CIPM 10 kN key comparison

NPL results

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Abstract

This report details the results obtained at NPL during work on a CIPM key comparison in the force range up to 10 kN. The protocol of the exercise enabled a direct comparison between the forces realised at NPL and those generated at the pilot laboratory to be made. The results give confidence that the uncertainties claimed by the two laboratories are reasonable and should be acceptable to the international community for inclusion in the BIPM database of measurement capabilities.

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1. Background

1.1 Mutual Recognition Arrangement

The Mutual Recognition Arrangement (MRA) has been drawn up by the International Committee of Weights and Measures (CIPM), under the authority given to it in the Metre Convention. Its objectives are to:

- establish the degree of equivalence of national measurement standards maintained by National Metrology Institutes (NMIs)
- provide for the mutual recognition of calibration and measurement certificates issued by NMIs
- provide governments and other parties with a secure technical foundation for wider agreements related to international trade, commerce, and regulatory affairs

The process by which this occurs comprises of:

- international comparisons of measurements, to be known as key comparisons
- supplementary international comparisons of measurements
- quality systems and demonstrations of competence by NMIs

The outcome of this process is a set of statements of the measurement capabilities of each NMI in a database maintained by the International Office of Weights and Measures (BIPM) and publicly available on the World Wide Web. The work is organised as follows:

- overall coordination is by the BIPM under the authority of the CIPM, which is itself under the authority of the Member States of the Metre Convention
- the Consultative Committees of the CIPM, the Regional Metrology Organizations, and the BIPM are responsible for carrying out the key and supplementary comparisons
- a Joint Committee of the Regional Metrology Organizations and the BIPM (the JCRB) is responsible for analysing and transmitting entries into the database for the calibration and measurement capabilities declared by the NMIs

The organisational structure of the MRA is indicated in Figure 1 and the scheme for key comparisons is shown in Figure 2. The regional metrology organizations (RMOs) play an important role in the MRA. They have responsibility for carrying out key comparisons within their regions, they carry out supplementary comparisons and other actions to support mutual confidence in the validity of calibration and measurement certificates of their member NMIs, and they are responsible for coordinating, through the JCRB, the entries into Appendix C of the MRA of the calibration and measurement capabilities of their member NMIs.

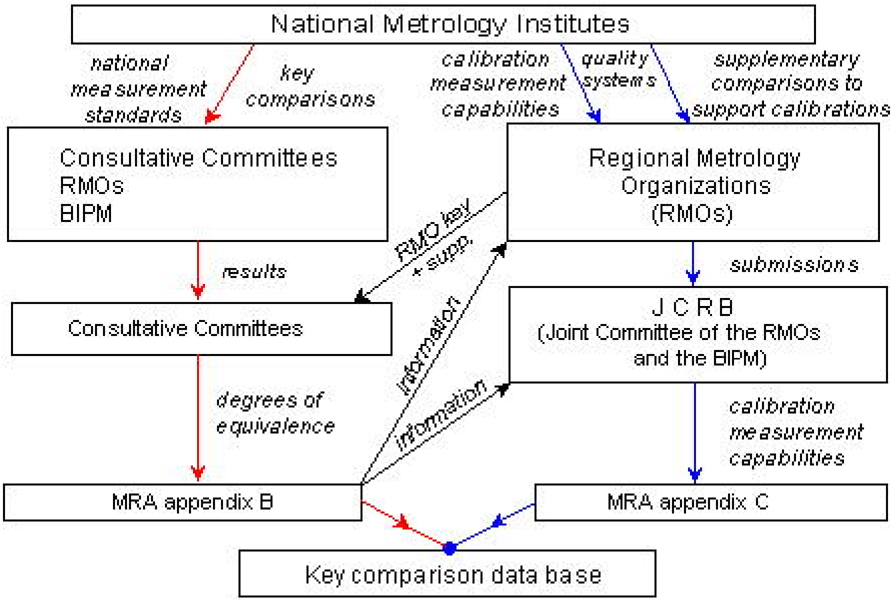
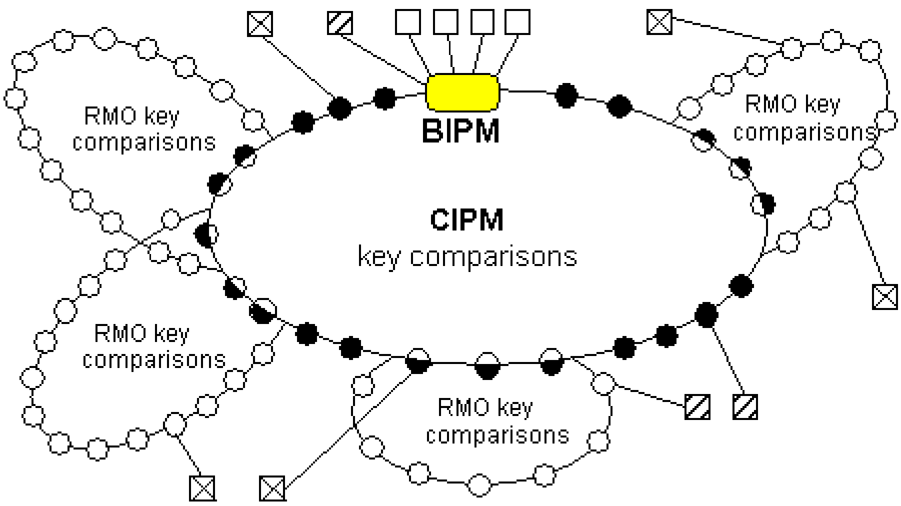


Figure 1 An outline of the organisation of the MRA



● NMI participating in CIPM key comparisons

◐ NMI participating in CIPM and RMO key comparisons

○ NMI participating in RMO key comparisons

□ NMI participating in ongoing BIPM key comparisons

☒ NMI participating in a bilateral key comparison

▨ International organization signatory to the MRA

Figure 2 The scheme for key comparisons

1.2 Key comparisons

National accreditation and regulatory bodies require multilateral agreements or arrangements to define the conditions under which they can accept calibration, measurement, and test certificates issued by laboratories accredited in other countries. These agreements or arrangements depend for their validity on the accuracy of both national measurement standards and calibration and measurement certificates issued by national metrology institutes (NMIs). The MRA provides for the mutual recognition of both national measurement standards and calibration and measurement certificates issued by national metrology institutes, and is founded on the efforts of each individual national metrology institute to base its measurements and measurement uncertainties on SI units.

To put the criteria for mutual recognition on an objective footing, the arrangement calls upon:

- the results of a set of key comparisons carried out using specified procedures which lead to a quantitative measure of the degree of equivalence of national measurement standards
- the operation by each NMI of a suitable way of assuring quality
- successful participation by each NMI in appropriate supplementary comparisons

Together, these three procedures demonstrate to participating institutions the degree to which each may have confidence in the results reported by others, and so promote mutual confidence between them.

The technical basis of this arrangement is the set of results obtained in the course of time through key comparisons carried out by the Consultative Committees of the CIPM, the BIPM, and the RMOs, and published by the BIPM and maintained in the key comparison database. Key comparisons carried out by Consultative Committees or the BIPM are referred to as CIPM key comparisons; key comparisons carried out by regional metrology organizations are referred to as RMO key comparisons; RMO key comparisons must be linked to the corresponding CIPM key comparisons by means of joint participants. The degree of equivalence derived from an RMO key comparison has the same status as that derived from a CIPM key comparison.

The Consultative Committees have the responsibility for choosing the key comparisons and affirming the validity of the results. Participation in a CIPM key comparison is open to laboratories having the highest technical competence and experience, normally the member laboratories of the appropriate Consultative Committee. In choosing participants, the Consultative Committees should take proper account of regional representation. The number of laboratories participating in CIPM key comparisons may be restricted for technical reasons.

1.3 CCM force working group

The Consultative Committee responsible for Force is the Consultative Committee for Mass and Related Quantities (CCM) - this has a Working Group on Force chaired by Prof Manfred Peters of the German NMI, Physikalisch-Technische Bundesanstalt (PTB).

1.4 Force key comparisons

At a meeting of the CCM Working Group on Force in October 1998, a set of eight CIPM key comparisons of force was agreed upon. These key comparisons are detailed in Table 1.

Identification	Force level	Force values	Pilot	Dates
CCM.F-K1.a	Low	0 kN : 5 kN : 10 kN	MIKES	2000 - 2001
CCM.F-K1.b	Low	0 kN : 5 kN	MIKES	2000 - 2001
CCM.F-K2.a	Medium	0 kN : 50 kN : 100 kN	NPL	2001 - 2002
CCM.F-K2.b	Medium	0 kN : 50 kN	NPL	2001 - 2002
CCM.F-K3.a	High	0 MN : 0,5 MN : 1 MN	PTB	2003 - 2004
CCM.F-K3.b	High	0 MN : 0,5 MN	PTB	2003 - 2004
CCM.F-K4.a	Very high	0 MN : 2 MN : 4 MN	NIST	2002 - 2003
CCM.F-K4.b	Very high	0 MN : 2 MN	NIST	2002 - 2003

Table 1 CIPM key comparisons

This report covers the results obtained by NPL in CIPM key comparison CCM.F-K1.a. A full list of participants is given in Table 2.

RMO	Participant	Country
APMP	NIM	China
	NRLM	Japan
EUROMET	MD	Belgium
	MIKES	Finland
	PTB	Germany
	CNR-IMGC	Italy
	VSL	Netherlands
	CEM	Spain
	UME	Turkey
	NPL	UK
SIM	INMETRO	Brazil
	CENAM	Mexico
	NIST	USA

Table 2 CIPM key comparison CCM.F-K1.a participants

2. CCM.F-K1.a

2.1 Organisation

As stated in Table 1, the pilot for CIPM key comparison CCM.F-K1.a was MIKES, the Finnish Centre for Metrology and Accreditation. MIKES has a contract with Raute Precision Oy, an accredited calibration laboratory, to act as a reference laboratory for force and torque measurements, as no Finnish national force standards of these values have been established.

2.2 Protocol

One of the major problems in the comparison of force machines, and deadweight machines in particular, is that the uncertainties of the generated forces are often significantly smaller than the stability and reproducibility of the load cell used to compare the machines. The best solution to this problem is to use high quality load cells and to subject them to identical loading profiles in the machines, following a strict measurement protocol and using the same instrumentation.

At the meeting in October 1998, the CCM Force Working Group proposed the loading scheme shown in Figure 3. After 4 preloads at 0°, three measurement runs are carried out at just two incremental forces (5 kN and 10 kN), with a period of six minutes between readings. This compares with a standard dwell period of one minute during normal load cell calibrations, and is of this magnitude in an attempt to minimise any variation in output caused by creep of the load cell.

After the measurements at 0°, the load cell is rotated by 60°, preloaded, and then subjected to another measurement run following the same timing intervals. This procedure is then repeated a further eleven times, until the load cell has undergone two complete cycles of rotation.

The deflection of the load cell at a given force is defined as the output at that force minus the output at zero force prior to the force application. The three deflections at each force at the initial 0° position are used to calculate the repeatability of the load cell (the standard deviation of the three values), and the following twelve deflections at each force are used to calculate the mean deflection and the reproducibility (the standard deviation of the twelve values).

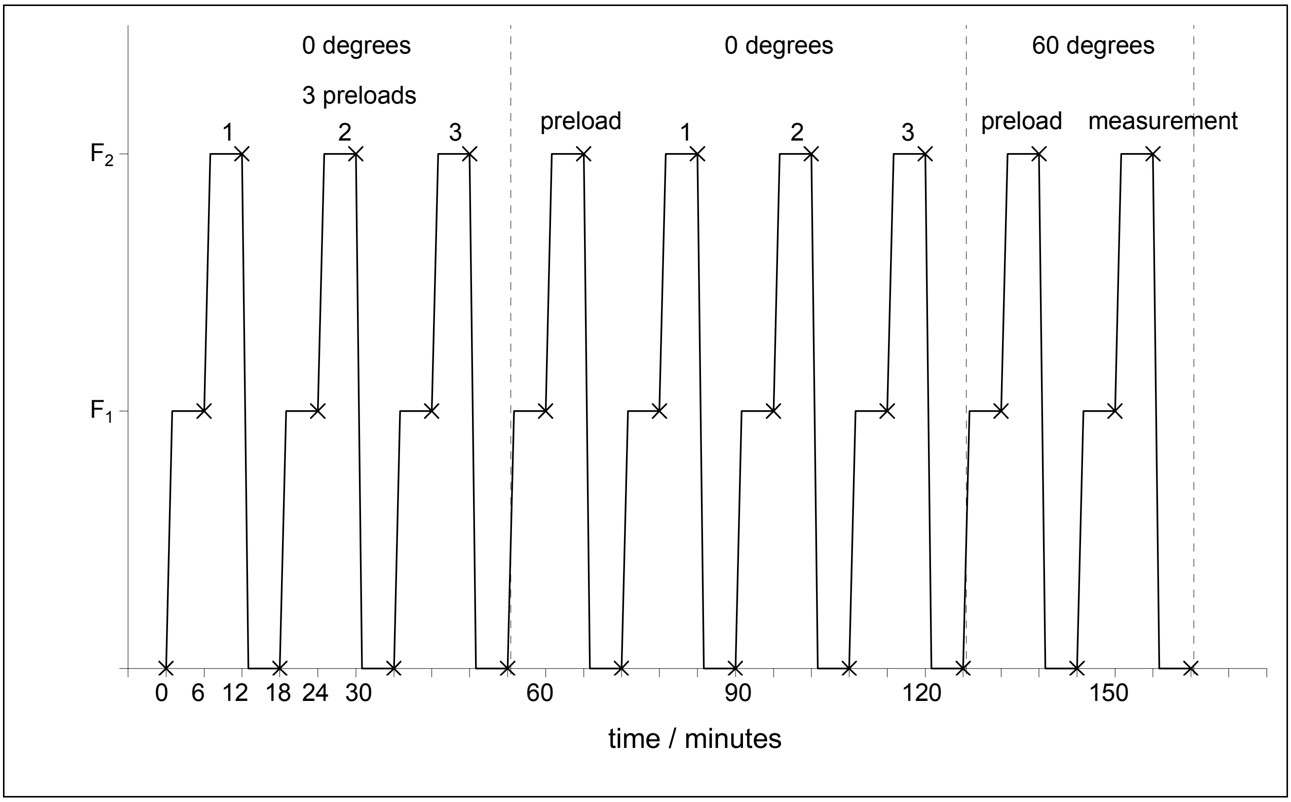


Figure 3 Key comparison loading scheme

Two force transducers of different designs were used in the exercise, both being calibrated at all laboratories. Device 1 was manufactured by GTM and device 2 by Raute Precision. Each had a nominal capacity of 10 kN.

Because the drift of sensitivity of force transducers can be significant, the comparison followed a star-type pattern, with the transducers being calibrated at the pilot laboratory both before and after each calibration at a participating laboratory. This involves the pilot laboratory in much more work than a round-robin type comparison, and it significantly increases the transportation costs, but it was deemed necessary in order to determine the effect of transducer drift on the results of the whole exercise.

The instrumentation with the best resolution, stability, and uncertainty for force measurement applications is generally agreed to be the Hottinger Baldwin Messtechnik (HBM) DMP40. This is a digital precision measuring amplifier, which provides the energising voltage to the load cell, reads the output signal from the load cell, and displays the ratio between the two. Due to the fragile nature of these instruments, it was agreed that each participating laboratory would use its own such instrument, rather than shipping one around with the load cells. This obviously brings in a possible error source to the results – namely that the instrumentation of the various laboratories may not be of equal sensitivity. In order to determine the lack of agreement between instruments, the pilot laboratory circulated a BN100 (bridge calibration unit) with the load cells. This is another HBM instrument which can be used to check the performance of the DMP40. As the same BN100 was used to check each DMP40, and making the reasonable assumption that the BN100 remained stable throughout the exercise (as could be demonstrated by the results at the pilot laboratory), a comparison between the sensitivities of the individual laboratories' instrumentation could be made, and their results corrected accordingly.

The results obtained at each laboratory were entered on a spreadsheet provided by the pilot and returned by e-mail to the pilot for analysis.

3. Work at NPL

3.1 Equipment

The work at NPL was carried out in a 20 kN deadweight force standard machine, shown in Figure 4. This machine was developed in the late 1980s, and incorporates a single stack of stainless steel weights supported on a screw jack. When the jack is driven down, the top weight is lowered onto the scalepan. As it is driven further down, each weight locates on the one above via three hangers (Figure 5). In this way, the machine is capable of applying 0,5 kN force increments up to 5 kN, and then 1 kN increments up to the full capacity of 20 kN.

Figure 4 20 kN deadweight force standard machine

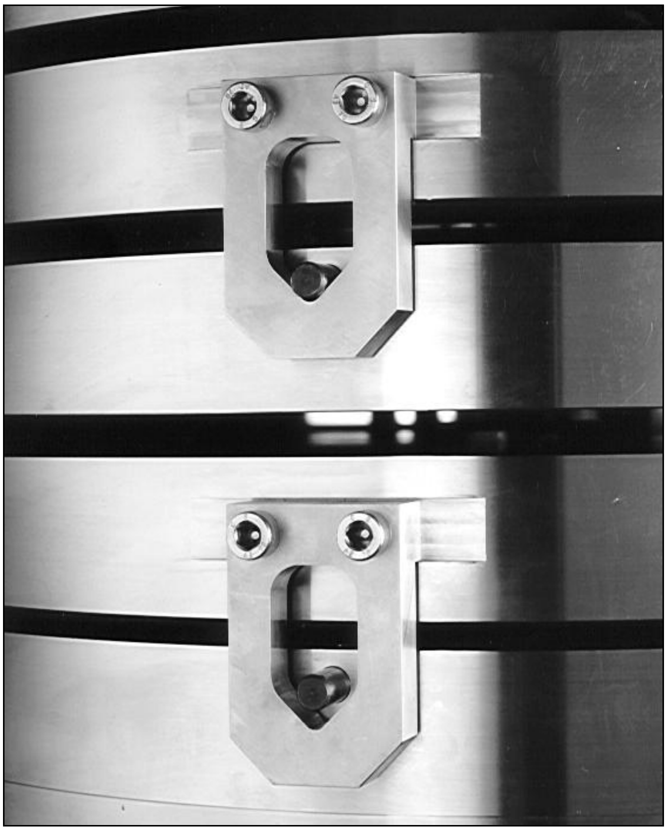


Figure 5 20 kN machine weight hanger system

The uncertainty of the vertical force generated by this machine is ±0,001 % (at a 95 % level of confidence). The two major contributions to this value are the uncertainty associated with the mass value (comprising both calibration uncertainty and also deviation from nominal value) and the uncertainty due to the variation in atmospheric air pressure, leading to a variation in air density and hence buoyancy force.

The serial number of the DMP40 used at NPL and its settings are given in Table 3.

Serial number:	015020001
Filter setting:	3 dB 0,45 Hz Bessel
Bridge supply:	5 V
Measuring range:	2,5 mV/V

Table 3 DMP40 details

3.2 Device 1

Device 1 was a 10 kN force transducer manufactured by GTM, serial number 40591. Work at NPL was performed on 14 March 2001. The environmental conditions throughout this work are given in Table 4. At the start and finish of the day's work, the DMP40 was checked against the BN100, serial number 402686, provided by the pilot. The results of these checks are given in Table 5. The results obtained during the calibration of device 1 are given in Table 6. The calculated values for deflection at each orientation, overall mean, repeatability, and reproducibility are given in Table 7.

	Time	Temperature	Humidity	Air pressure
		°C	% RH	hPa
At start	8:50	20,1	40	1 007,3
After Run 3	10:59	20,5		
After Run 6	12:58	20,6		
After Run 9	14:37	20,7		
After Run 12	16:25	20,8		
After Run 15	18:14	20,8	41	1 005,4

Table 4 Environmental conditions during work on device 1

Calibration value	**Before measurement**	**After measurement**	
	net	**net**	**gross**
mV/V	mV/V	mV/V	mV/V
-0,200 000	-0,200 000	-0,200 001	
0,000 000	0,000 000	0,000 000	0,000 018
0,200 000	0,200 002	0,200 002	
0,800 000	0,800 002	0,800 000	
1,000 000	1,000 000	0,999 999	
1,200 000	1,200 000	1,200 000	
1,800 000	1,799 999	1,799 997	
2,000 000	1,999 992	1,999 995	
2,200 000	2,199 988	2,199 995	
Calibration signal:	2,499 999	2,500 000	
Temperature:	20,2 °C	20,8 °C	

Table 5 Check of DMP40 with BN100 402686

Orientation	Stage	Force	Output	Deflection
		kN	mV/V	mV/V
0°	Initial preloads	0	0,004 491	
		5	0,984 188	0,979 697
		10	1,963 695	1,959 204
		0	0,004 519	
		5	0,984 173	0,979 654
		10	1,963 686	1,959 167
		0	0,004 518	
		5	0,984 203	0,979 685
		10	1,963 692	1,959 174
		0	0,004 517	
	Preload	5	0,984 211	0,979 694
		10	1,963 710	1,959 193
	Run 1	0	0,004 519	
		5	0,984 213	**0,979 694**
		10	1,963 711	**1,959 192**
	Run 2	0	0,004 517	
		5	0,984 213	**0,979 696**
		10	1,963 707	**1,959 190**
	Run 3	0	0,004 522	
		5	0,984 209	**0,979 687**
		10	1,963 705	**1,959 183**
		0	0,004 516	
60°	Preload	5	0,984 218	0,979 702
		10	1,963 724	1,959 208
	Run 4	0	0,004 520	
		5	0,984 219	**0,979 699**
		10	1,963 722	**1,959 202**
		0	0,004 518	
120°	Preload	5	0,984 223	0,979 705
		10	1,963 731	1,959 213
	Run 5	0	0,004 519	
		5	0,984 227	**0,979 708**
		10	1,963 734	**1,959 215**
		0	0,004 521	
180°	Preload	5	0,984 225	0,979 704
		10	1,963 731	1,959 210
	Run 6	0	0,004 522	
		5	0,984 226	**0,979 704**
		10	1,963 732	**1,959 210**
		0	0,004 523	
240°	Preload	5	0,984 225	0,979 702
		10	1,963 724	1,959 201
	Run 7	0	0,004 522	
		5	0,984 226	**0,979 704**
		10	1,963 729	**1,959 207**
		0	0,004 521	

Orientation	Stage	Force	Output	Deflection
		kN	mV/V	mV/V
300°	Preload	5	0,984 222	0,979 701
		10	1,963 723	1,959 202
	Run 8	0	0,004 522	
		5	0,984 221	**0,979 699**
		10	1,963 727	**1,959 205**
		0	0,004 520	
0°	Preload	5	0,984 218	0,979 698
		10	1,963 720	1,959 200
	Run 9	0	0,004 517	
		5	0,984 217	**0,979 700**
		10	1,963 722	**1,959 205**
		0	0,004 524	
60°	Preload	5	0,984 221	0,979 697
		10	1,963 730	1,959 206
	Run 10	0	0,004 519	
		5	0,984 221	**0,979 702**
		10	1,963 725	**1,959 206**
		0	0,004 519	
120°	Preload	5	0,984 222	0,979 703
		10	1,963 731	1,959 212
	Run 11	0	0,004 522	
		5	0,984 224	**0,979 702**
		10	1,963 733	**1,959 211**
		0	0,004 523	
180°	Preload	5	0,984 229	0,979 706
		10	1,963 735	1,959 212
	Run 12	0	0,004 525	
		5	0,984 231	**0,979 706**
		10	1,963 740	**1,959 215**
		0	0,004 523	
240°	Preload	5	0,984 228	0,979 705
		10	1,963 729	1,959 206
	Run 13	0	0,004 523	
		5	0,984 226	**0,979 703**
		10	1,963 733	**1,959 210**
		0	0,004 527	
300°	Preload	5	0,984 222	0,979 695
		10	1,963 725	1,959 198
	Run 14	0	0,004 522	
		5	0,984 224	**0,979 702**
		10	1,963 726	**1,959 204**
		0	0,004 519	
0°	Preload	5	0,984 221	0,979 702
		10	1,963 724	1,959 205
	Run 15	0	0,004 521	
		5	0,984 224	**0,979 703**
		10	1,963 726	**1,959 205**
		0	0,004 522	

Table 6 Device 1 readings and deflections

Runs	Orientation	5 kN	10 kN
		mV/V	mV/V
9 and 15	0°	0,979 702	1,959 205
4 and 10	60°	0,979 701	1,959 204
5 and 11	120°	0,979 705	1,959 213
6 and 12	180°	0,979 705	1,959 213
7 and 13	240°	0,979 704	1,959 209
8 and 14	300°	0,979 701	1,959 205
	Mean:	0,979 703	1,959 208
	Repeatability:	4,8 ppm	2,4 ppm
	Reproducibility:	2,7 ppm	2,2 ppm

Table 7 Device 1 results

The deflections obtained in Runs 1 to 15 at 5 kN and 10 kN are shown in Figure 6 and Figure 7 respectively. The dotted lines indicate the mean values given in Table 7.

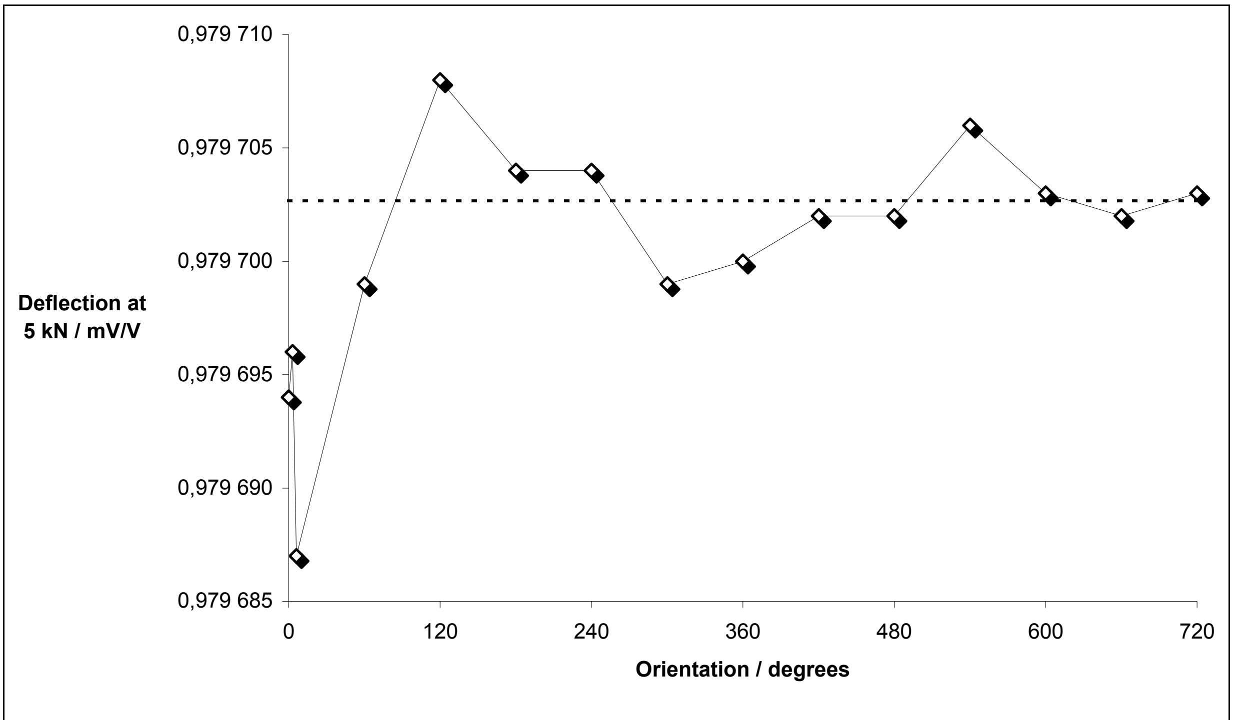


Figure 6 Deflections of device 1 at 5 kN in NPL machine

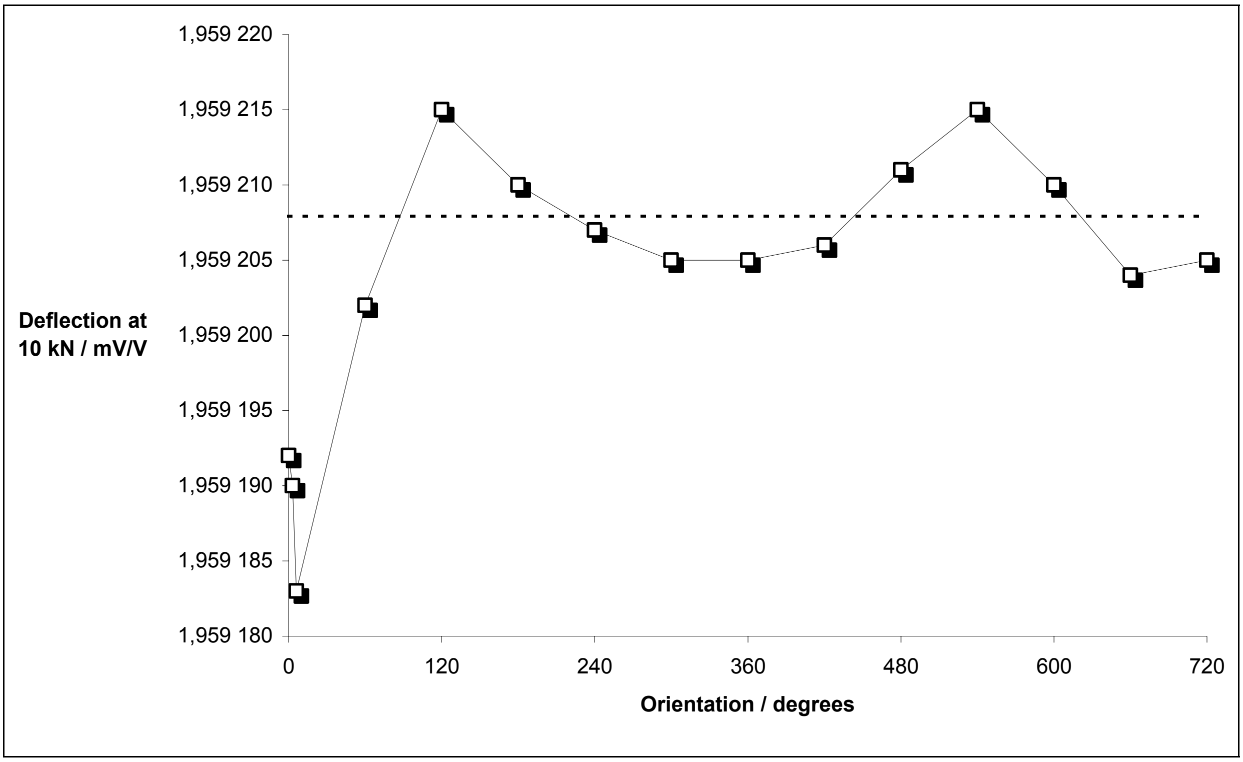


Figure 7 Deflections of device 1 at 10 kN in NPL machine

The variation in load cell output at zero force throughout the calibration is shown in Figure 8.

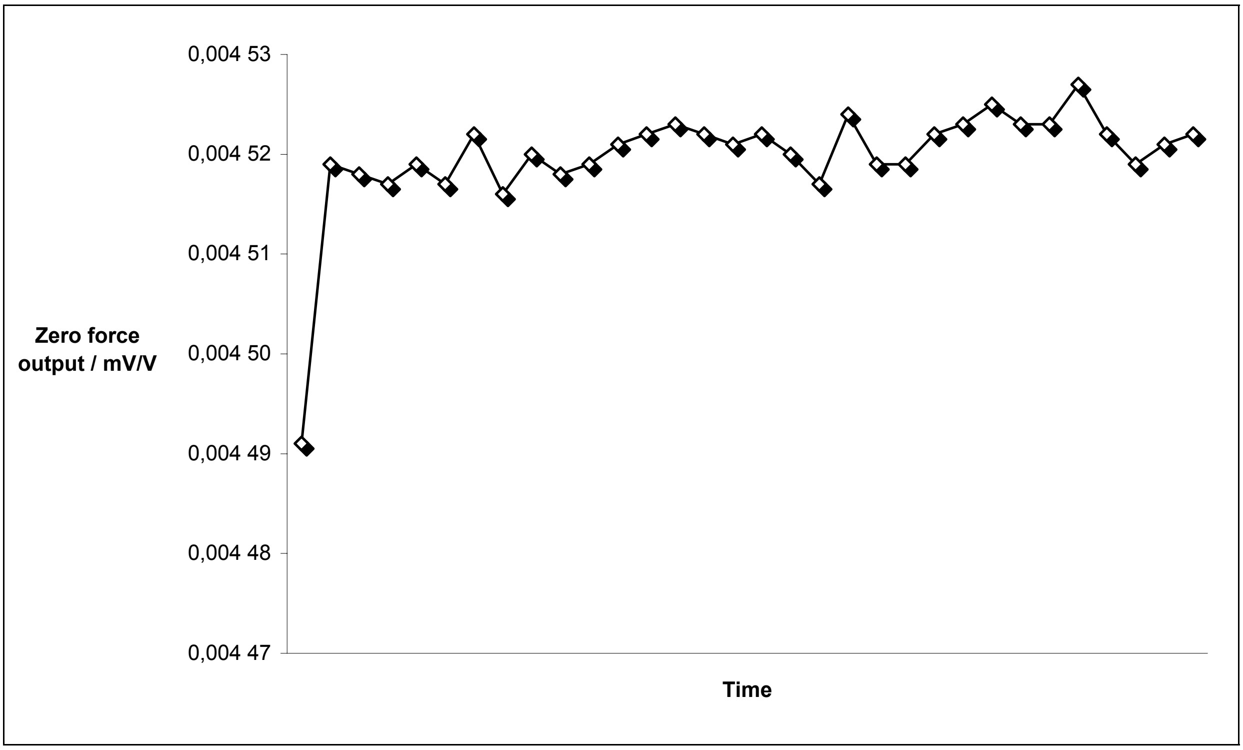


Figure 8 Variation in zero output from device 1 at NPL

3.3 Device 2

Device 2 was a 10 kN force transducer manufactured by Raute Precision Oy, serial number 34104. Work at NPL was performed on 16 March 2001. The environmental conditions throughout this work are given in Table 8. At the start and finish of the day's work, the DMP40 was checked against the BN100, serial number 402686, provided by the pilot. The results of these checks are given in Table 9. The results obtained during the calibration of device 2 are given in Table 10. The calculated values for deflection at each orientation, overall mean, repeatability, and reproducibility are given in Table 11.

	Time	**Temperature**	**Humidity**	**Air pressure**
		°C	% RH	hPa
At start	8:48	20,5	46	1 007,8
After Run 3	10:57	20,6		
After Run 6	12:46	20,7		
After Run 9	14:35	20,7		
After Run 12	16:24	20,7		
After Run 15	18:12	20,8	45	1 004,4

Table 8 Environmental conditions during work on device 2

Calibration value	**Before measurement**		**After measurement**	
	net	**gross**	**net**	**gross**
mV/V	mV/V	mV/V	mV/V	mV/V
-0,200 000	-0,199 999		-0,200 004	
0,000 000	0,000 000	0,000 020	0,000 000	0,000 018
0,200 000	0,200 001		0,200 000	
0,800 000	0,799 999		0,799 999	
1,000 000	1,000 000		1,000 000	
1,200 000	1,200 000		1,200 000	
1,800 000	1,799 995		1,800 000	
2,000 000	1,999 991		1,999 995	
2,200 000	2,199 991		2,199 995	
Calibration signal:	2,500 004		2,500 004	
Temperature:	20,5 °C		20,8 °C	

Table 9 Check of DMP40 with BN100 402686

Orientation	Stage	Force	Output	Deflection
		kN	mV/V	mV/V
0°	Initial preloads	0	-0,011 287	
		5	0,998 709	1,009 996
		10	2,008 690	2,019 977
		0	-0,011 259	
		5	0,998 732	1,009 991
		10	2,008 721	2,019 980
		0	-0,011 227	
		5	0,998 760	1,009 987
		10	2,008 747	2,019 974
		0	-0,011 205	
	Preload	5	0,998 778	1,009 983
		10	2,008 766	2,019 971
	Run 1	0	-0,011 190	
		5	0,998 790	**1,009 980**
		10	2,008 778	**2,019 968**
	Run 2	0	-0,011 175	
		5	0,998 805	**1,009 980**
		10	2,008 788	**2,019 963**
	Run 3	0	-0,011 166	
		5	0,998 813	**1,009 979**
		10	2,008 801	**2,019 967**
		0	-0,011 162	
60°	Preload	5	0,998 818	1,009 980
		10	2,008 812	2,019 974
	Run 4	0	-0,011 153	
		5	0,998 828	**1,009 981**
		10	2,008 817	**2,019 970**
		0	-0,011 144	
120°	Preload	5	0,998 835	1,009 979
		10	2,008 817	2,019 961
	Run 5	0	-0,011 138	
		5	0,998 842	**1,009 980**
		10	2,008 828	**2,019 966**
		0	-0,011 130	
180°	Preload	5	0,998 849	1,009 979
		10	2,008 827	2,019 957
	Run 6	0	-0,011 124	
		5	0,998 855	**1,009 979**
		10	2,008 834	**2,019 958**
		0	-0,011 111	
240°	Preload	5	0,998 850	1,009 961
		10	2,008 838	2,019 949
	Run 7	0	-0,011 122	
		5	0,998 861	**1,009 983**
		10	2,008 860	**2,019 982**
		0	-0,011 112	

Orientation	Stage	Force	Output	Deflection
		kN	mV/V	mV/V
300°	Preload	5	0,998 863	1,009 975
		10	2,008 866	2,019 978
	Run 8	0	-0,011 114	
		5	0,998 873	**1,009 987**
		10	2,008 872	**2,019 986**
		0	-0,011 108	
0°	Preload	5	0,998 879	1,009 987
		10	2,008 882	2,019 990
	Run 9	0	-0,011 101	
		5	0,998 886	**1,009 987**
		10	2,008 888	**2,019 989**
		0	-0,011 098	
60°	Preload	5	0,998 893	1,009 991
		10	2,008 911	2,020 009
	Run 10	0	-0,011 094	
		5	0,998 891	**1,009 985**
		10	2,008 900	**2,019 994**
		0	-0,011 089	
120°	Preload	5	0,998 892	1,009 981
		10	2,008 903	2,019 992
	Run 11	0	-0,011 085	
		5	0,998 897	**1,009 982**
		10	2,008 899	**2,019 984**
		0	-0,011 083	
180°	Preload	5	0,998 896	1,009 979
		10	2,008 892	2,019 975
	Run 12	0	-0,011 084	
		5	0,998 898	**1,009 982**
		10	2,008 897	**2,019 981**
		0	-0,011 079	
240°	Preload	5	0,998 893	1,009 972
		10	2,008 886	2,019 965
	Run 13	0	-0,011 077	
		5	0,998 902	**1,009 979**
		10	2,008 895	**2,019 972**
		0	-0,011 076	
300°	Preload	5	0,998 901	1,009 977
		10	2,008 897	2,019 973
	Run 14	0	-0,011 069	
		5	0,998 909	**1,009 978**
		10	2,008 907	**2,019 976**
		0	-0,011 068	
0°	Preload	5	0,998 914	1,009 982
		10	2,008 918	2,019 986
	Run 15	0	-0,011 070	
		5	0,998 918	**1,009 988**
		10	2,008 920	**2,019 990**
		0	-0,011 061	

Table 10 Device 2 readings and deflections

Runs	Orientation	5 kN	10 kN
		mV/V	mV/V
9 and 15	0°	1,009 988	2,019 990
4 and 10	60°	1,009 983	2,019 982
5 and 11	120°	1,009 981	2,019 975
6 and 12	180°	1,009 981	2,019 970
7 and 13	240°	1,009 981	2,019 977
8 and 14	300°	1,009 983	2,019 981
	Mean:	1,009 983	2,019 979
	Repeatability:	0,6 ppm	1,3 ppm
	Reproducibility:	3,4 ppm	5,3 ppm

Table 11 Device 2 results

The deflections obtained in Runs 1 to 15 at 5 kN and 10 kN are shown in Figure 9 and Figure 10 respectively. The dotted lines indicate the mean values given in Table 11.

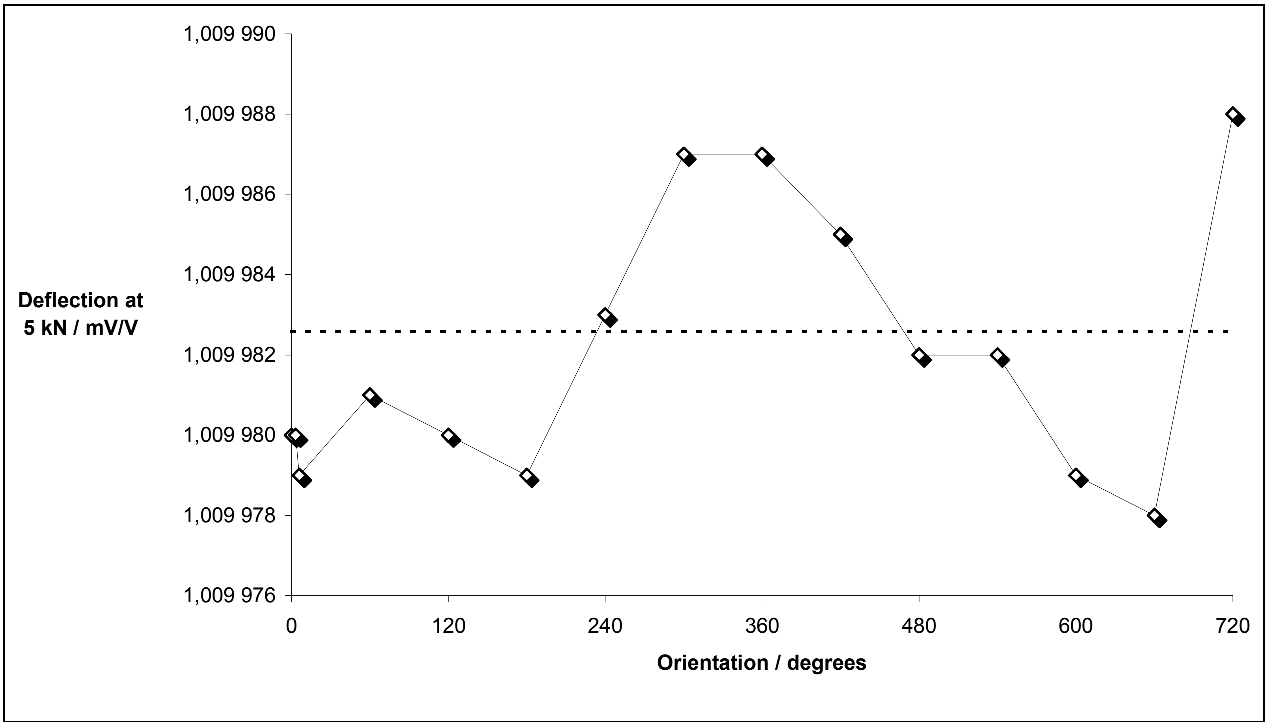


Figure 9 Deflections of device 2 at 5 kN in NPL machine

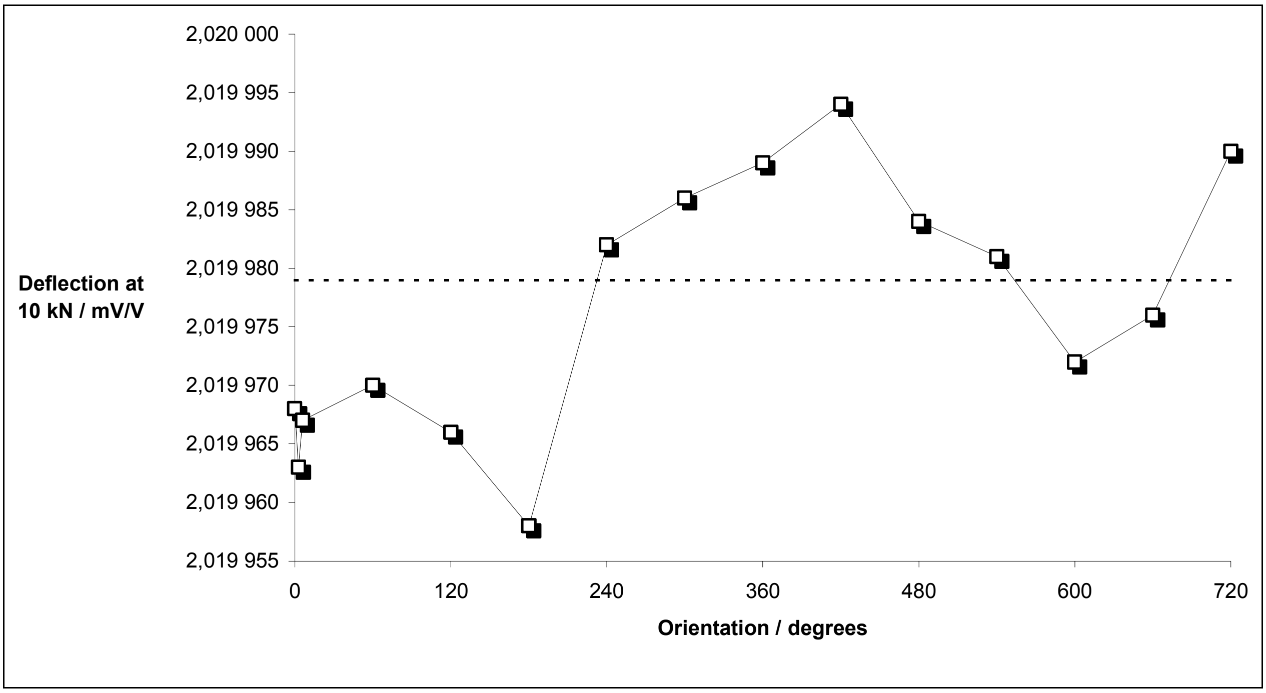


Figure 10 Deflections of device 2 at 10 kN in NPL machine

The variation in load cell output at zero force throughout the calibration is shown in Figure 11.

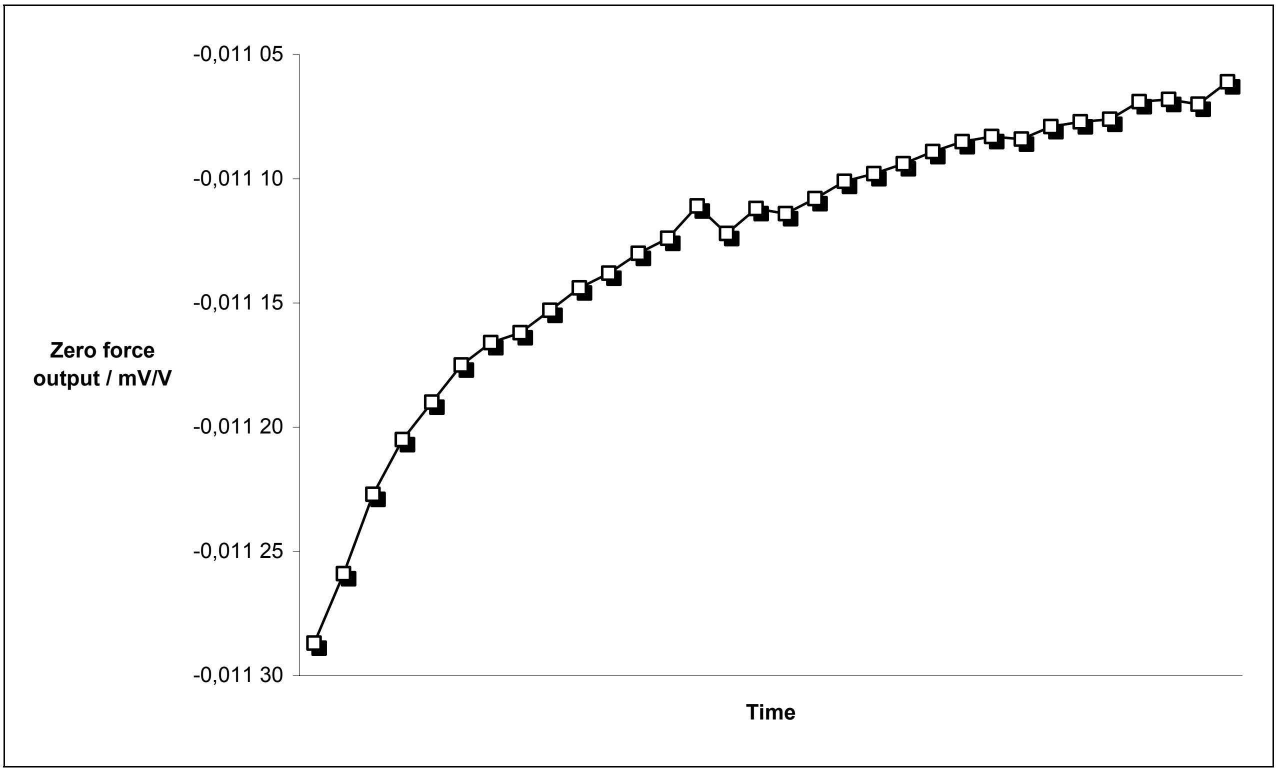


Figure 11 Variation in zero output from device 2 at NPL

3.4 Both devices

The stability of the zero output for the two devices is shown in Figure 12 and demonstrates that the zero output from device 2 varies much more than that from device 1. This variation could be due to the device's greater sensitivity to temperature, which increased throughout both calibrations.

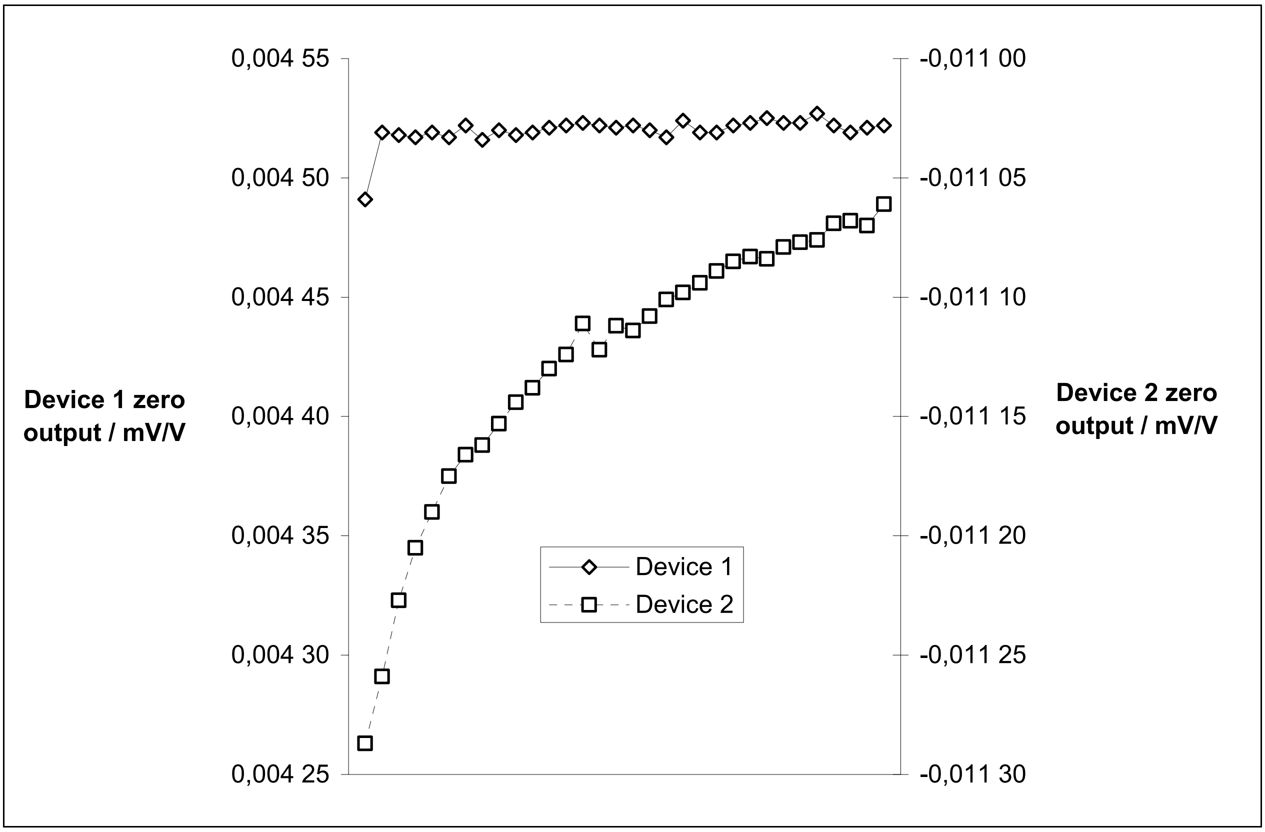


Figure 12 Stability of zero force output throughout the calibration

Figure 13 plots, at each force with each device, the differences between the mean deflection and the deflections obtained in Runs 4 to 15. The magnitude of the device 1 differences are slightly smaller than those for device 2, leading to the smaller reproducibility figures, but all show a significant periodic effect, with a period of approximately 360°. For each device, the 5 kN differences are in phase with the 10 kN ones. The cause of this effect is likely to be non-perfect manufacture of the device, or its sensitivity to non-perfect loading conditions. These could be eccentric or inclined applications of force, due to any initial non-horizontality of the machine's compression platen or its deformation under load.

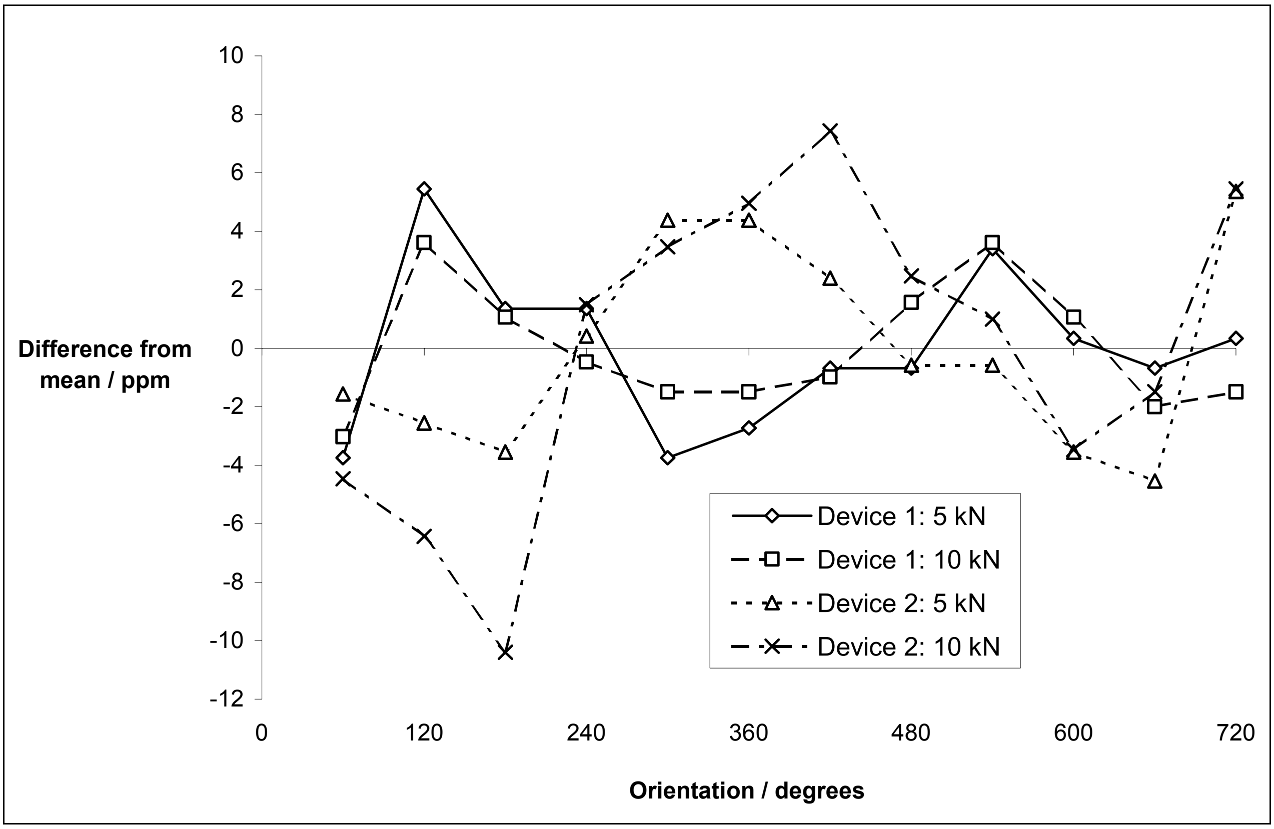


Figure 13 Reproducibility of both devices in NPL machine

4. Raute work

4.1 Machine

The work at Raute Precision was carried out in 10 kN deadweight force standard machine, with an accredited uncertainty in applied force of ±0,002 % (at a 95 % level of confidence).

4.2 Device 1

The initial work on device 1 was carried out on 8 March 2001 and the final work on 26 March 2001. The results obtained are given in Table 12, and comparisons with the range of deflections obtained at NPL are given in Figure 14 and Figure 15, in which the mean NPL values are shown by the dotted lines.

	5 kN	10 kN
Initial work		
Mean	0,979 729 mV/V	1,959 257 mV/V
Repeatability	0,7 ppm	5,8 ppm
Reproducibility	11,7 ppm	10,4 ppm
Final work		
Mean	0,979 707 mV/V	1,959 222 mV/V
Repeatability	4,1 ppm	5,8 ppm
Reproducibility	11,4 ppm	9,8 ppm

Table 12 Device 1 results from Raute Precision

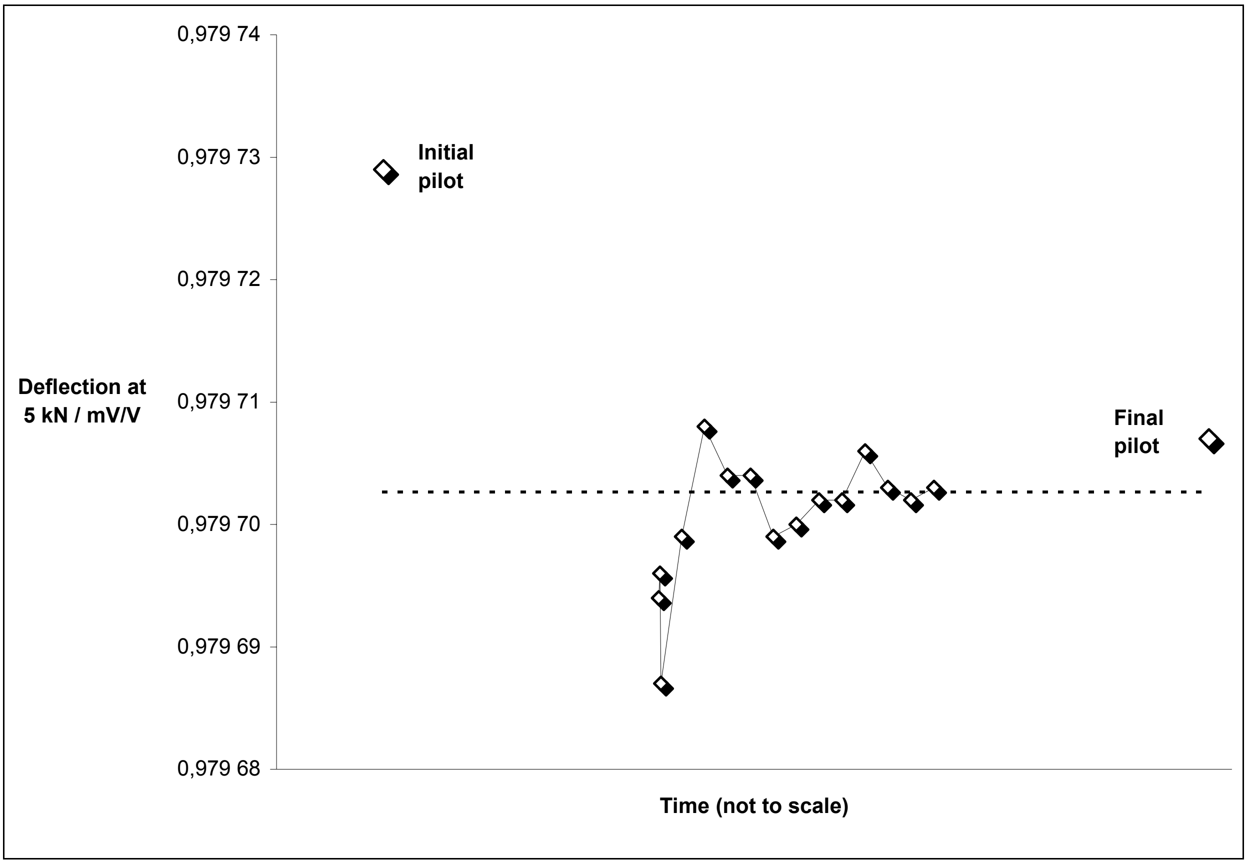


Figure 14 Comparison between deflections of device 1 at 5 kN at NPL and Raute

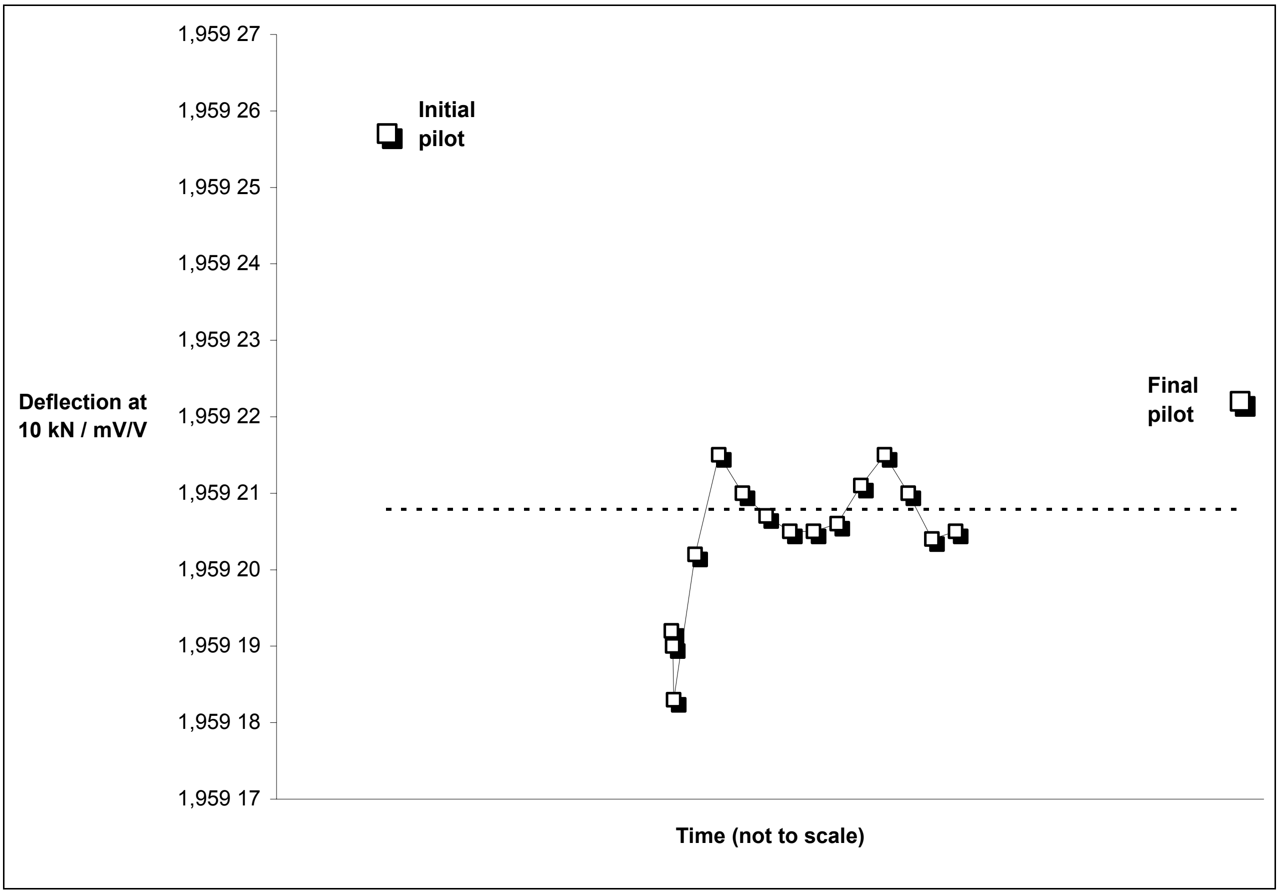


Figure 15 Comparison between deflections of device 1 at 10 kN at NPL and Raute

4.3 Device 2

The initial work on device 2 was carried out on 7 March 2001 and the final work on 27 March 2001. The results obtained are given in Table 13, and comparisons with the range of deflections obtained at NPL are given in Figure 16 and Figure 17, in which the mean NPL values are shown by the dotted lines.

	5 kN	10 kN
Initial work		
Mean	1,009 965 mV/V	2,019 959 mV/V
Repeatability	6,0 ppm	3,2 ppm
Reproducibility	9,8 ppm	10,8 ppm
Final work		
Mean	1,009 960 mV/V	2,019 952 mV/V
Repeatability	3,0 ppm	2,6 ppm
Reproducibility	8,9 ppm	9,0 ppm

Table 13 Device 2 results from Raute Precision

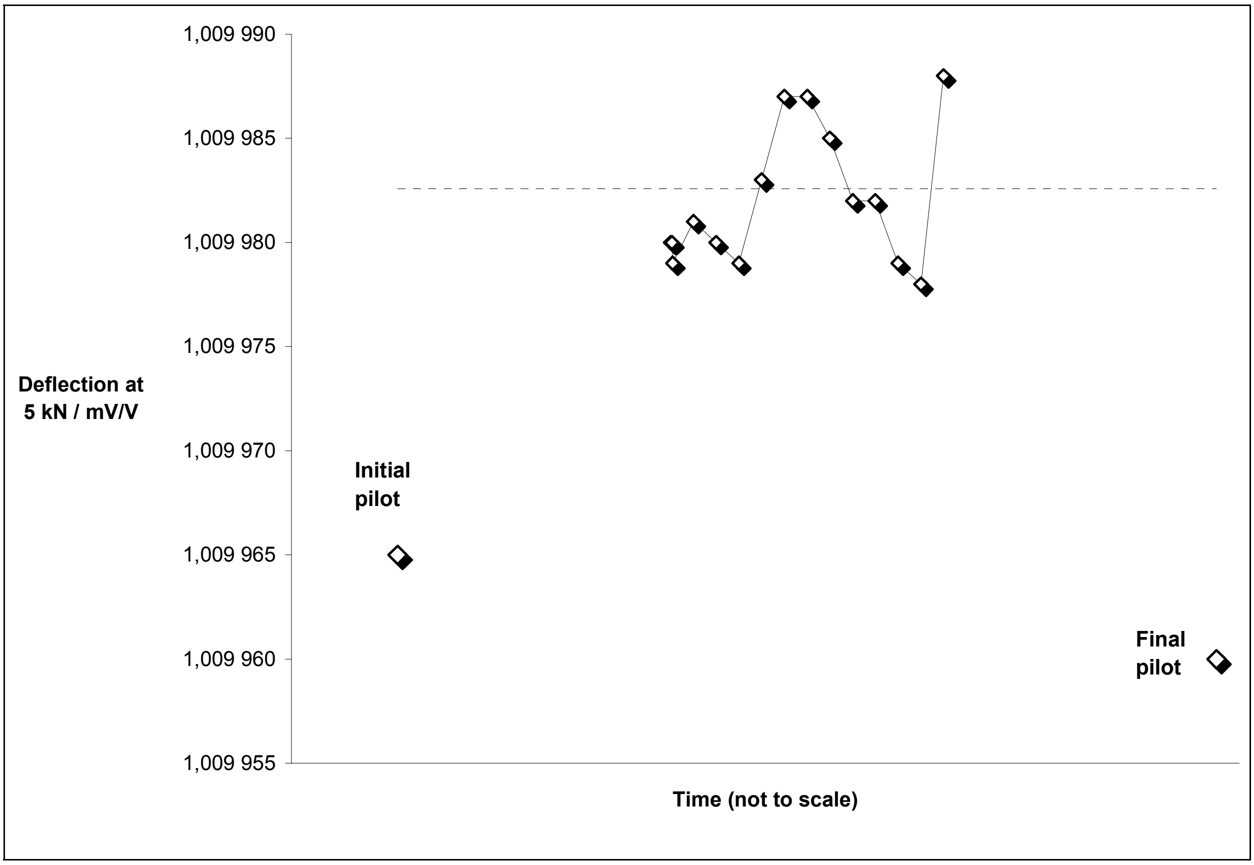


Figure 16 Comparison between deflections of device 2 at 5 kN at NPL and Raute

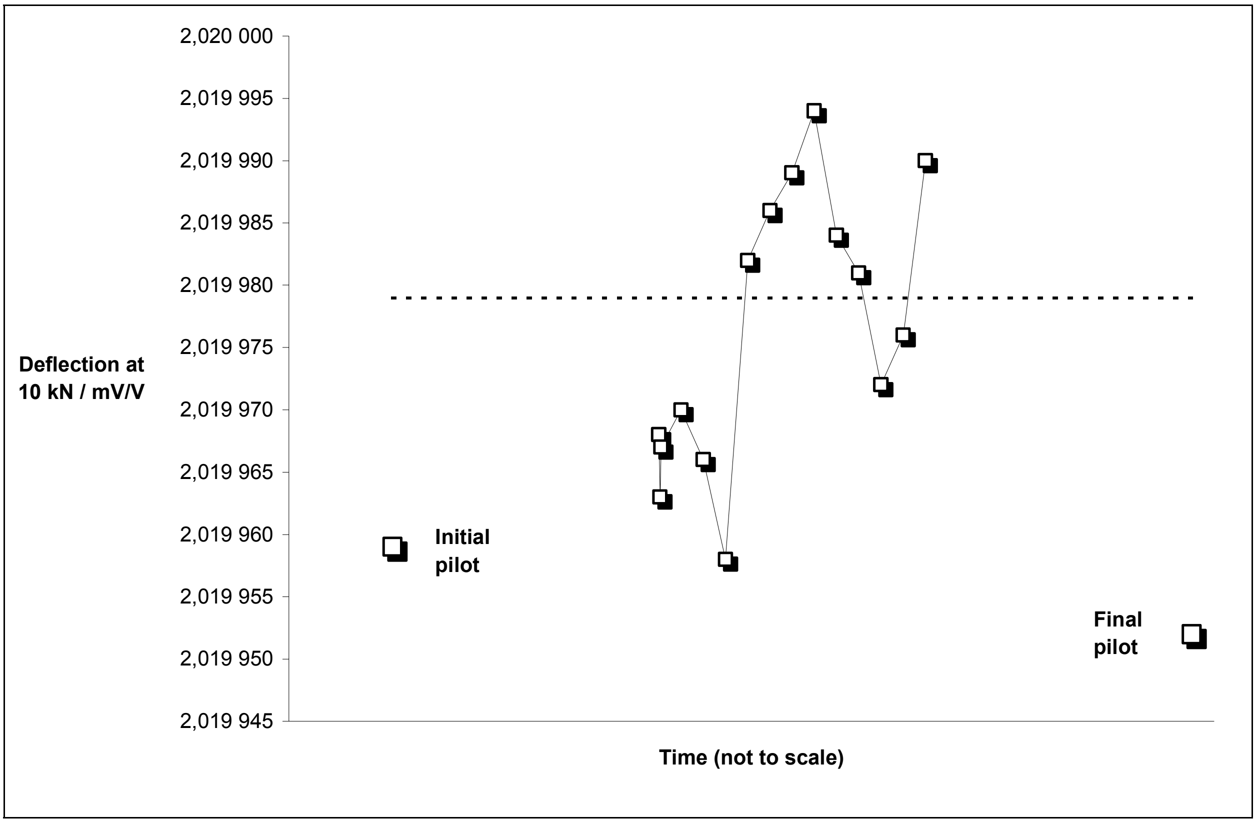


Figure 17 Comparison between deflections of device 2 at 10 kN at NPL and Raute

5. Analysis

It would be possible to analyse the results of the two devices separately, but it makes more sense to look at all of the results together, as will become apparent.

Figure 18 gives the values of repeatability obtained in all of the calibrations. In three of the four cases, the value of the repeatability is lowest at NPL suggesting that the 20 kN machine is capable of applying a given force in a very repeatable manner. In the fourth case (5 kN force on device 1), NPL has the highest figure. This appears to be a result of the readings for Run 3, where a high initial zero output combines with a relatively low output under load to generate a significantly low deflection.

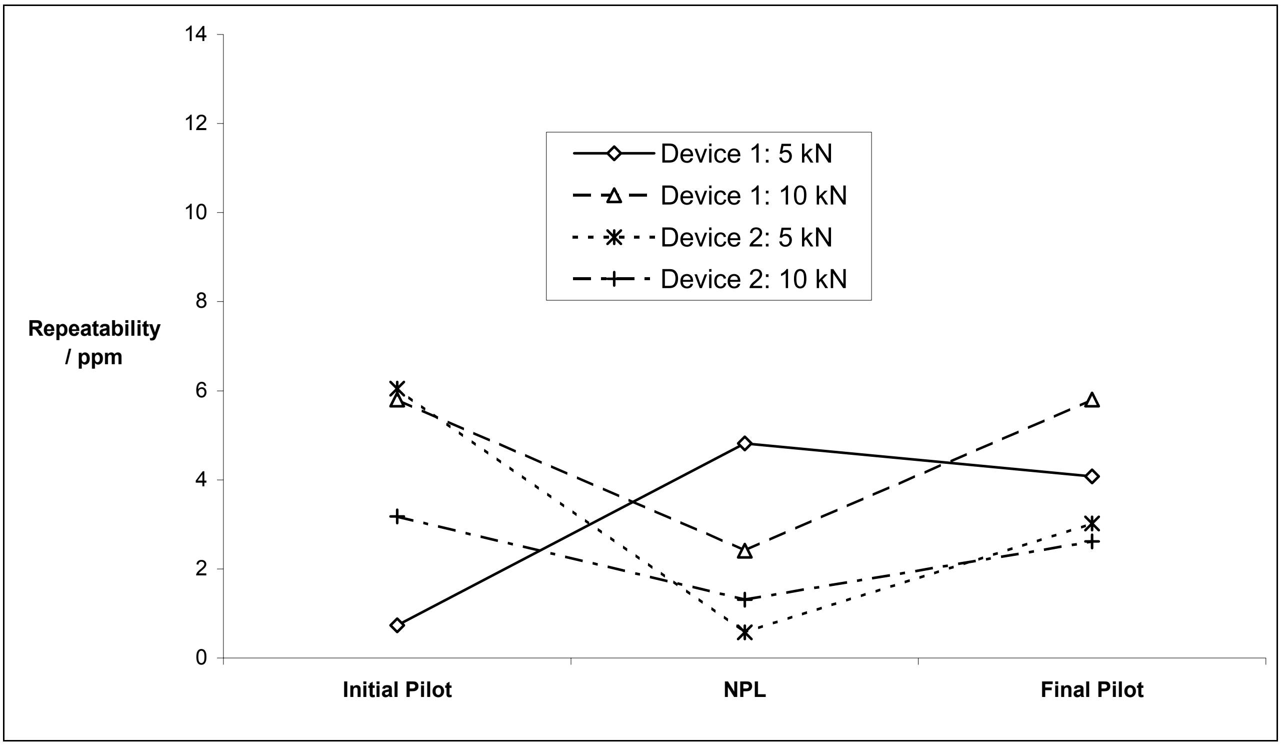


Figure 18 Repeatability of load cell deflections

Figure 19 demonstrates that the reproducibility at NPL was significantly lower than for either calibration at the pilot laboratory and that, at NPL, the reproducibility for device 1 was slightly better than that for device 2.

This suggests that both devices are more sensitive to the loading conditions in the machine at the pilot laboratory than they are to those in NPL's machine.

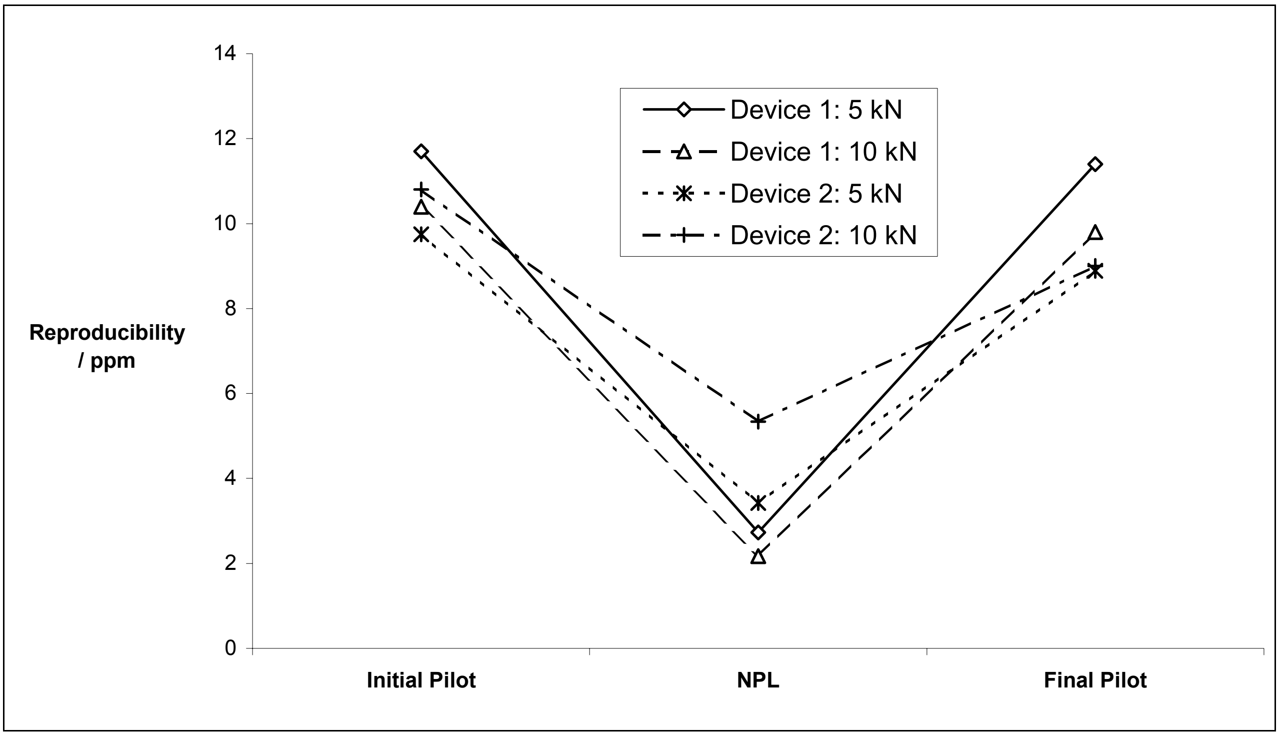


Figure 19 Reproducibility of load cell deflections

Figure 20 shows the absolute differences between the results recorded at NPL and the pilot laboratory. The mean device 1 deflections at the pilot laboratory were larger than those at NPL, whereas the device 2 deflections at the pilot were smaller than those at NPL. The error bars on the differences relate to the ±20 ppm (±0,002 %) uncertainty claimed by the pilot, and the horizontal dashed lines at ±10 ppm to the ±0,001 % uncertainty claimed by NPL.

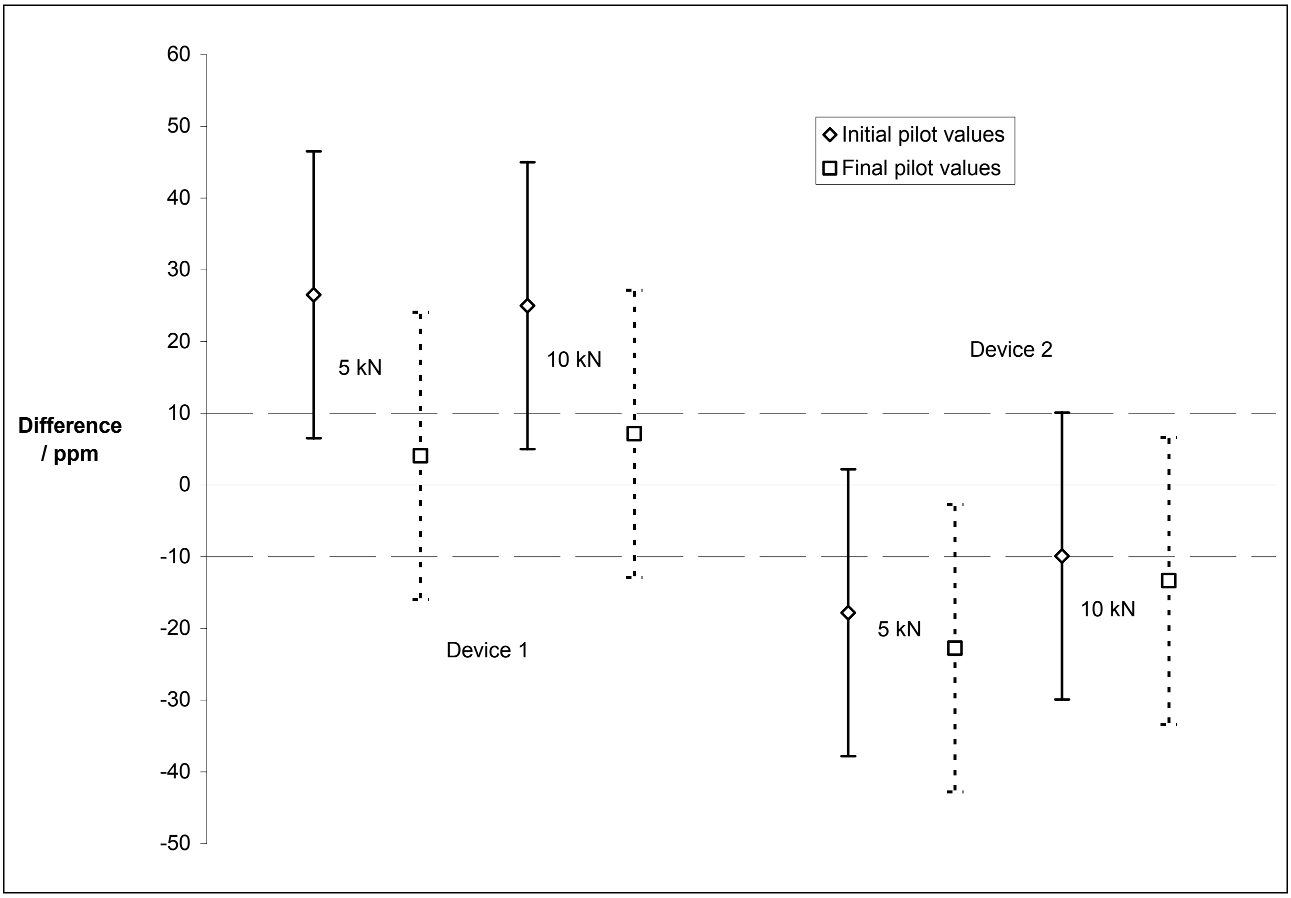


Figure 20 Differences between results at the two laboratories

Figure 21 plots the same figures, after making corrections to allow for the fact that NPL's DMP40 had a slightly different sensitivity to that of the pilot laboratory, as demonstrated by checks using the same BN100.

Even after these corrections, it is apparent that the two devices give inconsistent results, with one suggesting that the forces generated by the NPL machine are higher than those generated by the pilot, and the other suggesting the opposite. However, in all cases, the uncertainty bands of the two laboratories overlap each other, and there is no evidence to suggest that there is a significant difference between the forces generated at the two laboratories.

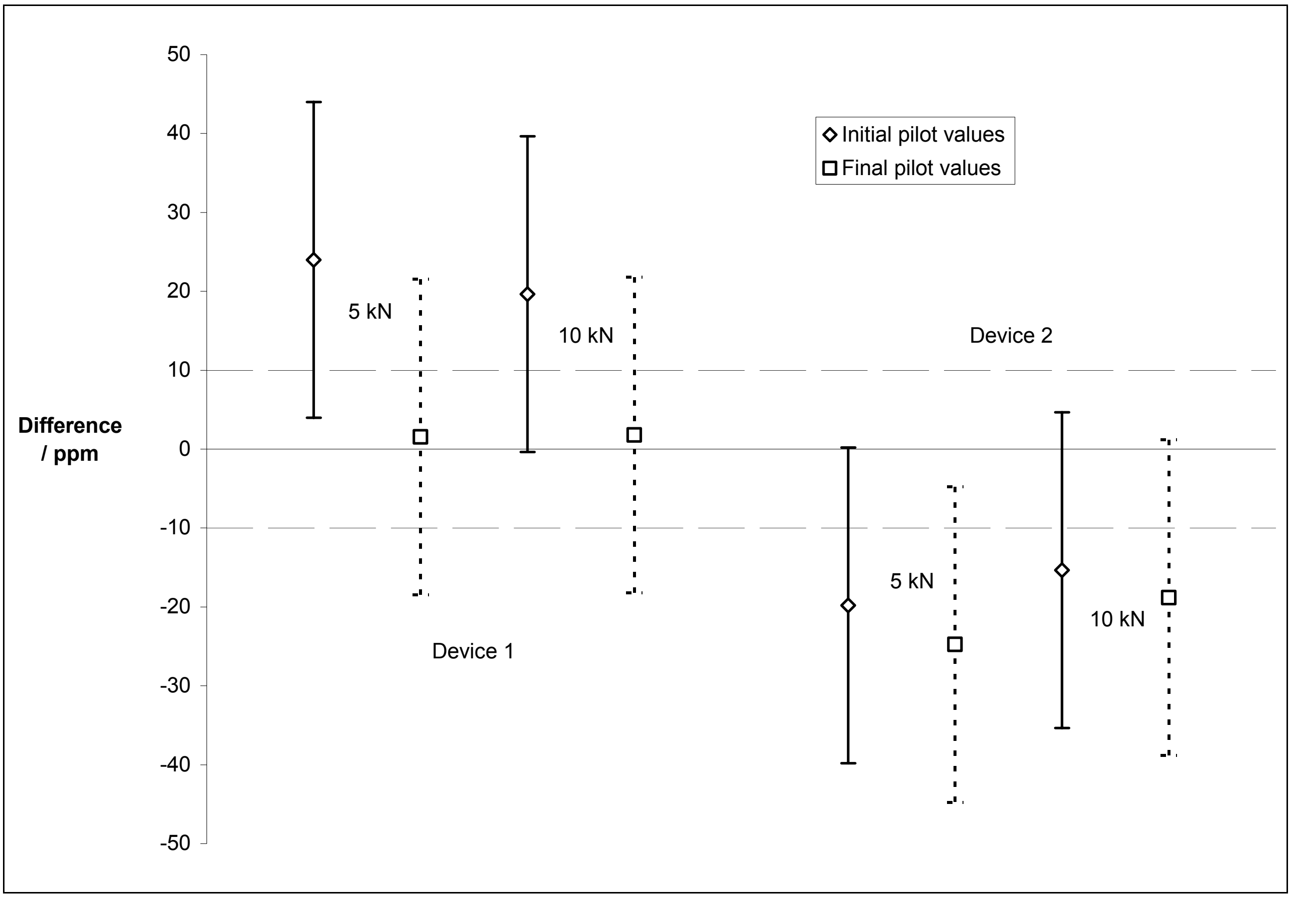


Figure 21 Differences between results at the two laboratories, with DMP40 corrections

6. Conclusions

The repeatability and reproducibility figures obtained at NPL ranged from 0,6 ppm to 5,3 ppm. These are very low numbers and suggest that the load cells used were of very good quality, and that the NPL 20 kN machine is well aligned and works in a very repeatable manner.

The overall comparison between the mean deflections at NPL and the pilot laboratory does not imply that there is any significant difference between the realisation of force values in the two countries, but the differences between the results from the two devices and the stability of their deflections at the pilot laboratory introduce uncertainty into the exercise. When the full comparison is completed, the effect of device stability throughout the exercise will be more quantifiable.

From NPL's point of view, the key comparison has been completed successfully, and publication of the final report should be no barrier to NPL's claimed uncertainty (±0,001 % for the forces generated by its 20 kN machine) being accepted internationally.

Acknowledgement

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