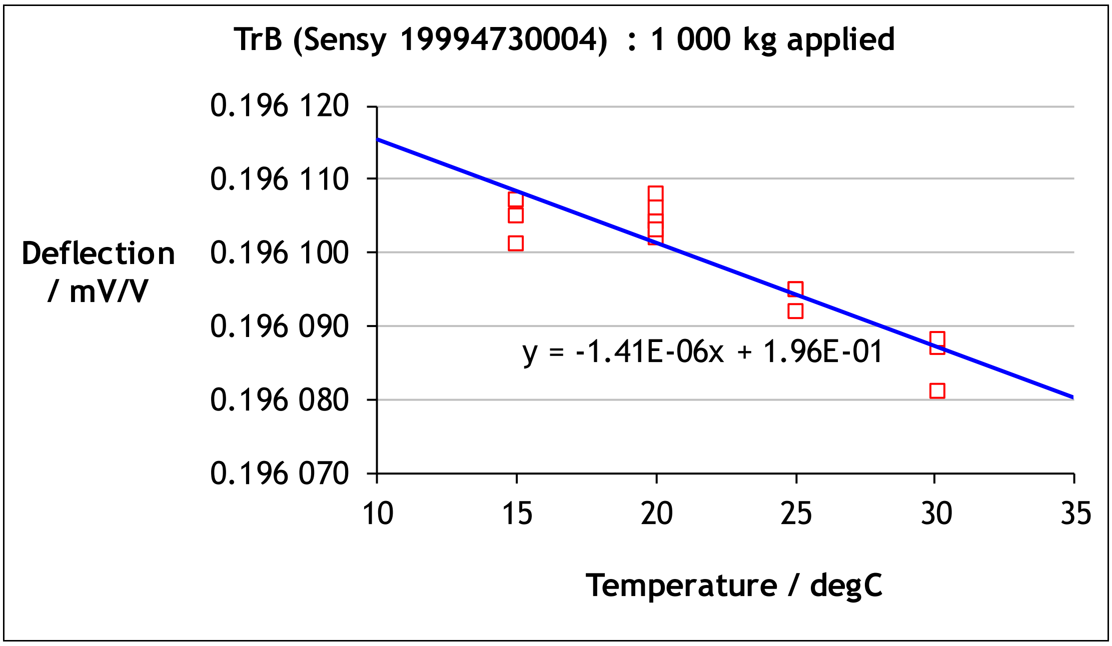

Figure 3. Temperature sensitivity results for TrB at an applied load of 1 000 kg

From these test results, relative temperature sensitivities for TrA and TrB of -7.56×10^{-6} K^{-1} and -7.17×10^{-6} K^{-1} respectively were determined. The relative uncertainty estimates associated with these values were determined, from analysis of the linear fit results, to be 4.10×10^{-6} K^{-1} and 1.99×10^{-6} K^{-1} respectively, at a 95 % (k = 2) level of confidence.

5 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.

6 Limitations of the comparison

Due to the fact that there is no real reference value to circulate (as the sensitivity of the force transducers varies over time), the following conditions apply:

- each measurement loop is independent of the others
- numerical values of different loops are not easily comparable
- only relative deviations can be compared
- there is no absolute numerical reference value

7 Instrumentation used in the comparison

In practice, it is not possible to calibrate the DMP40 measurement instruments used (one at each laboratory) against a single reference standard. The uniformity of the DMP40s used was confirmed by comparison against the same BN100 calibrator unit, circulated with the transducers. Each laboratory measured the indication of its DMP40 against the signal of the BN100 at a number of representative voltage ratios.

The deflections obtained at each laboratory were adjusted using the assumption that the signal generated by the BN100 was absolutely correct. For example, if BN100 output settings of +0.0 mV/V and +2.0 mV/V resulted in DMP40 readings of +0.000 012 mV/V and +2.000 042 mV/V, giving a deflection of +2.000 030 mV/V instead of the nominal +2.000 000 mV/V, the assumption was made that the DMP40 was reading 1.5×10^{-5} too high and the measured deflection was reduced by this relative amount.

Figures 4 and 5 show the DMP40 readings at the participating laboratories, at two different BN100 settings, corresponding to the different transducer deflection levels. The values obtained at the pilot vary over the period of the comparison by less than 5×10^{-6} – this indicates that the instability of the BN100 throughout the comparison is no greater than this value.

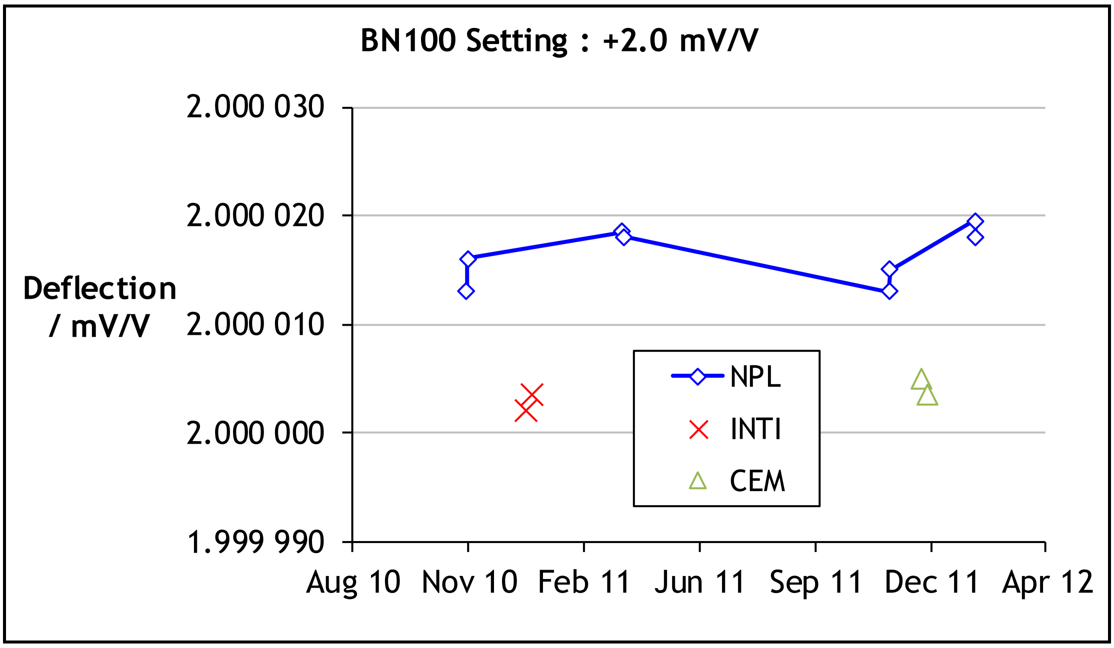

Figure 4. BN100 check results for a setting of +2.0 mV/V

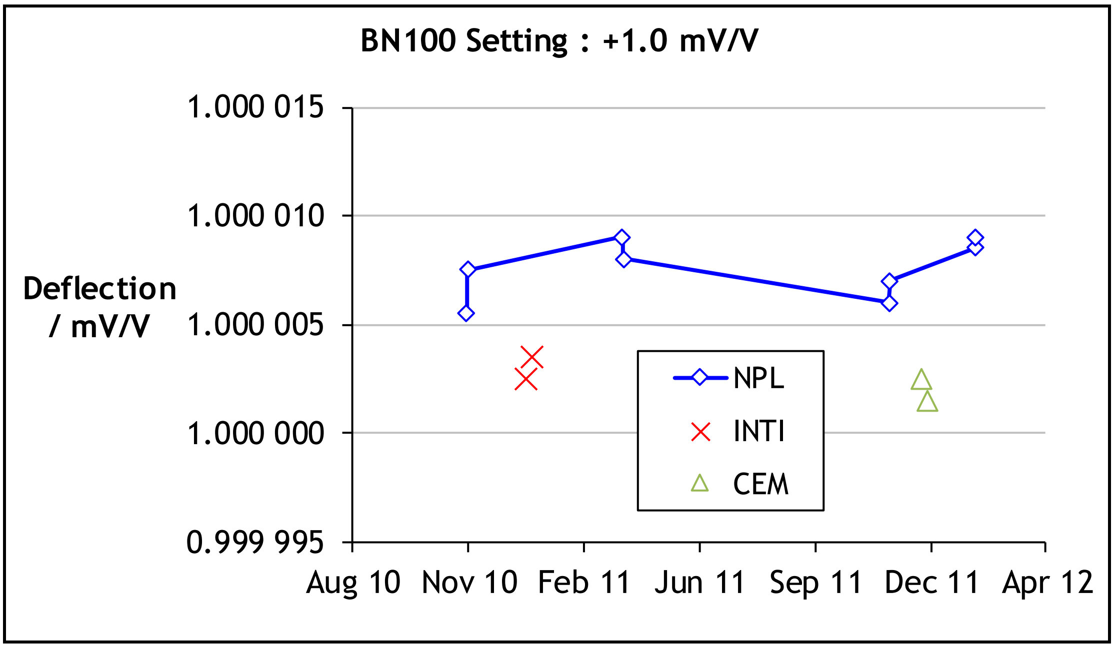

Figure 5. BN100 check results for a setting of +1.0 mV/V

8 Stability of transducer sensitivity

Because the quality of the comparison is dependent upon the three measurements made during each loop, the stability of each transducer's sensitivity is critical. Tables 2 to 5 detail the results obtained at the pilot and Figures 6 to 9 plot each transducer's mean deflection over the period of the comparison – these graphs also show the individual data points (at the twelve orientations) from which the mean deflection is calculated. For comparison purposes, in each graph, the y-axis gridline separation is approximately equal to a relative value of 5×10^{-5}. As TrA was also used during the CIPM and subsequent

EURAMET Key Comparisons, and TrB was used during the EURAMET Key Comparison, their results during these periods are also plotted in the relevant figures to show their long-term stability.

The adjusted deflections take into account the results of the BN100 checks and also the difference in calibration temperature from the nominal 20 °C, using the temperature sensitivity values described earlier.

TrA (GTM 42793) - 50 kN			
Date	**Deflection**	**Adjusted Deflection**	**Loop Value**
	mV/V	**mV/V**	**mV/V**
17 Nov 2010	0.999 827	0.999 822	0.999 827
31 Mar 2011	0.999 838	0.999 832	
17 Nov 2011	0.999 847	0.999 843	0.999 840
30 Jan 2012	0.999 843	0.999 838	

Table 2. Results obtained from TrA (50 kN) at pilot laboratory

TrA (GTM 42793) - 100 kN			
Date	**Deflection**	**Adjusted Deflection**	**Loop Value**
	mV/V	**mV/V**	**mV/V**
17 Nov 2010	1.999 959	1.999 948	1.999 958
31 Mar 2011	1.999 981	1.999 968	
17 Nov 2011	1.999 993	1.999 985	1.999 982
30 Jan 2012	1.999 991	1.999 978	

Table 3. Results obtained from TrA (100 kN) at pilot laboratory

TrB (Sensy 19994730004) - 50 kN			
Date	Deflection mV/V	Adjusted Deflection mV/V	Loop Value mV/V
16 Nov 2010	0.999 953	0.999 946	0.999 955
1 Apr 2011	0.999 969	0.999 964	
18 Nov 2011	0.999 983	0.999 979	0.999 977
31 Jan 2012	0.999 981	0.999 975	

Table 4. Results obtained from TrB (50 kN) at pilot laboratory

TrB (Sensy 19994730004) - 100 kN			
Date	Deflection mV/V	Adjusted Deflection mV/V	Loop Value mV/V
16 Nov 2010	1.999 841	1.999 827	1.999 831
1 Apr 2011	1.999 848	1.999 836	
18 Nov 2011	1.999 876	1.999 867	1.999 861
31 Jan 2012	1.999 865	1.999 854	

Table 5. Results obtained from TrB (100 kN) at pilot laboratory

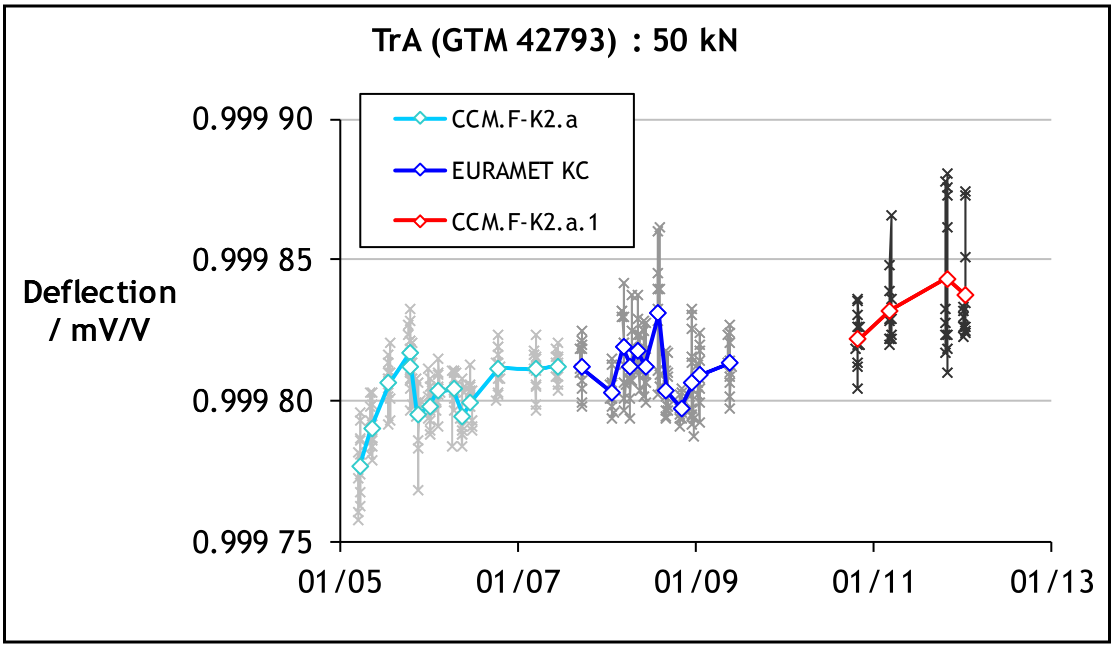

Figure 6. Stability of TrA at 50 kN throughout the comparison

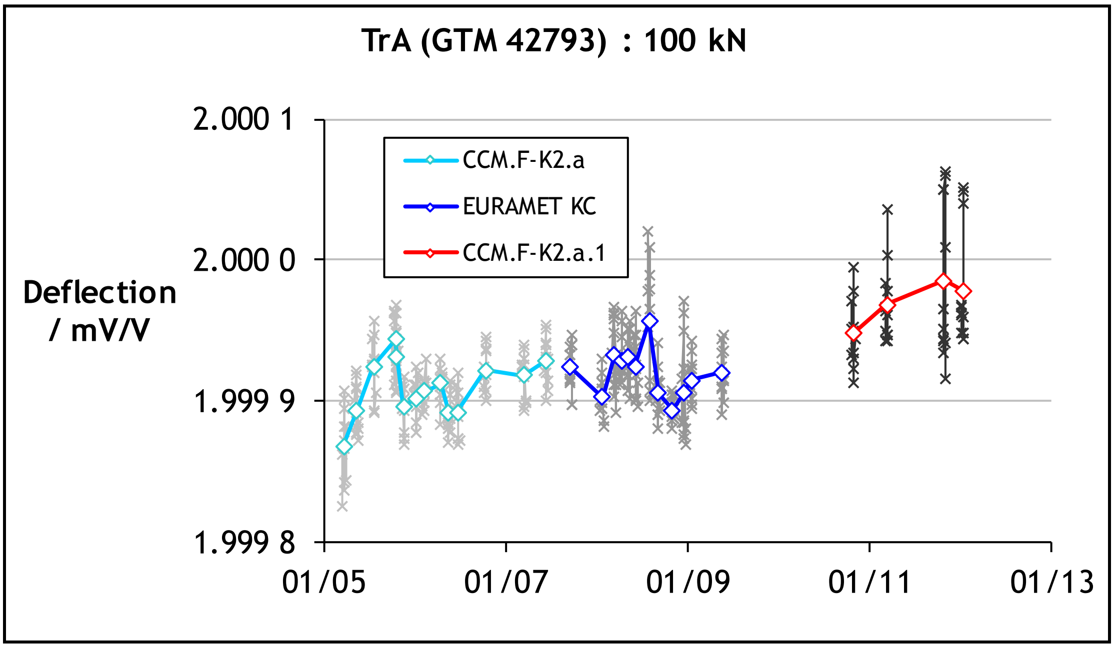

Figure 7. Stability of TrA at 100 kN throughout the comparison

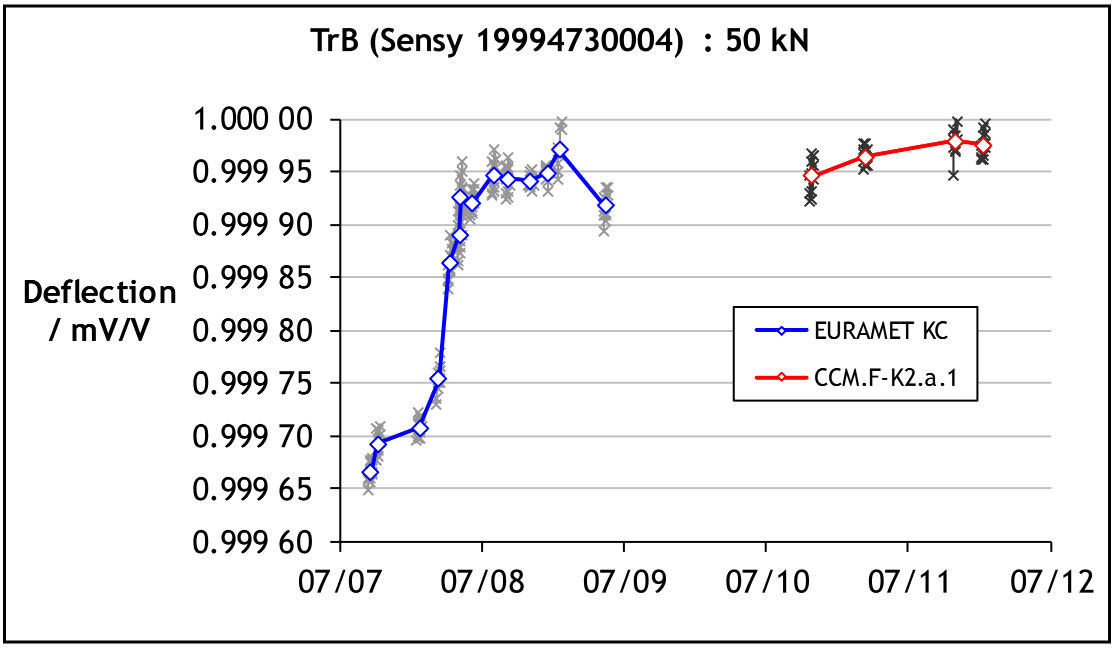

Figure 8. Stability of TrB at 50 kN throughout the comparison

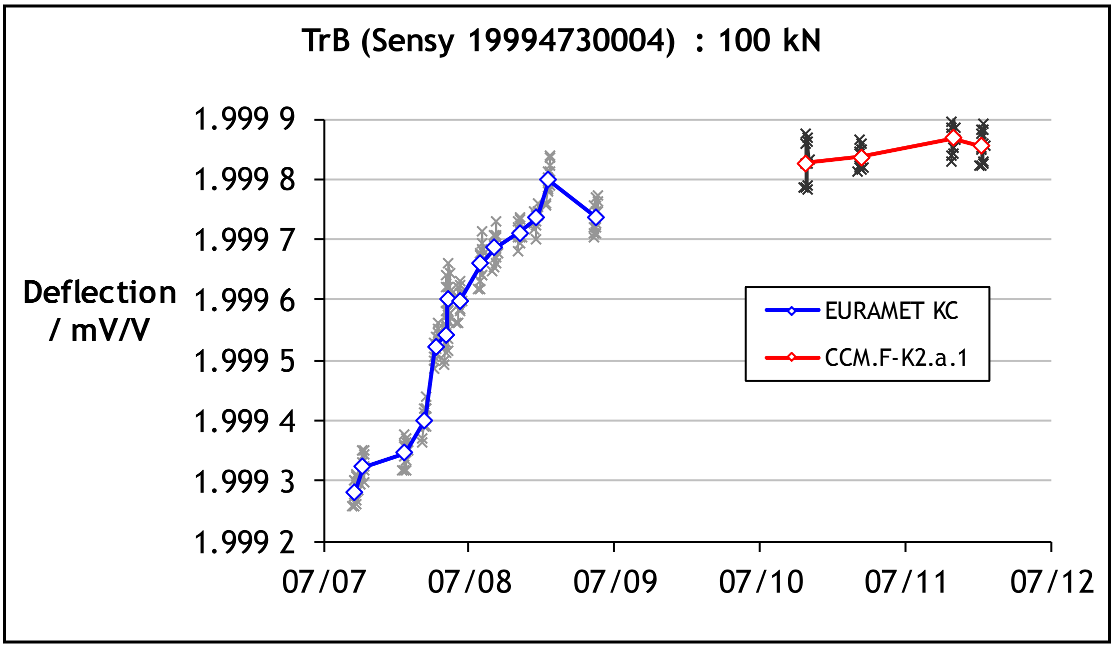

Figure 9. Stability of TrB at 100 kN throughout the comparison

9 Results obtained at INTI and CEM

Tables 6 to 9 detail the results obtained at INTI and CEM and give the difference from each loop's reference value (given in Tables 3 to 6) in both absolute and relative terms. As with the calibrations at the pilot laboratory, the adjusted deflections compensate both for the BN100 values and for the calibrations not being performed at 20 °C.

TrA (GTM 42793) - 50 kN					
Date (Lab)	Deflection	Adjusted Deflection	Loop Value	Difference	
	mV/V	mV/V	mV/V	mV/V	Relative
6 Jan 2011 (INTI)	0.999 810	0.999 807	0.999 827	-0.000 020	-1.98E-05
20 Dec 2011 (CEM)	0.999 778	0.999 776	0.999 840	-0.000 065	-6.48E-05

Table 6. Results obtained from TrA (50 kN) at INTI and CEM

TrA (GTM 42793) - 100 kN					
Date (Lab)	Deflection	Adjusted Deflection	Loop Value	Difference	
	mV/V	mV/V	mV/V	mV/V	Relative
6 Jan 2011 (INTI)	1.999 943	1.999 939	1.999 958	-0.000 019	-0.93E-05
20 Dec 2011 (CEM)	1.999 888	1.999 883	1.999 982	-0.000 099	-4.94E-05

Table 7. Results obtained from TrA (100 kN) at INTI and CEM

TrB (Sensy 19994730004) - 50 kN					
Date (Lab)	Deflection	Adjusted Deflection	Loop Value	Difference	
	mV/V	mV/V	mV/V	mV/V	Relative
12 Jan 2011 (INTI)	0.999 954	0.999 951	0.999 955	-0.000 004	-0.39E-05
15 Dec 2011 (CEM)	0.999 935	0.999 932	0.999 977	-0.000 045	-4.47E-05

Table 8. Results obtained from TrB (50 kN) at INTI and CEM

TrB (Sensy 19994730004) - 100 kN					
Date (Lab)	Deflection	Adjusted Deflection	Loop Value	Difference	
	mV/V	mV/V	mV/V	mV/V	Relative
12 Jan 2011 (INTI)	1.999 801	1.999 798	1.999 831	-0.000 033	-1.64E-05
15 Dec 2011 (CEM)	1.999 801	1.999 796	1.999 861	-0.000 064	-3.22E-05

Table 9. Results obtained from TrB (100 kN) at INTI and CEM

Figure 10 summarises these results, expressed as differences from the loop value, and Figure 11 shows the unweighted mean relative differences from the loop value obtained at forces of 50 kN and 100 kN. Note that weighted mean differences cannot be calculated until estimates of uncertainty have been made.

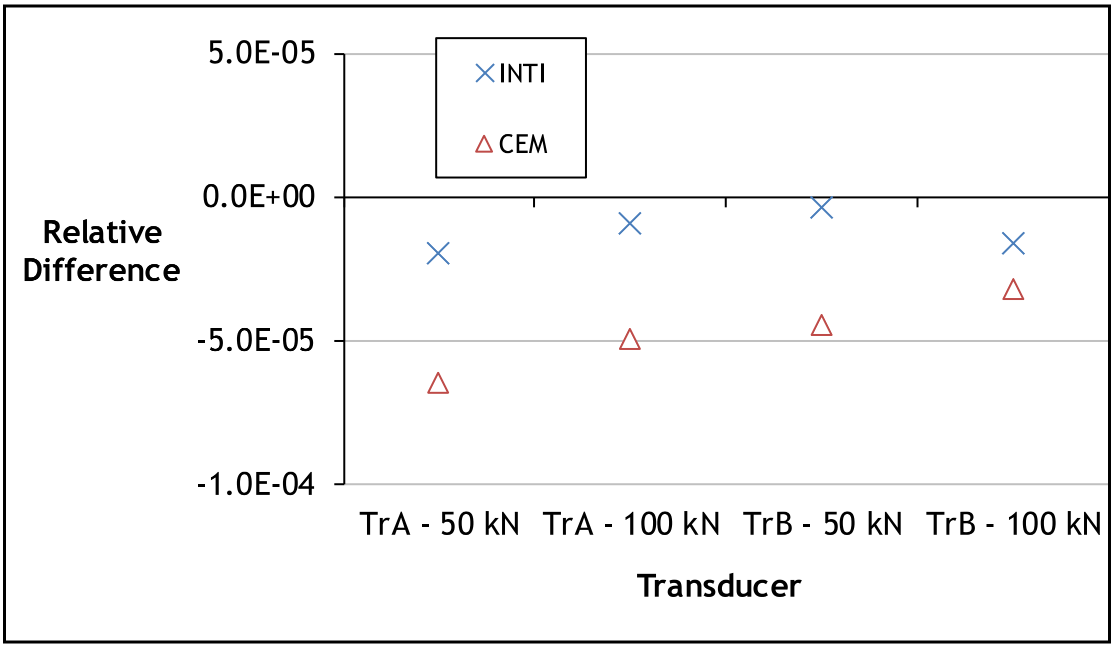

Figure 10. Summary of results

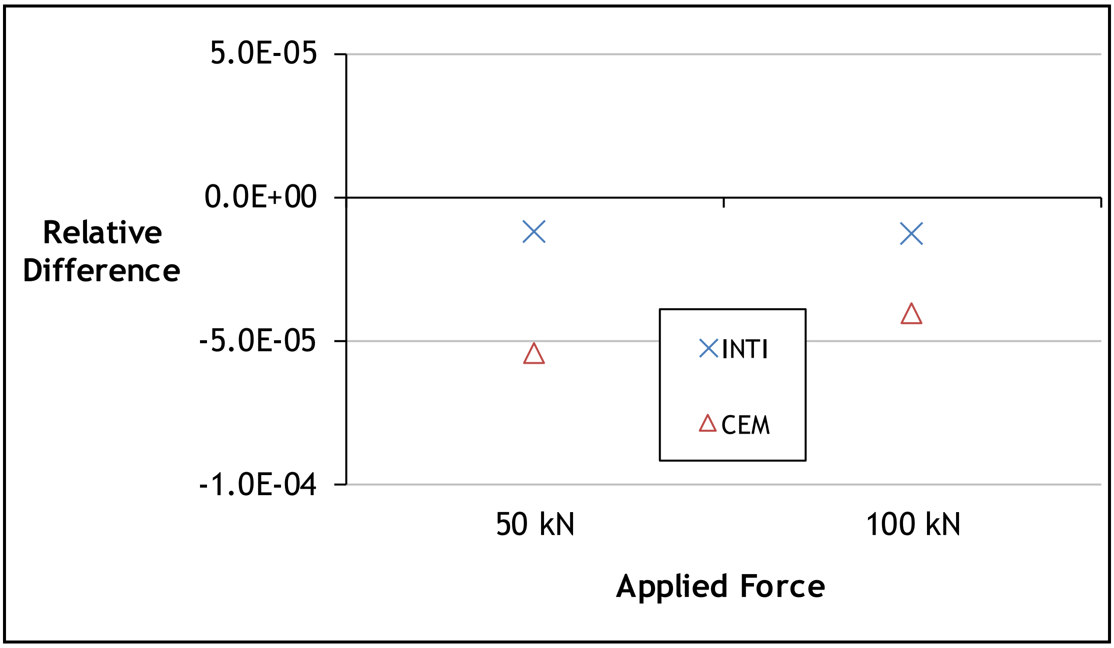

Figure 11. Mean differences obtained from both transducers

10 Uncertainty analysis

Table 10 calculates, for each mean deflection obtained in each participating laboratory, an expanded relative uncertainty value. Each uncertainty value is calculated in the same way, with contributions due to the applied force, the reproducibility of the readings (calculated as the standard deviation of the mean), and the resolution of the DMP40. No allowance is made yet for the BN100 checks or temperature corrections – these will be dealt with in conjunction with the effect of drift of the transducer at a later stage.

Lab	Transducer / Force	Relative Standard Uncertainty			Relative Expanded Uncertainty (k=2)
		Force	Reproducibility	Resolution	
NPL	TrA / 50 kN	5.0E-06	5.0E-06	4.1E-07	1.4E-05
	TrA / 100 kN	5.0E-06	5.4E-06	2.0E-07	1.5E-05
	TrB / 50 kN	5.0E-06	3.6E-06	4.1E-07	1.2E-05
	TrB / 100 kN	5.0E-06	3.8E-06	2.0E-07	1.3E-05
INTI	TrA / 50 kN	5.0E-05	6.4E-06	4.1E-07	1.0E-04
	TrA / 100 kN	5.0E-05	4.4E-06	2.0E-07	1.0E-04
	TrB / 50 kN	5.0E-05	1.2E-06	4.1E-07	1.0E-04
	TrB / 100 kN	5.0E-05	2.1E-06	2.0E-07	1.0E-04
CEM	TrA / 50 kN	1.0E-05	2.0E-06	4.1E-07	2.0E-05
	TrA / 100 kN	1.0E-05	1.6E-06	2.0E-07	2.0E-05
	TrB / 50 kN	1.0E-05	3.8E-06	4.1E-07	2.1E-05
	TrB / 100 kN	1.0E-05	3.3E-06	2.0E-07	2.1E-05

Table 10. Relative expanded uncertainty value for each mean deflection

For each deflection value obtained by INTI or CEM, the difference between it and the loop value is calculated. The uncertainty associated with this difference is a combination of INTI or CEM's measurement uncertainty, the uncertainty of the loop value, and the uncertainty associated with the temperature corrections. The uncertainty of the loop value includes contributions due to the drift of the transducer, the effect of the BN100 corrections, and any change in the force applied at the pilot laboratory (note that this is smaller than the uncertainty of generated force, as the same masses are used for each pilot calibration – the main contribution will be a change in buoyancy force due to air pressure variation, and it is evident that this effect is negligible when compared to the magnitudes of the drift and BN100 effects).

Considering both Figures 4 and 5, and also previous experience, an estimate of a relative standard uncertainty associated with the BN100 corrections of 5×10^{-6} would not seem unreasonable, and 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. Drift of each transducer is dealt with by considering the changes between the two deflections measured at the pilot laboratory as the extremes of a rectangular distribution – this approach does have the danger of possibly underestimating the drift's magnitude, but the values resulting from this approach do not appear unreasonable when compared with the known history of each device.

When the drift, BN100, and temperature uncertainty contributions are incorporated with the uncertainty associated with the deflection at each laboratory, the results are as shown in Figure 12.

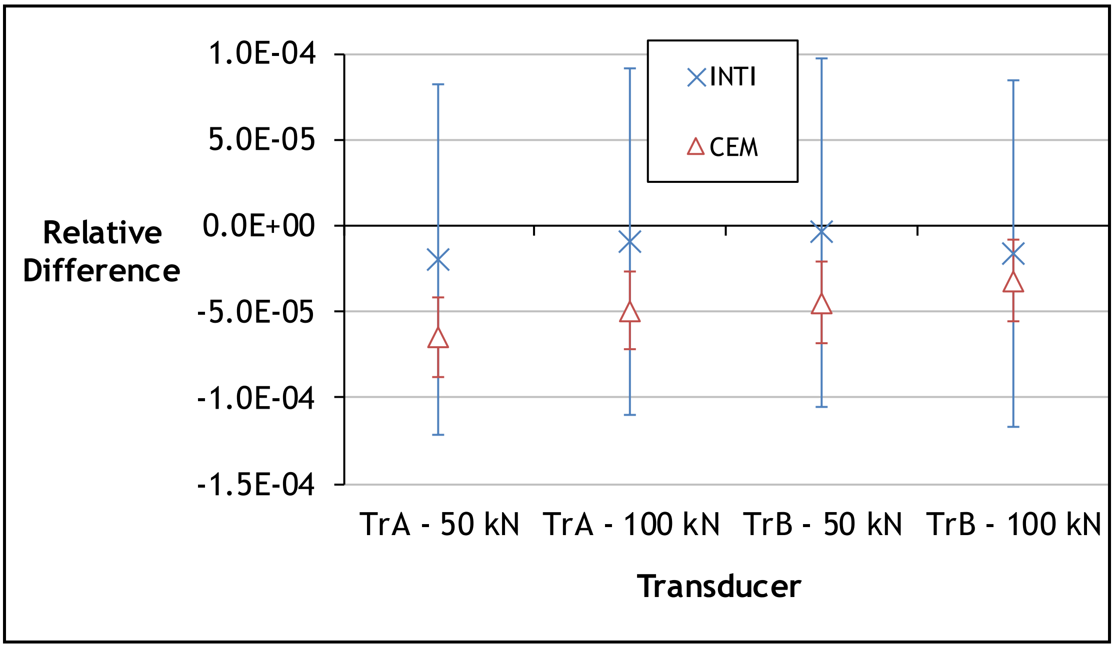

Figure 12. Differences from the loop value together with associated expanded uncertainties

The next step is to combine the results from each laboratory at each force and this is done as a weighted mean of each laboratory's results, giving more weight to the values with lower associated uncertainties. Results are given in Table 11.

Lab	Force	Relative Mean Deviation From Loop Value	Relative Expanded Uncertainty (*k*=2)
INTI	50 kN	-1.0E-05	1.0E-04
	100 kN	-1.4E-05	1.0E-04
CEM	50 kN	-5.6E-05	2.2E-05
	100 kN	-4.2E-05	2.2E-05

Table 11. Relative mean deviation and expanded uncertainty at each force level

Appendix – Key Comparison Reference Values

In order to link the results of this comparison to the KCRVs determined in CIPM Key Comparison CCM.F-K2.a, the assumption is made that the forces generated by the machine at NPL have not changed significantly. The results of CCM.F-K2.a indicate that the 50 kN and 100 kN forces generated by NPL are both 0.5×10^{-5} smaller than the KCRV, with expanded uncertainty values of 1.6×10^{-5} and 1.7×10^{-5} respectively.

In order to determine degrees of equivalence for INTI and CEM, their deviations from the loop value need adjusting by the deviation between NPL and the KCRV, and the uncertainties increasing to incorporate the uncertainty in this deviation. When this is done, the figures in Table 12 are calculated and plotted in Figure 13.

The conclusions to be drawn from these results, at both force values, are that the INTI results are consistent with their uncertainty claims but the results at CEM are inconsistent with their CMCs.

	50 kN		100 kN	
Laboratory	**Deviation from KCRV**	**Expanded Uncertainty of Deviation**	**Deviation from KCRV**	**Expanded Uncertainty of Deviation**
INTI	-1.5	10.2	-1.9	10.2
CEM	-6.1	2.7	-4.7	2.8

Table 12. Degrees of equivalence of individual laboratories, all relative figures × 10^{-5}

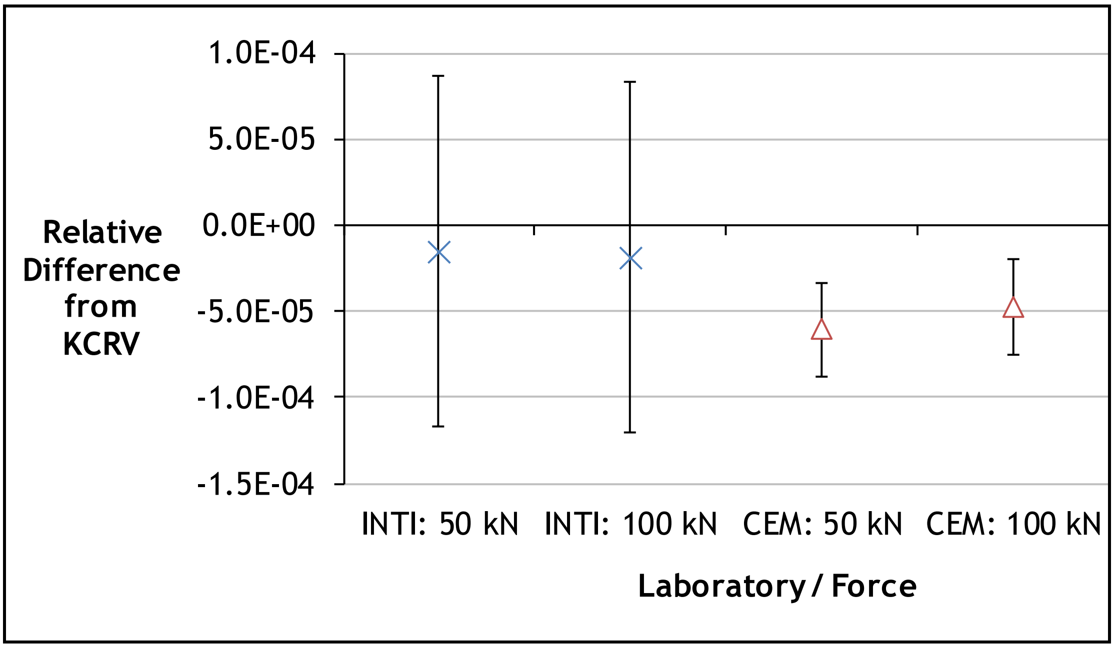

Figure 13. Deviations from KCRV with associated expanded uncertainties