Force Supplementary Comparison

EURAMET.M.F-S3

(1 kN, 2 kN, 5 kN, and 10 kN)

Final Report

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ABSTRACT

This report describes EURAMET Supplementary Comparison EURAMET.M.F-S3, a comparison between the 20 kN force standard machine of NPL and the 10 kN force standard machine of INMETRO, at generated forces of 1 kN, 2 kN, 5 kN, and 10 kN, in both tension and compression, with both incremental and decremental loading. Two different transducers were used and the force-time profile was strictly controlled, to minimise effects of creep. At all four force levels, the results demonstrate that there is no evidence that either machine fails to generate forces in accordance with its CMC.

Contents

1 Foreword

This report describes EURAMET Supplementary Comparison EURAMET.M.F-S3, a bilateral comparison between NPL (United Kingdom) and INMETRO (Brazil) at force values of 1 kN, 2 kN, 5 kN, and 10 kN.

2 Participants in the comparison

The two participants in the comparison were NPL (United Kingdom), who acted as the pilot, and INMETRO (Brazil). The work at NPL was performed in October 2014 and June 2015, and the work at INMETRO in March 2015. The machine used at NPL has a capacity of 20 kN and previously participated in CIPM Comparison CCM.F-K1.a at forces of 5 kN and 10 kN, whereas the INMETRO machine has been recently commissioned and has a 10 kN capacity. The NPL machine has an expanded uncertainty of 0.001 % while the INMETRO machine has one of 0.06 %.

3 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.

In contrast to other recent Key Comparisons in the force area, which have concentrated on only one or two incremental force values applied in compression, this comparison involved a range of four different forces, applied both incrementally and decrementally, in both tension and compression. As with other recent Key Comparisons, two different force transducers, detailed in Table 1, were used for the whole set of measurements.

Identification Code	Manufacturer	Serial Number	Capacity
TrA	Interface	70443	22 kN (5 000 lbf)
TrB	Revere	952248TP	22 kN (5 000 lbf)

Table 1. Transducers used in the comparison

For each force transducer, in each mode, a set of four incremental then three decremental forces (1 kN, 2 kN, 5 kN, 10 kN, 5 kN, 2 kN, 1 kN) was applied at each of three rotational positions (0°, 120°, and 240°). Prior to each measurement series, the transducer was preloaded at least once (three times after a change of mode) to 10 kN, and all forces throughout were maintained for 3 minutes (to minimise the effect of creep) before a reading was taken.

4 Format of the comparison

The comparison was made in an ABA format; the transducers came back to the pilot for re-measurement after the measurements at INMETRO. The measurement cycle (pilot > participant > 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 termed the drift. The reference value for the loop is taken as the mean of the two pilot measurements and is called the loop value.

5 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 agreement between the DMP40s used had been confirmed by comparison against the same BN100 calibrator unit, during a previous 100 kN comparison exercise, and suggested that the INMETRO measurements would be 5 ppm lower than the NPL ones at the same force, with an estimated expanded uncertainty of 2 ppm. The INMETRO deflections were adjusted by this amount to enable a proper comparison to be made with the NPL deflections.

6 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, while Figures 1 and 2 plot the transducers' sensitivities, expressed in mV/V per kN, resulting from their A- and B-measurements. In these figures, compression forces are taken as being negative, and the decremental loading direction is indicated by the dashed, rather than solid, lines. The vertical error bars correspond to one standard deviation associated with the three deflections measured at each point.

Date	Force / kN	Deflection / mV/V	Loop Value / mV/V
22/10/2014	1	-0.187 283	-0.187 273
02/06/2015		-0.187 263	
22/10/2014	2	-0.374 577	-0.374 557
02/06/2015		-0.374 536	
22/10/2014	5	-0.936 580	-0.936 533
02/06/2015		-0.936 486	
22/10/2014	10	-1.873 648	-1.873 539
02/06/2015		-1.873 430	
22/10/2014	5	-0.936 991	-0.936 933
02/06/2015		-0.936 875	
22/10/2014	2	-0.374 853	-0.374 826
02/06/2015		-0.374 799	
22/10/2014	1	-0.187 432	-0.187 418
02/06/2015		-0.187 403	

Table 2. Results obtained from TrA in compression at pilot laboratory

Date	Force / kN	Deflection / mV/V	Loop Value / mV/V
22/10/2014	1	0.187 288	0.187 277
02/06/2015		0.187 266	
22/10/2014	2	0.374 593	0.374 573
02/06/2015		0.374 552	
22/10/2014	5	0.936 603	0.936 556
02/06/2015		0.936 508	
22/10/2014	10	1.873 659	1.873 567
02/06/2015		1.873 476	
22/10/2014	5	0.936 998	0.936 950
02/06/2015		0.936 902	
22/10/2014	2	0.374 857	0.374 834
02/06/2015		0.374 811	
22/10/2014	1	0.187 433	0.187 419
02/06/2015		0.187 404	

Table 3. Results obtained from TrA in tension at pilot laboratory

Date	Force	Deflection	Loop Value
	/ kN	/ mV/V	
21/10/2014	1	-0.134 994	-0.135 007
01/06/2015		-0.135 020	
21/10/2014	2	-0.270 013	-0.270 042
01/06/2015		-0.270 072	
21/10/2014	5	-0.675 179	-0.675 235
01/06/2015		-0.675 292	
21/10/2014	10	-1.350 672	-1.350 793
01/06/2015		-1.350 915	
21/10/2014	5	-0.675 430	-0.675 486
01/06/2015		-0.675 542	
21/10/2014	2	-0.270 191	-0.270 222
01/06/2015		-0.270 254	
21/10/2014	1	-0.135 096	-0.135 110
01/06/2015		-0.135 125	

Table 4. Results obtained from TrB in compression at pilot laboratory

Date	Force	Deflection	Loop Value
	/ kN	/ mV/V	
21/10/2014	1	0.134 983	0.134 988
01/06/2015		0.134 993	
21/10/2014	2	0.269 990	0.269 994
01/06/2015		0.269 999	
21/10/2014	5	0.675 083	0.675 111
01/06/2015		0.675 139	
21/10/2014	10	1.350 316	1.350 371
01/06/2015		1.350 426	
21/10/2014	5	0.675 293	0.675 322
01/06/2015		0.675 351	
21/10/2014	2	0.270 153	0.270 153
01/06/2015		0.270 153	
21/10/2014	1	0.135 083	0.135 084
01/06/2015		0.135 084	

Table 5. Results obtained from TrB in tension at pilot laboratory

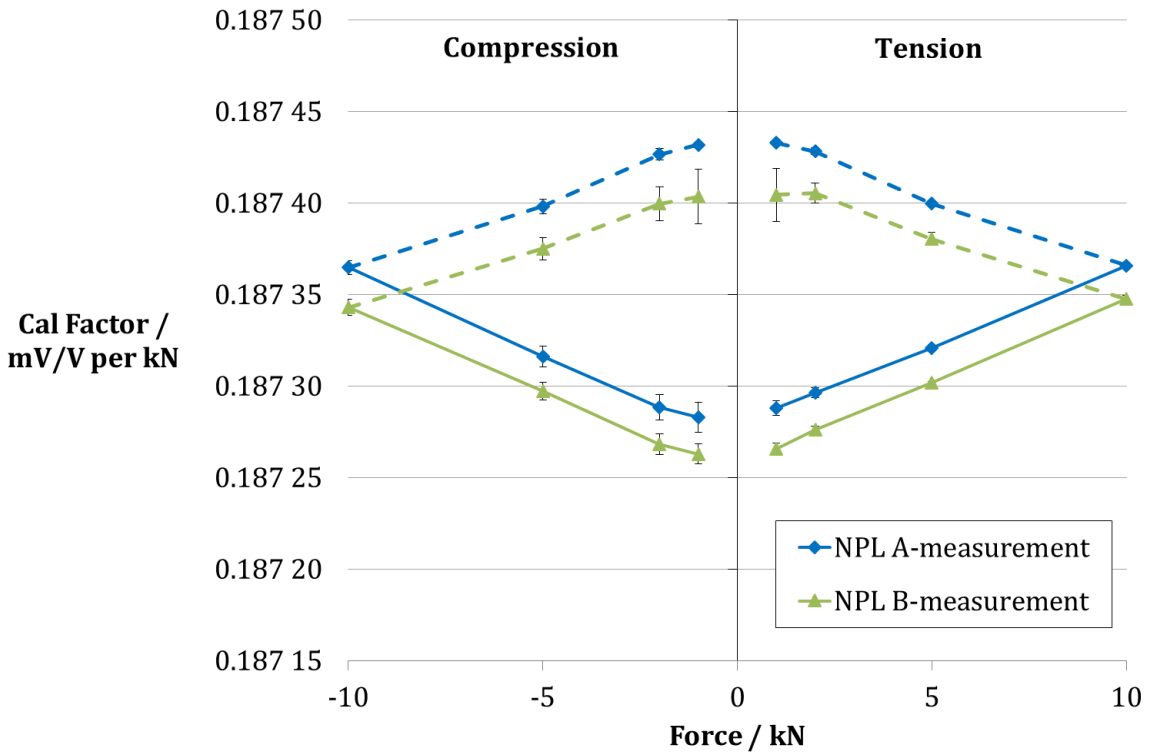

Figure 1. Sensitivity of TrA throughout the comparison

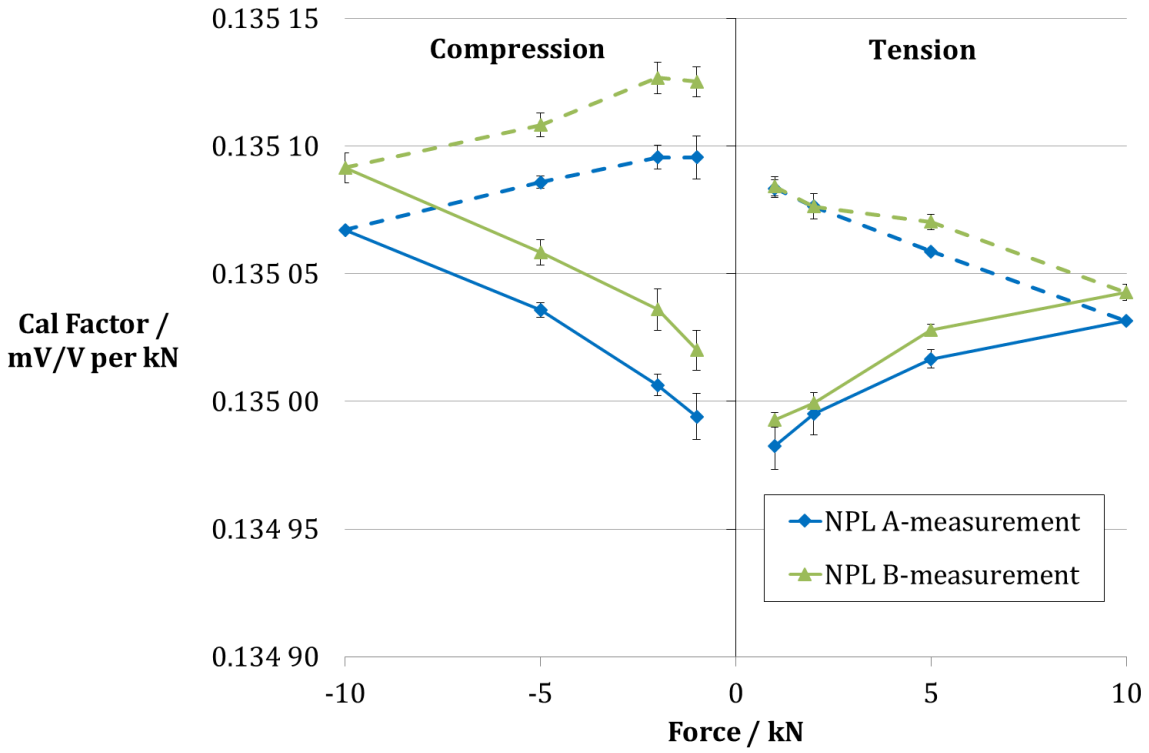

Figure 2. Sensitivity of TrB throughout the comparison

7 Results obtained at INMETRO

Tables 6 to 9 detail the results obtained at INMETRO and give the difference from the loop value (given in Tables 2 to 5) in both absolute and relative terms.

TrA - Compression: 25/03/2015				
Force	**Deflection**	**Loop Value**	**Difference**	
kN	**mV/V**			**%**
1	-0.187 202	-0.187 273	0.000 071	-0.038
2	-0.374 398	-0.374 557	0.000 159	-0.042
5	-0.936 335	-0.936 533	0.000 198	-0.021
10	-1.873 284	-1.873 539	0.000 254	-0.014
5	-0.936 717	-0.936 933	0.000 216	-0.023
2	-0.374 638	-0.374 826	0.000 188	-0.050
1	-0.187 339	-0.187 418	0.000 079	-0.042

Table 6. Results obtained from TrA in compression at INMETRO

TrA - Tension: 19/03/2015				
Force	**Deflection**	**Loop Value**	**Difference**	
kN	**mV/V**			**%**
1	0.187 209	0.187 277	-0.000 067	-0.036
2	0.374 402	0.374 573	-0.000 170	-0.045
5	0.936 360	0.936 556	-0.000 195	-0.021
10	1.873 277	1.873 567	-0.000 290	-0.015
5	0.936 725	0.936 950	-0.000 225	-0.024
2	0.374 653	0.374 834	-0.000 181	-0.048
1	0.187 346	0.187 419	-0.000 072	-0.039

Table 7. Results obtained from TrA in tension at INMETRO

TrB - Compression: 12/03/2015				
Force	**Deflection**	**Loop Value**	**Difference**	
kN	**mV/V**			**%**
1	-0.134 965	-0.135 007	0.000 042	-0.031
2	-0.269 921	-0.270 042	0.000 121	-0.045
5	-0.675 079	-0.675 235	0.000 157	-0.023
10	-1.350 545	-1.350 793	0.000 249	-0.018
5	-0.675 319	-0.675 486	0.000 167	-0.025
2	-0.270 090	-0.270 222	0.000 132	-0.049
1	-0.135 062	-0.135 110	0.000 049	-0.036

Table 8. Results obtained from TrB in compression at INMETRO

TrB - Tension: 16/03/2015				
Force	**Deflection**	**Loop Value**	**Difference**	
kN	**mV/V**			**%**
1	0.134 957	0.134 988	-0.000 031	-0.023
2	0.269 898	0.269 994	-0.000 096	-0.036
5	0.674 971	0.675 111	-0.000 140	-0.021
10	1.350 157	1.350 371	-0.000 214	-0.016
5	0.675 182	0.675 322	-0.000 141	-0.021
2	0.270 039	0.270 153	-0.000 114	-0.042
1	0.135 049	0.135 084	-0.000 035	-0.026

Table 9. Results obtained from TrB in tension at INMETRO

Figures 3 and 4 incorporate the INMETRO results within the sensitivity plots given in Figures 1 and 2. Again, the error bars on the INMETRO values correspond to one standard deviation associated with the measured deflections. Figure 5 plots the relative difference between the INMETRO and loop values at each incremental and decremental force, for each force transducer, in both tension and compression.

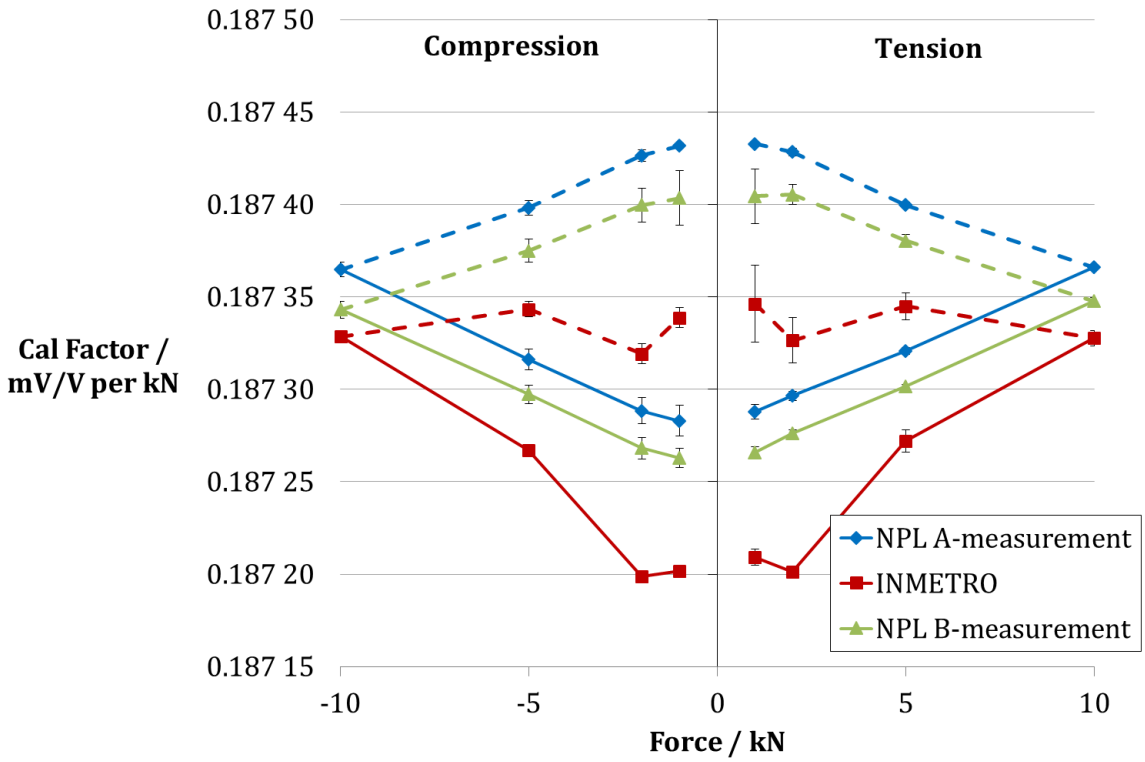

Figure 3. TrA sensitivity measurements

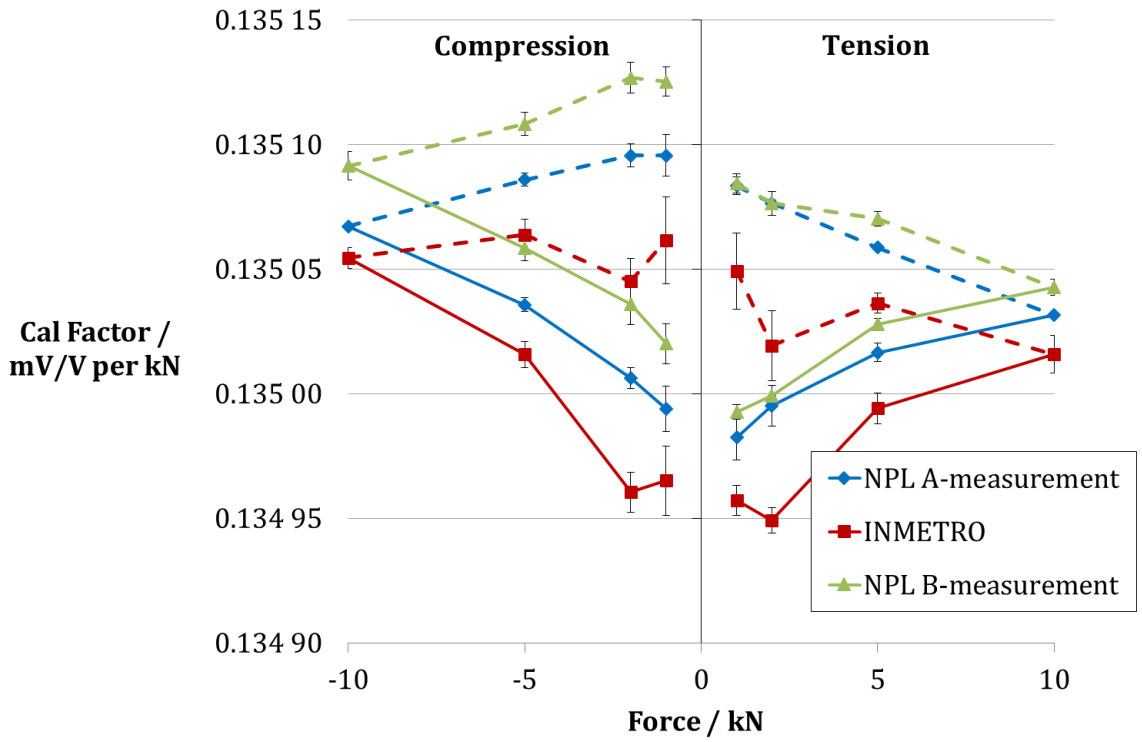

Figure 4. TrB sensitivity measurements

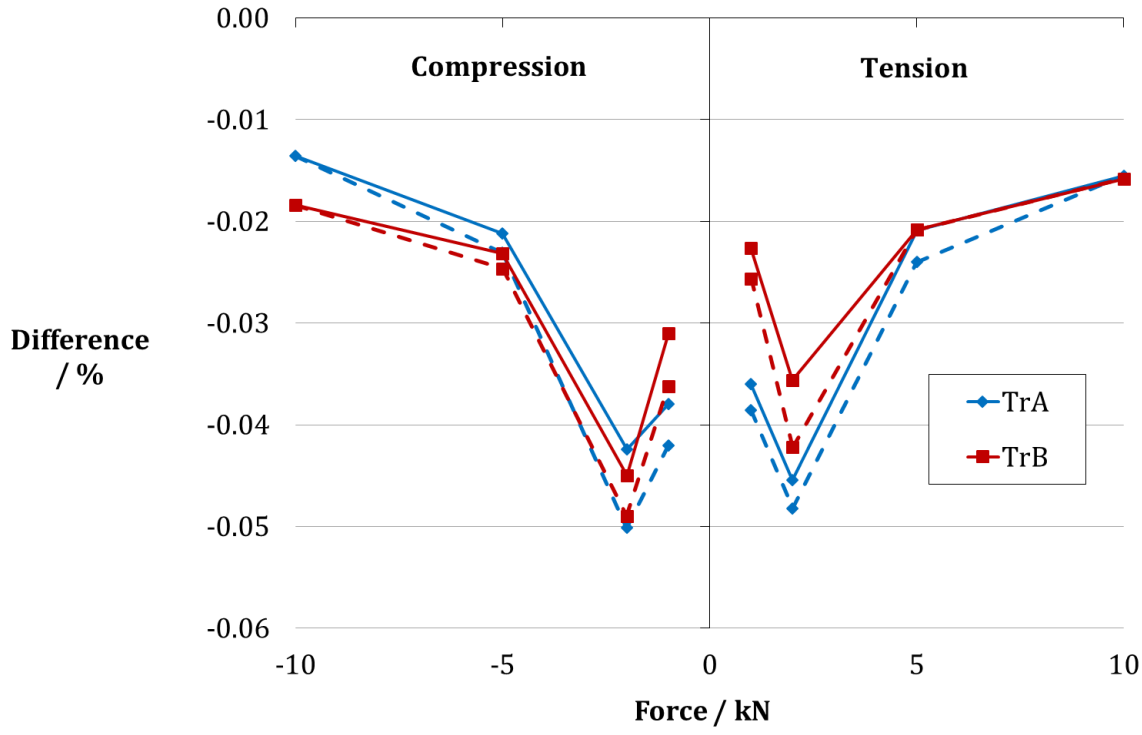

Figure 5. Difference between INMETRO and loop values

8 Analysis of Results

The symmetry apparent in Figure 5 suggests that, for a given nominal force, each machine applies the same force in tension as it does in compression. Similarly, the agreement between the incremental and decremental differences in each run suggests that neither machine generates significant hysteresis. All the results have therefore been combined in Figure 6, giving eight differences from the loop value at forces of 1 kN, 2 kN, and 5 kN, and four differences at 10 kN.

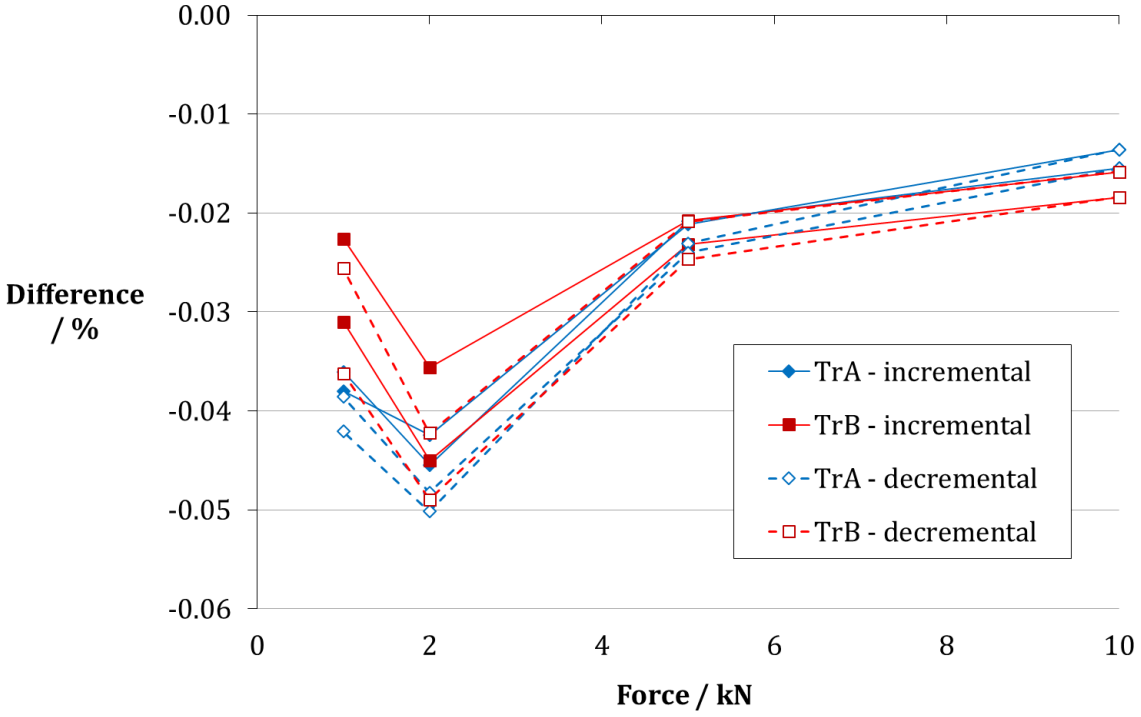

Figure 6. Summary of differences from the loop values

The uncertainty associated with each of these differences is a combination of INMETRO's measurement reproducibility and the uncertainty of the loop value. The uncertainty of the loop value includes contributions due to the drift of the transducer and the reproducibility of the two sets of results at NPL. Drift of each transducer is dealt with by considering the changes between the two mean deflections measured at NPL 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.

In Figure 7, at each force, the individual differences and associated uncertainties are plotted, together with (in red) the mean differences and their associated uncertainties, also detailed in Table 10. For clarity, the points are clustered around the nominal force value rather than all being plotted at the single correct force. The uncertainty associated with each mean difference includes an additional component related to the drift of the transducer, to allow for the correlation between results from the same transducer at the same force.

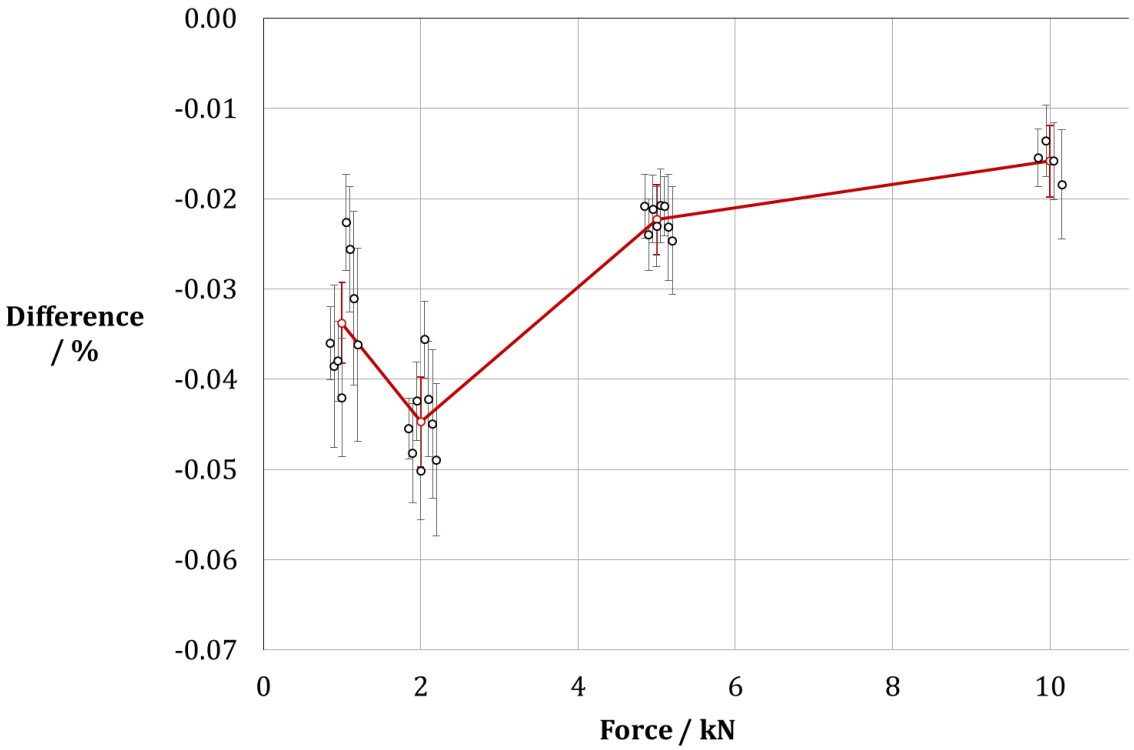

Figure 7. Individual differences from the loop values and associated uncertainties

Force	Relative Mean Difference From Loop Value	Relative Standard Uncertainty (k = 1)
1 kN	-3.4E-04	0.4E-04
2 kN	-4.5E-04	0.5E-04
5 kN	-2.2E-04	0.4E-04
10 kN	-1.6E-04	0.4E-04

Table 10. Relative mean difference and expanded uncertainty at each force level

For each of the four force levels, an E_n number was calculated to determine whether or not the two machines agreed within their claimed calibration and measurement capabilities (CMCs). For this statistic, the numerator was taken as the average difference δ and the uncertainty of the reference value u_{ref} as the sum in quadrature of the uncertainty u_δ associated with this difference and the claimed uncertainty of the force generated at NPL. At each specific force, the uncertainty of the participant's result is simply the CMC associated with the INMETRO machine.

These values are given in Table 11 and plotted in Fig. 8.

	F = 1 kN	F = 2 kN	F = 5 kN	F = 10 kN
δ / %	-0.034	-0.045	-0.022	-0.016
u_δ / %	0.004	0.005	0.004	0.004
u_{ref} / %	0.004	0.005	0.004	0.004
u_{INMETRO} / %	0.030	0.030	0.030	0.030
E_n	**-0.56**	**-0.74**	**-0.37**	**-0.26**

Table 11. E_n numbers at the four force levels

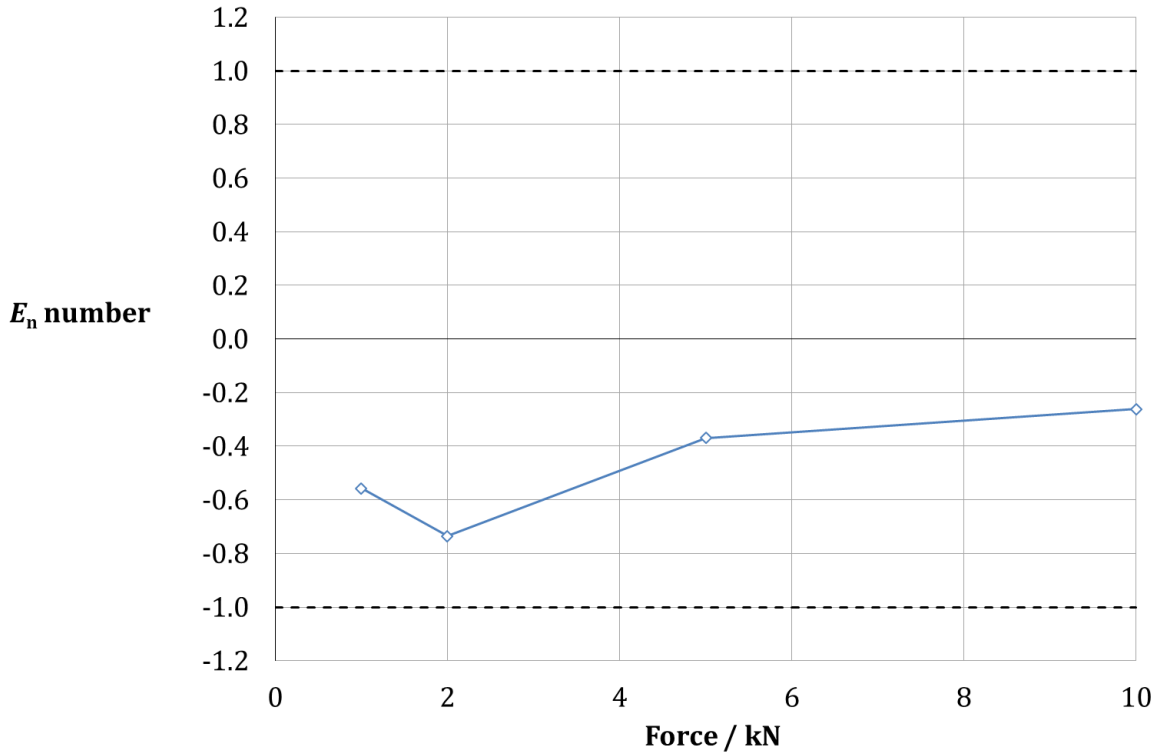

Figure 8. E_n numbers

The results of this comparison cannot be easily linked to any others within the KCDB, as the protocol is very different to any existing ones. All that can be stated is that the NPL machine participated in CIPM Comparison CCM.F-K1.a at forces of 5 kN and 10 kN, with the results given in Table 12. As this is a supplementary comparison, degrees of equivalence do not have to be calculated.

5 kN		10 kN	
Deviation from KCRV	**Expanded Uncertainty of Deviation**	**Deviation from KCRV**	**Expanded Uncertainty of Deviation**
1.1	2.0	1.1	1.9

Table 12. Degrees of equivalence of NPL in CCM.F-K1.a, all relative figures × 10^{-5}

9 Conclusions

As the magnitudes of all four E_n numbers shown in Table 11 and Figure 8 are lower than unity, there is no evidence to suggest that either machine is failing to generate forces in accordance with its CMC.

The reproducibility and drift performance of the two transducers used were not as good as initially hoped, and would have been the limiting factor if comparing two machines of very low CMC values. However, the INMETRO machine CMC of 0.06 % was easily the most significant component in the calculation of the E_n numbers, and so the transducer performance proved acceptable for the exercise.