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Report

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UK torque intercomparison - 2007

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Department for **Innovation, Universities** & **Skills**

UK torque intercomparison - 2007

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Industry and Innovation Division

ABSTRACT

This report gives details of a round robin torque comparison involving the National Physical Laboratory and nine UK laboratories. The comparison covers two ranges, 20 N·m to 100 N·m and 200 N·m to 1 kN·m. The work is an effective way of disseminating the unit of torque to industry via the new national torque standard, giving assurance to UK laboratories and customers and identifying areas for possible improvement.

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by Susan Evans, Director, *Industry and Innovation Division*

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1 Introduction

The aim of this round robin comparison was to give participants an opportunity to evaluate the performance of their torque rig in comparison with the UK national torque standard, held at NPL (see Figure 1) [1] The comparison was a joint NPL/UKAS initiative, with NPL acting as the pilot laboratory. In addition to UKAS accredited torque laboratories, the comparison was open to other UK based torque laboratories with a suitable torque facility. All measurements were carried out at the cost of the participants and the pilot laboratory. Arrangements for the transportation of the equipment and costs were covered by UKAS.

This comparison was made possible through the recent development of the UK national torque standard. It was decided that such a round robin exercise would provide a good starting point in the dissemination of the unit of torque throughout UK industry. This work has a precedent in two audit exercises in 1995 and 1996, undertaken by three of the laboratories involved in this comparison [2]. This latest comparison differs significantly on two points; the number of laboratories involved (ten including NPL) and, via the national standard, the ability to have an established reference value for the measurements.

Figure 1. NPL national torque standard machine

While NPL were primarily concerned with the technical performance of each torque rig, UKAS were additionally interested in auditing the whole calibration process. To satisfy both requirements each laboratory was told to follow their usual calibration procedures, where not in conflict with the protocol, and UKAS laboratories were encouraged to provide calibration certificates.

2 Protocol

2.1 Participants

The list of participants is shown in Table 1. There were no minimum requirements for inclusion in the comparison. If a laboratory could derive benefit through their involvement and they had facilities capable of following the protocol, even if only approximately, then participation was encouraged. The participants torque rigs included both supported and unsupported beams.

Table 1. Participants in the torque round robin comparison

Participant	**100 N·m**	**1 kN·m**
ASAP Calibration Services Ltd	●	●
Crane Electronics Ltd	●	●
Datum Electronics Ltd	-	●
GT Certification Ltd	●	●
Industrial Measurements Ltd	●	●
Land Rover	●	●
Norbar Torque Tools Ltd	●	●
Scientific Electro Systems Ltd	●	-
Sensor Technology Ltd	●	●

2.2 Equipment

The measurement equipment was provided by UKAS (see Table 2 & Figure 2). The transducers were commercially available square-drive transducers, which are in widespread use in industry. An NPL-owned indicator was chosen to ensure the ability to compare rigs was not limited by resolution. It was an intentional decision to use commonly available transducers rather than higher performance reference transducers. The calibrations were to be representative of those readily undertaken in industry. The exercise would provide information on each torque rig but would also highlight more generic calibration issues.

Table 2. List of equipment

		Part No	Serial No
Transducers	Norbar 100 N·m transducer (½" male/female square)	50593.log	52210
	Norbar 1 kN·m transducer (1" male/female square)	50597.log	52209
Indicator	DC ratio meter - Nobel Elektronik	E-2-TAD	97-6423
Lead	Transducer lead	60217.200	52344
	Adapter (provided by Norbar)		

Figure 2. Left; Transducers and indicator: Right; the equipment packed for despatch

2.3 Timetable

The timetable for the comparison is given in Figure 3. The comparison started and finished with calibrations at NPL. Each leg of the comparison lasted for two weeks, incorporating the calibration at the participating laboratory, the return of the equipment to UKAS and the sending out of the equipment to the next participant. At UKAS, a zero value was taken with the transducer stood upright to check the integrity of the measurement system. During the comparison, the socket to the 1 kN·m transducer and the transducer lead were damaged at different times. In both cases, repairs had to be made by the manufacturer. To check that the damages had no effect on the transducers' outputs, the equipment was returned to NPL part way through the exercise. A calibration check was performed and, as the results showed good agreement with the initial calibration, it was determined that there was no influence on the calibration. As a consequence the comparison fell slightly behind plan, finishing around six weeks late.

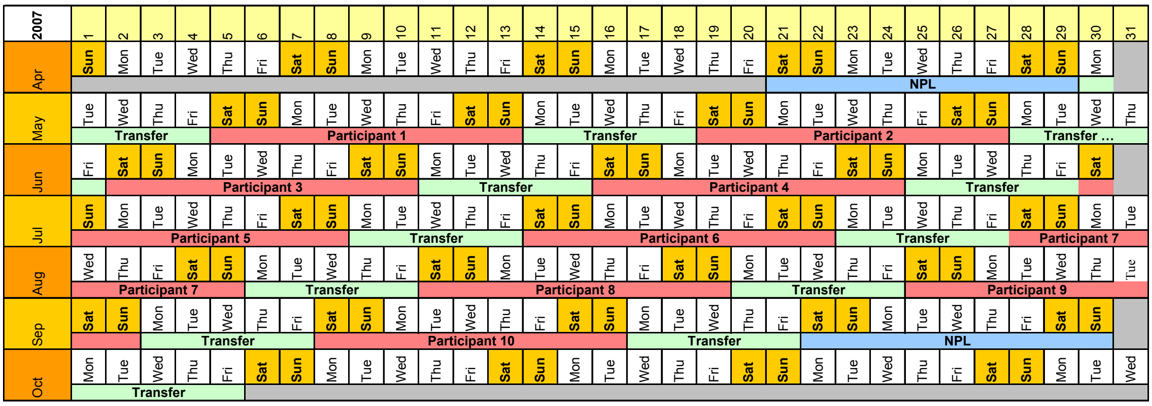

Figure 3. Provisional timetable for the comparison

2.4 Measurement Instructions

Each laboratory was told to follow their normal calibration procedure as far as possible. The measurement instructions were based around BS 7882:2008 [3], the only difference being that the decremental series was added to the first measurement series rather than the last.

2.4.1 Preparation

The instructions given to the participants are listed below.

- Connect the transducer to the DC ratio meter. The equipment is ready for use once thermally stabilised.
- The zero signal of the transducer should be taken with the transducer upright before it is mounted in the torque rig.
- The transducer should be mounted in the rig, connected to the DC ratio meter and left to thermally stabilise for at least one hour before measurements commence.
- Results are recorded in **mV/V.** Please **record** the **gross readings** and do not tare the output. (this will be done in the spreadsheet) **Note an LED indicates the sign of the reading**.

2.4.2 Calibration

The instructions given to the participants are listed below.

Clockwise calibration
1. Preload the transducer 3 times to 100% of the measurement range.
2. Apply an increasing series of torques in 20% steps up to 100% of the measurement range.
3. Apply a decreasing series of torques in 20% steps down to 0 N·m.
4. Apply a further increasing series of torques as before.
5. Rotate the transducer in a clockwise direction through 90°.
6. Preload the transducer once to 100% of the measurement range.
7. Apply a single increasing series of torques in 20% steps up to 100% of the measurement range.
8. Repeat from step 5 until the transducer has been calibrated on all 4 sides.

Anticlockwise calibration
Repeat steps 1 to 8 for the anticlockwise calibration.

The measurement protocol is illustrated in Figure 4.

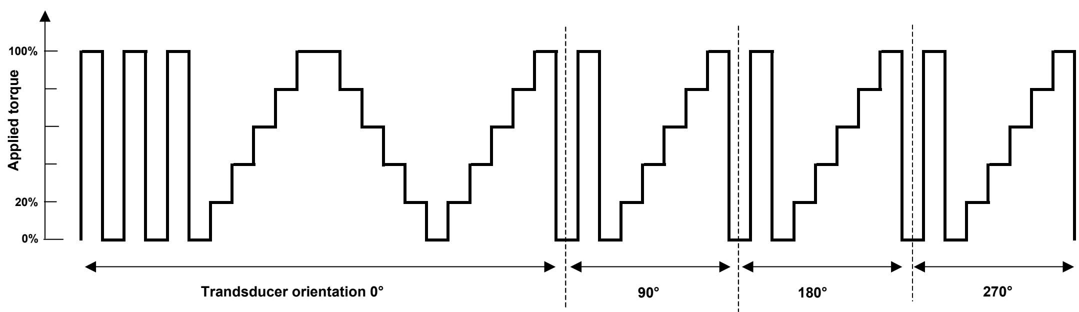

Figure 4. Calibration protocol. To be repeated for the anti-clockwise calibration

2.5. Results and Information policy

A spreadsheet, as shown in Figure 5, was provided for the results. Each participant was also asked to produce a certificate for the results if this was normal practice.

The results from each participant are held in confidence by NPL and UKAS. Each participant had an opportunity to review their measurement results.

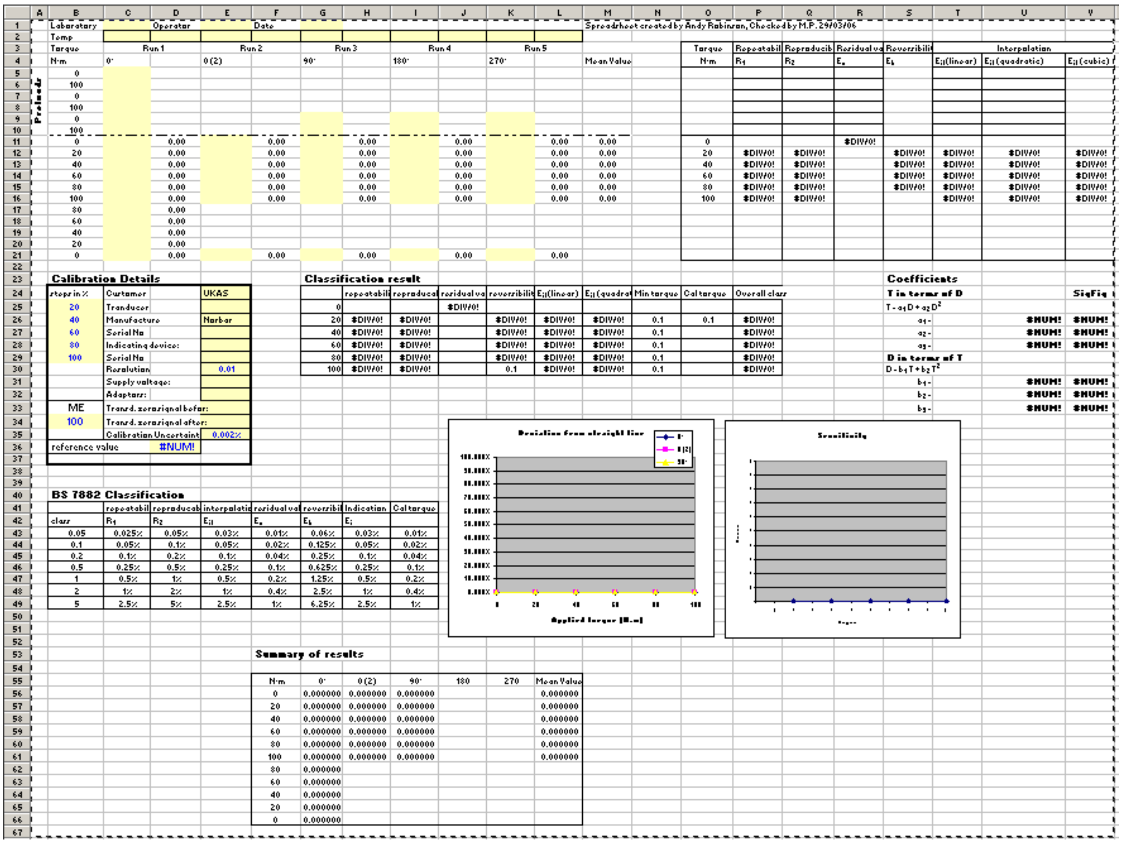

Figure 5. Spreadsheet for the recording of results

3 Results

3.1 NPL calibrations

The graphs in Figures 6 and 7 show the calibration parameters for the two transducers calculated using the methods in BS 7882:2008. The clockwise results are plotted on the positive axis and the anticlockwise results are plotted on the negative axis. The results are taken from the second calibration at NPL because this gave the larger values for each of the four parameters. It is important to understand something about the performance of both transducers prior to analysing the comparison results.

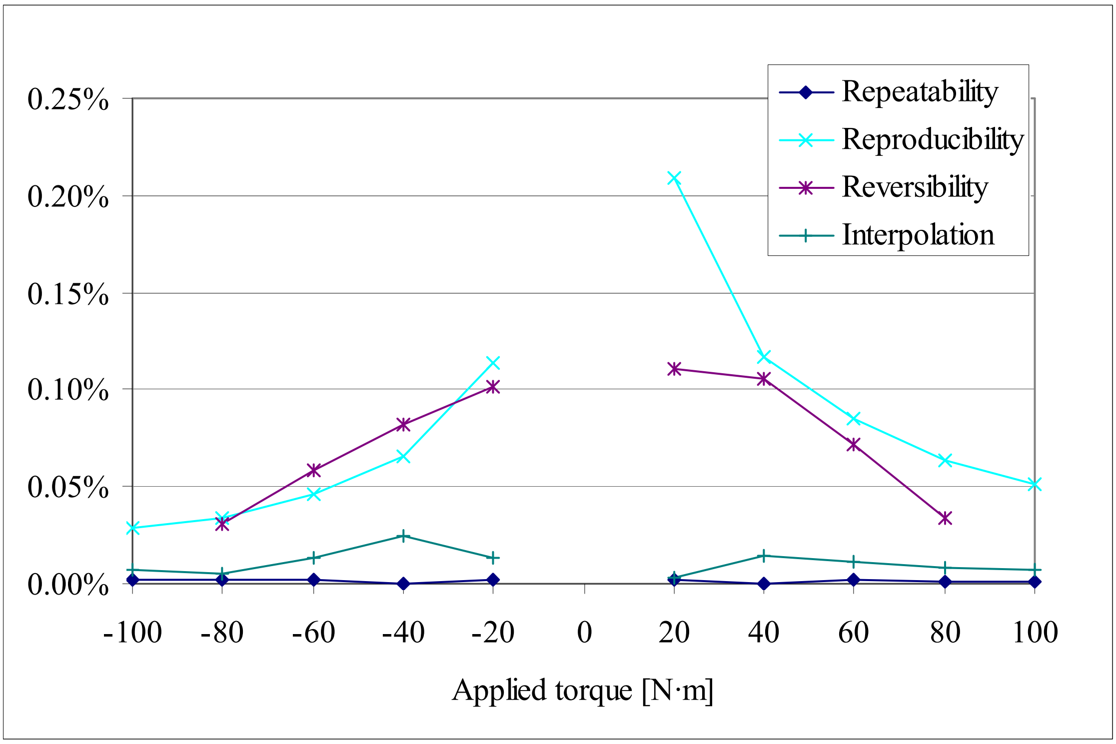

Figure 6. Calibration parameters for the 100 N·m transducer calibrated at NPL

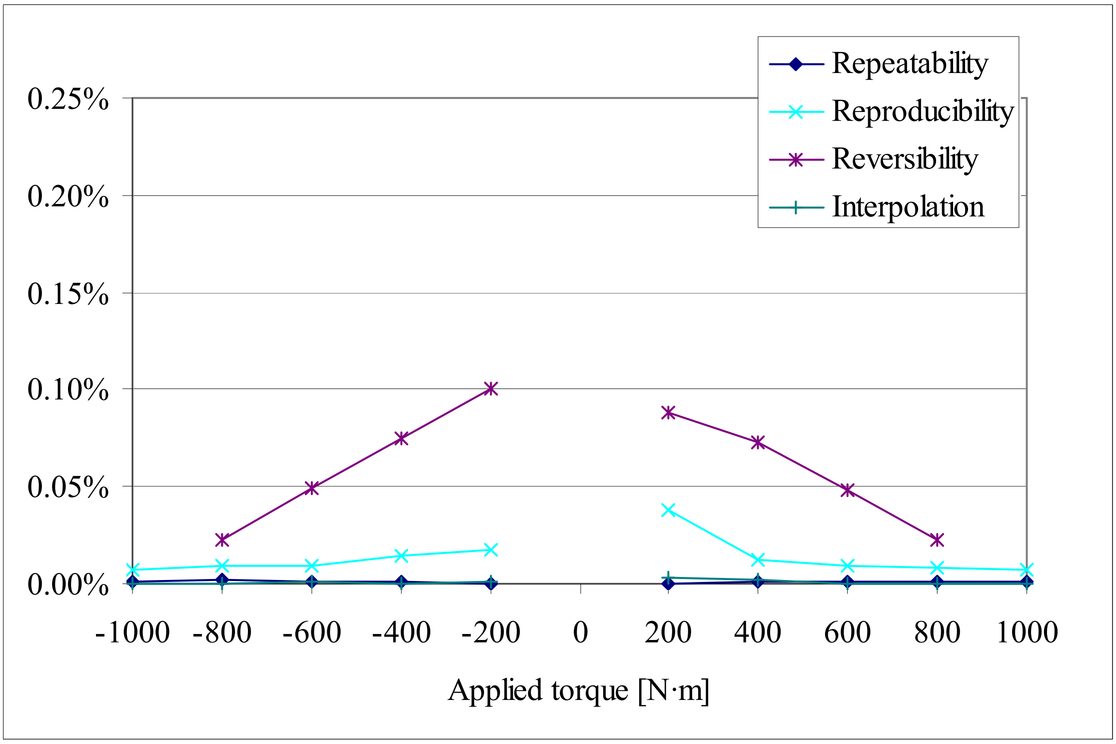

Figure 7. Calibration parameters for the 1 kN·m transducer calibrated at NPL

The major difference between the two transducers is that the reproducibility of the 100 N·m transducer is over 5 times greater than the reproducibility of the 1 kN·m transducer.

The temperature coefficient for the sensitivity of the transducers was given by the manufacturers as +0.035% per degree Celsius.

3.2 Reference value

The NPL torque machine was to be used as a reference for the comparison. From the initial and final calibrations of the comparison, undertaken at NPL, a reference value needed to be calculated. The data was analysed prior to this calculation, particularly with regard to the drift and temperature sensitivity of the transducers.

3.2.1 Drift considerations

Figures 8 and 9 show the drift in calibration value between the two NPL calibrations for each transducer. The first calibration was in May 2007 and the second calibration was in November 2007.

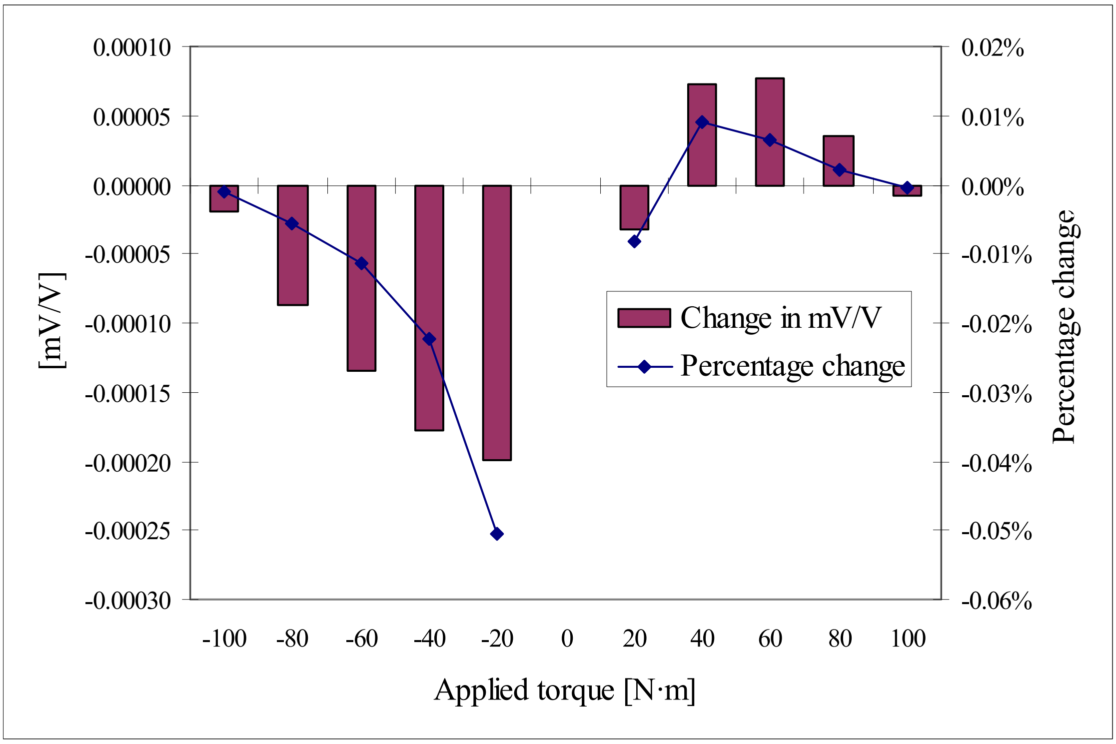

Figure 8. The drift of the 100 N·m transducer between the two NPL calibrations expressed in absolute units and as a percentage of the mean value

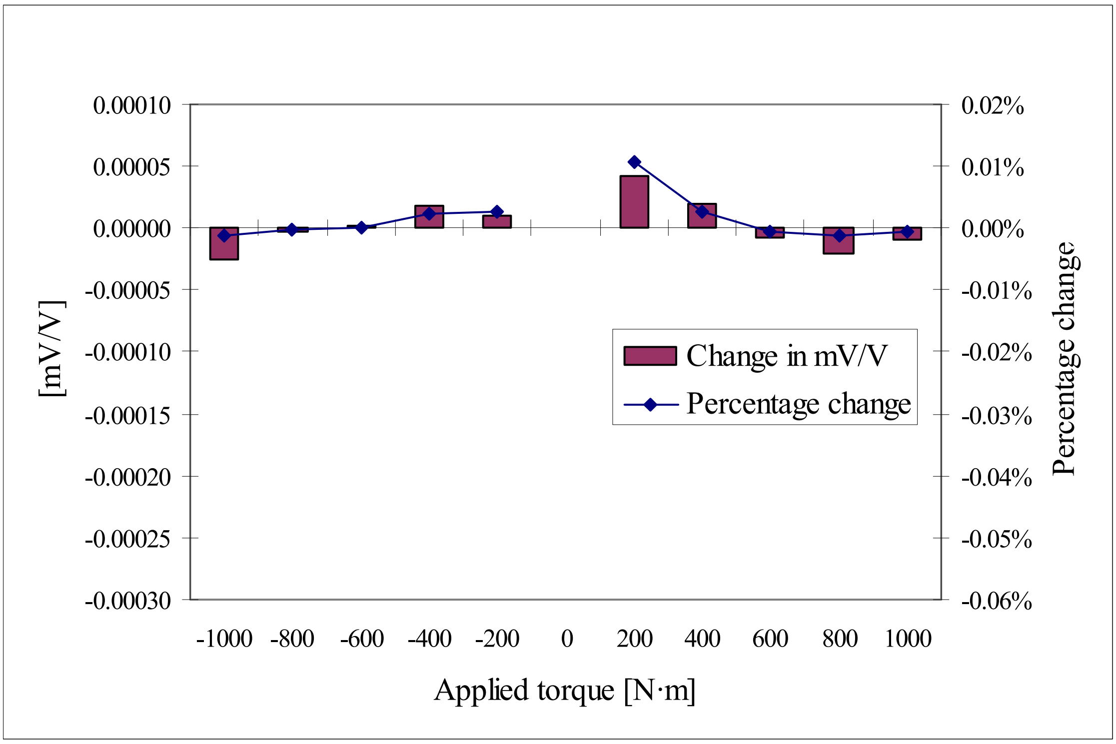

Figure 9. The drift of the 1 kN·m transducer between the two NPL calibrations expressed in absolute units and as a percentage of the mean value

The 1 kN·m transducer shows negligible drift. The difference is almost at the level of the resolution of the indicator. The 100 N·m transducer shows greater drift particularly in the anticlockwise direction for the lower applied torques, although this could be an influence of reproducibility rather than true drift.

3.2.2 Temperature considerations

The temperature difference between the first and second calibrations at NPL for both transducers was minimal. The mean temperature for each calibration was calculated. For the clockwise calibration of both transducers the difference was 0.1 °C and was less than 0.1 °C for the corresponding anticlockwise calibrations. The temperature span in each case was typically 0.1°C – 0.2 °C. As the temperature change is relatively small (the resolution of the temperature sensor was only 0.1 °C) no adjustments were made to the reference value for changes in temperature.

3.2.3 Reference value calculation

The mean of the two NPL calibrations was calculated to establish a reference value for the comparison. No allowances were made for drift as Figures 8 and 9 show that the drift was minimal. Additionally any allowance for drift would need to make an assumption that the drift was linear, which may not necessarily be the case. The mean temperature over the two calibrations was also calculated, giving a reference point from which any subsequent temperature compensation for the participant results could be calculated.

3.3 Calibration data

In the analysis of the data it was difficult to produce graphs that incorporated all the data, without the loss of detail, as the range of uncertainty of applied torque covered orders of magnitude, across the range of participants. Where data is missing for some participants in this section due to scaling, the graphs have been reproduced in the Appendix with a larger scale.

3.3.1 100 N·m transducer

The mean incremental calibration results for each of the participants, together with the NPL reference value, are shown in Table 3.

Table 3. Mean calibration results for the 100 N·m transducer – deflections given in mV/V

	Torque N·m	NPL	Lab a	Lab b	Lab c	Lab d	Lab e	Lab f	Lab g	Lab h
clockwise	20	-0.39656	-0.39601	-0.39593	-0.39982	-0.39596	-0.39961	-0.39725	-0.39612	-0.39791
	40	-0.79353	-0.79294	-0.79301	-0.79603	-0.79298	-0.80099	-0.79441	-0.79321	-0.79480
	60	-1.19061	-1.19010	-1.19025	-1.19282	-1.19059	-1.20205	-1.19279	-1.19048	-1.19307
	80	-1.58782	-1.58739	-1.58764	-1.59009	-1.58821	-1.60324	-1.59132	-1.58790	-1.59047
	100	-1.98506	-1.98468	-1.98506	-1.98750	-1.98585	-2.00424	-1.98970	-1.98535	-1.98604
anticlockwise	20	0.39588	0.39604	0.39610	0.39932	0.39608	0.40360	0.39701	0.39617	0.39485
	40	0.79256	0.79287	0.79315	0.79515	0.79298	0.80643	0.79394	0.79293	0.79145
	60	1.18952	1.18990	1.19038	1.19199	1.19014	1.20727	1.19156	1.18990	1.18876
	80	1.58662	1.58704	1.58772	1.58923	1.58747	1.60873	1.58901	1.58703	1.58590
	100	1.98374	1.98422	1.98517	1.98646	1.98494	2.00940	1.98662	1.98425	1.98315

Laboratory *c* were only able to calibrate in 3 orientations because of physical limitations. In this case the mean value was calculated from the 3 measurement series. The possibility of using the data from just two series, 0° and 90° was considered as allowed in BS 7882:2008 for lower classifications. However the use of two or three measurement series made little difference to the mean value and no difference to the calibration parameters.

Laboratory *d* calibrated the transducer in just two orientations at 0° and 90°, and the mean value and measurement parameters were calculated from these two series. Laboratory *d* were also unable to apply a decremental series of torques.

The mean deflections in Table 3 were divided by the applied torque to give a sensitivity at each applied torque in units of mV/V/N·m. The values are plotted in Figure 10, but with the clockwise sensitivities displayed as positive values, to aid comparison.

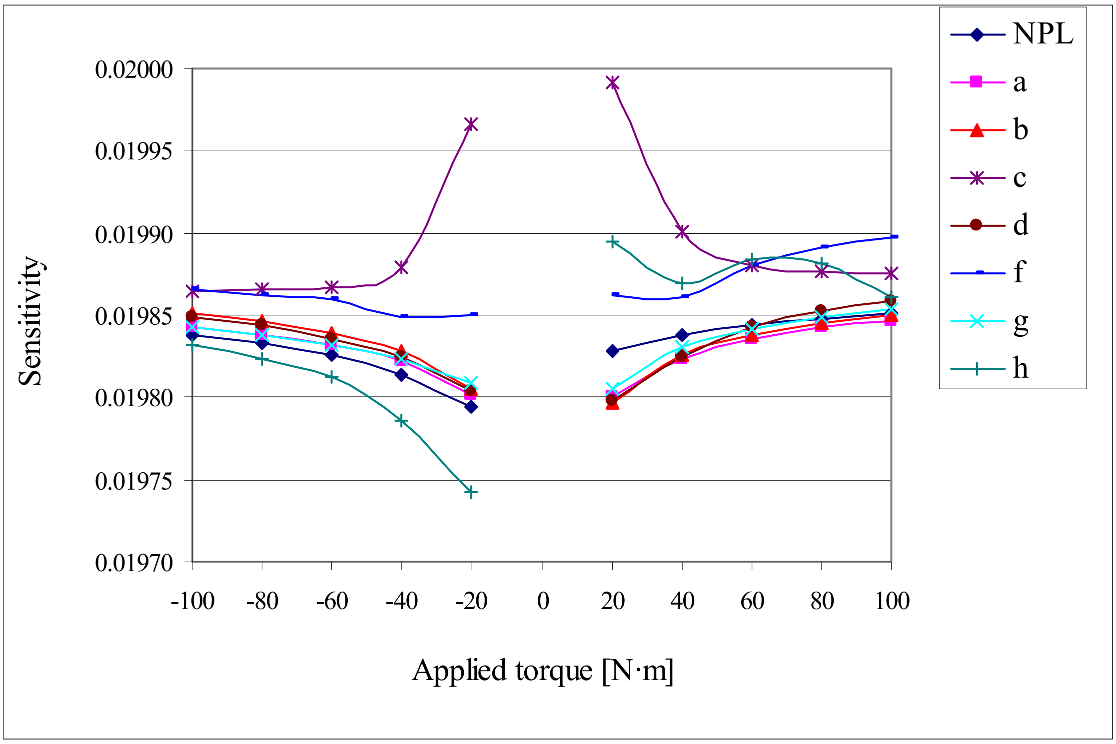

Figure 10. Sensitivity of the 100 N·m transducer for each participant

For each participant the departure of the mean values from the NPL reference value was calculated as a percentage of the NPL value. The results for 20 N·m and 100 N·m in the clockwise and anticlockwise directions are shown in Figures 11 to 14. The error bars shown for each value correspond to the uncertainty of applied torque for each participant.

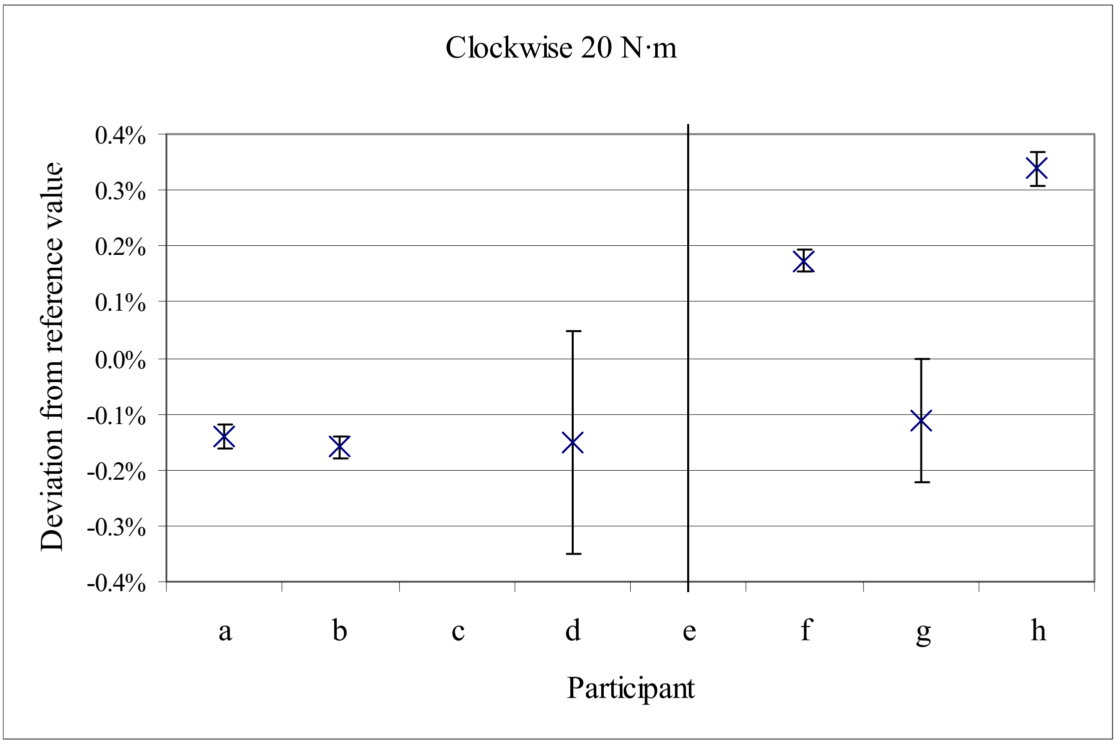

Figure 11. Percentage deviation from the reference value for a 20 N·m clockwise torque

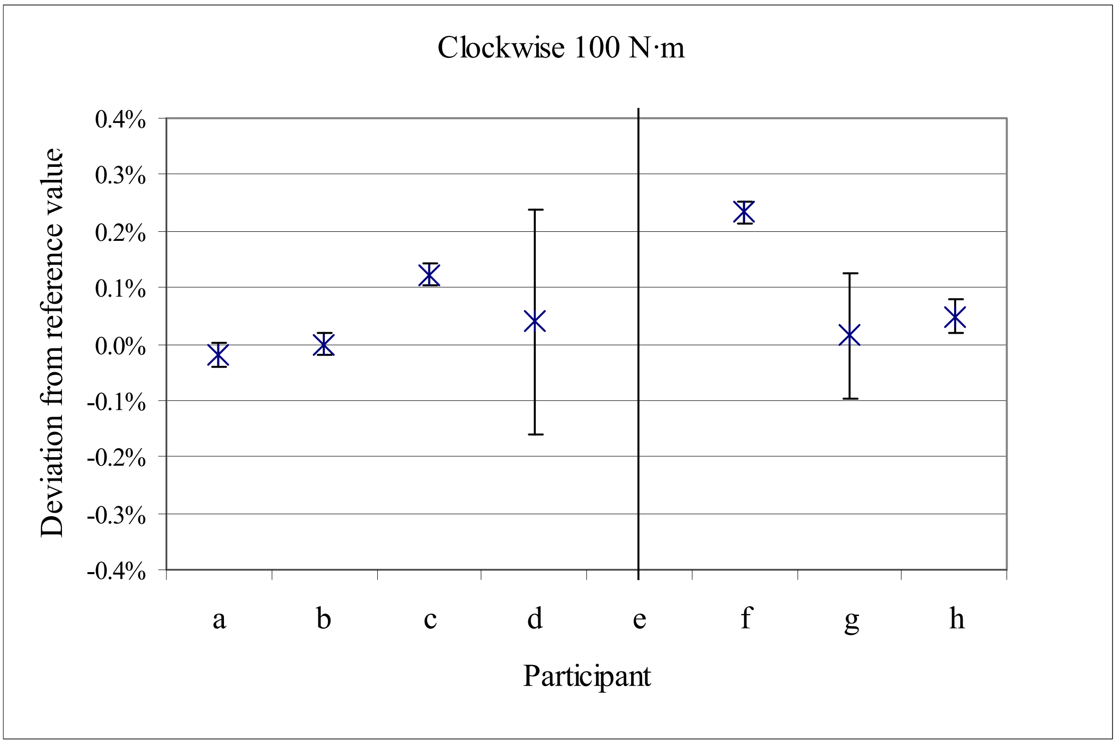

Figure 12. Percentage deviation from the reference value for a 100 N·m clockwise torque

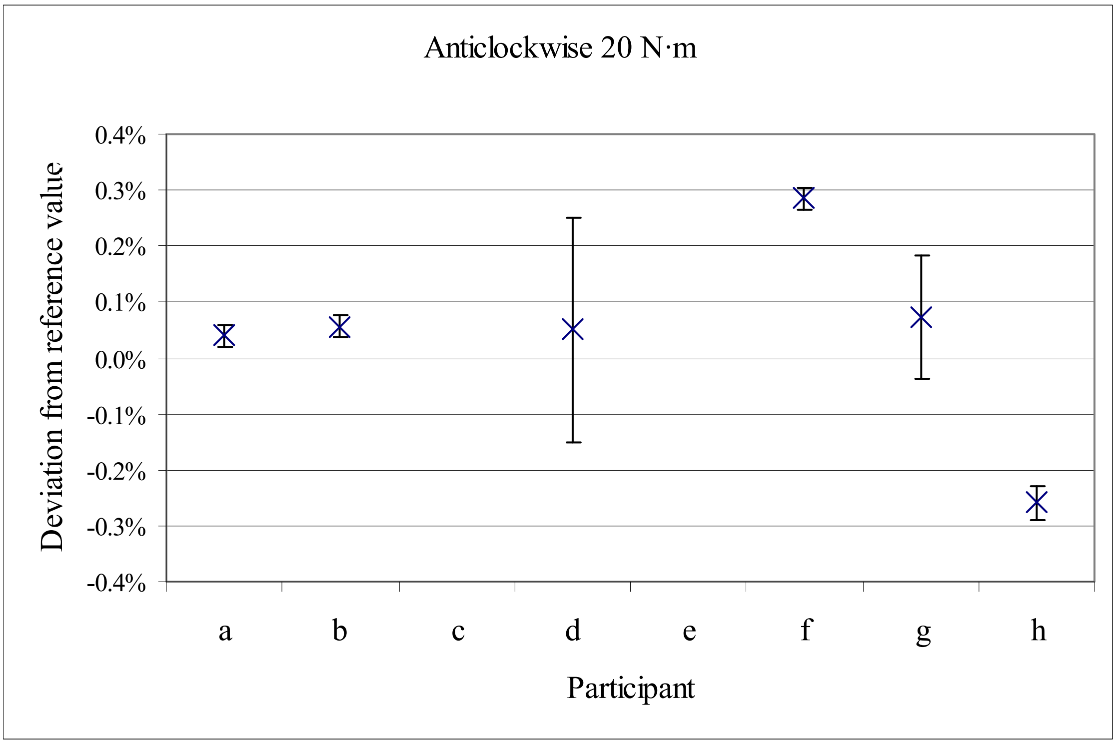

Figure 13. Percentage deviation from the reference value for a 20 N·m anticlockwise torque

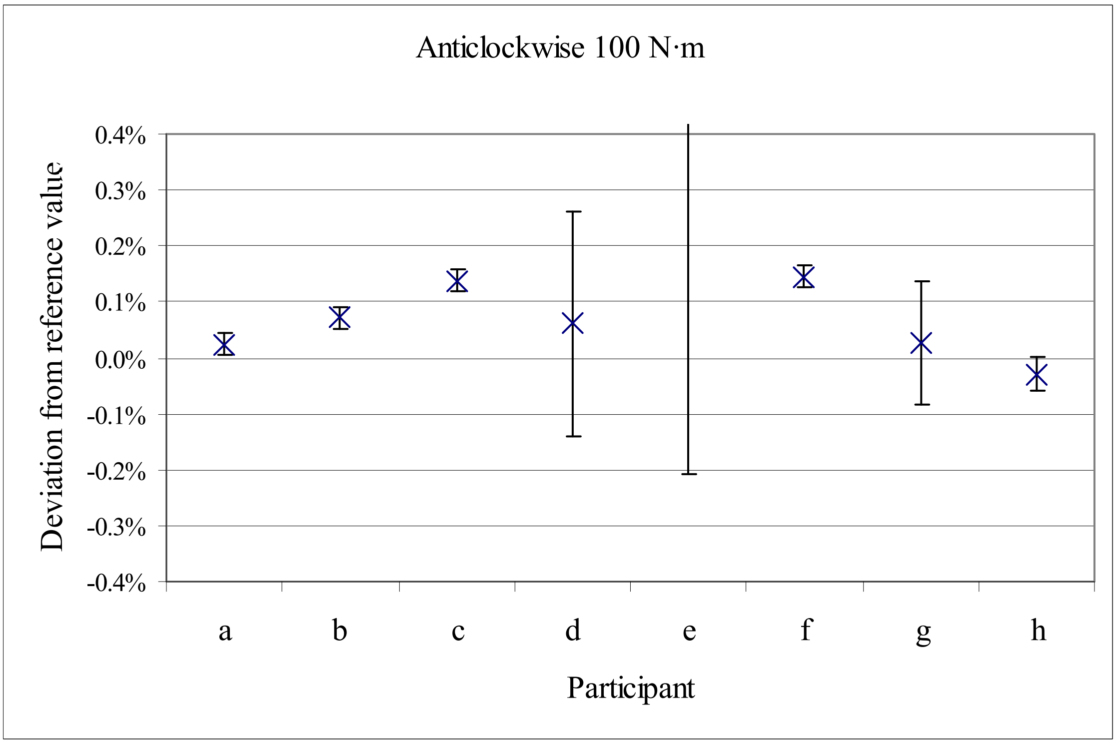

Figure 14. Percentage deviation from the reference value for a 100 N·m anticlockwise torque

3.3.2 1 kN·m transducer

The mean incremental calibration results for each of the participants together with the NPL reference value are shown in Table 4.

Table 4. Mean calibration results for the 1 kN·m transducer - deflections given in mV/V

	Torque N·m	NPL	Lab a	Lab b	Lab c	Lab d	Lab e	Lab f	Lab g	Lab h
clockwise	200	-0.39678	-0.39698	-0.39634	-0.39670	-0.39699	-0.40083	-0.39686	-0.39699	-0.39702
	400	-0.79381	-0.79412	-0.79317	-0.79389	-0.79407	-0.80186	-0.79382	-0.79412	-0.79413
	600	-1.19095	-1.19142	-1.19032	-1.19074	-1.19132	-1.20295	-1.19094	-1.19129	
	800	-1.58819	-1.58889	-1.58764	-1.58800	-1.58870	-1.60410	-1.58824	-1.58860	
	1000	-1.98547	-1.98647	-1.98495	-1.98487	-1.98615	-2.00532	-1.98557	-1.98596	
anticlockwise	200	0.39697	0.39716	0.39715	0.39697	0.39708	0.40354	0.39705	0.39688	0.39730
	400	0.79402	0.79443	0.79426	0.79416	0.79418	0.80413	0.79408	0.79502	0.79446
	600	1.19117	1.19177	1.19136	1.19122	1.19138	1.20482	1.19121	1.19178	
	800	1.58839	1.58924	1.58850	1.58834	1.58866	1.60572	1.58847	1.58812	
	1000	1.98563	1.98683	1.98570	1.98572	1.98604	2.00619	1.98581	1.98543	

Laboratory *g* calibrated the transducer in just two orientations at 0° and 90°. Laboratory *h* only measured two points, at 200 N·m and 400 N·m.

Laboratory *b* calibrated the transducer in pounds feet. A cubic equation was fitted to this data. From this equation interpolated values corresponding to the applied torques required in the comparison were calculated.

The sensitivity of the transducer as measured by each participant, calculated as in the previous section, is shown in Figure 15.

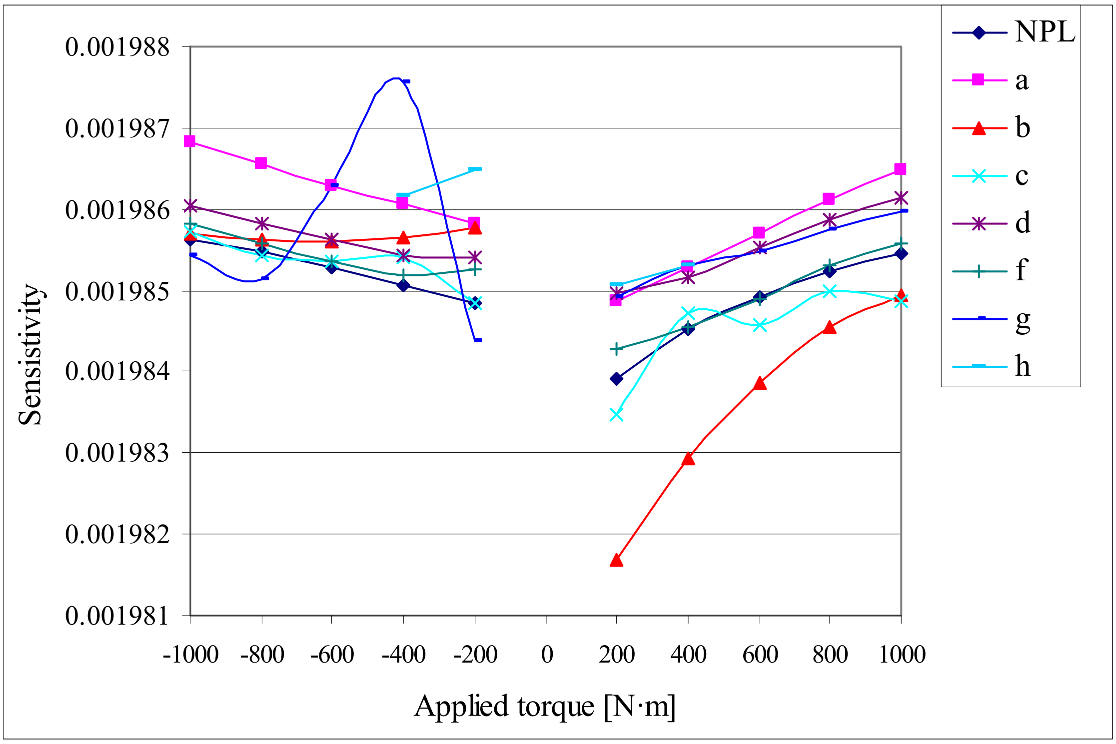

Figure 15. Sensitivity of the 1 kN·m transducer for each participant

For each participant the departure of the mean values from the NPL reference value was calculated as before. The results for 200 N·m and 1 kN·m in the clockwise and anticlockwise directions are shown in Figures 16 to 19. Again the error bars shown for each value correspond to the uncertainty of applied torque for each participant.

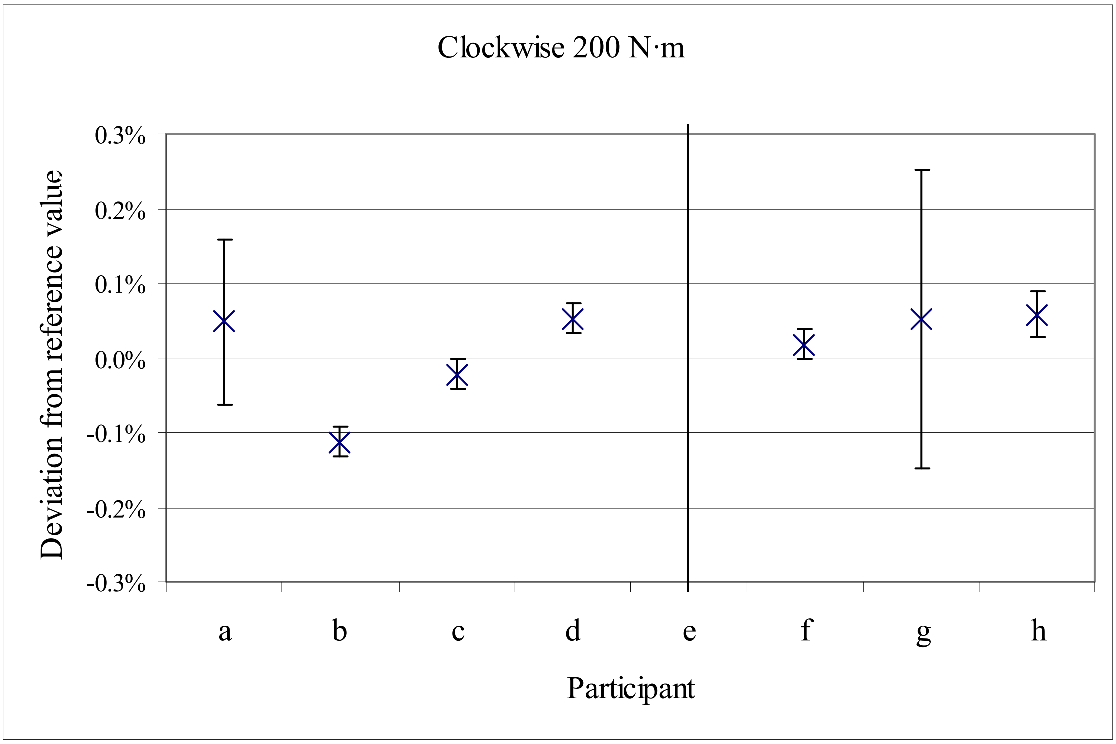

Figure 16. Percentage deviation from the reference value for a 200 N·m clockwise torque

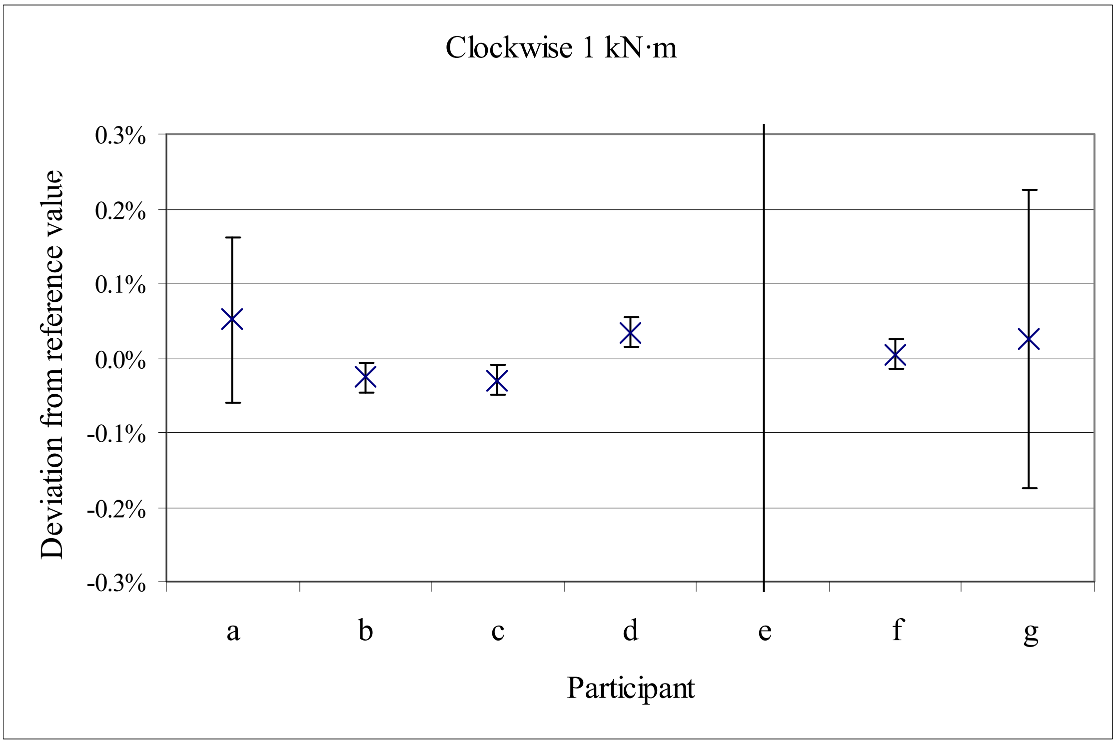

Figure 17. Percentage deviation from the reference value for a 1 kN·m clockwise torque

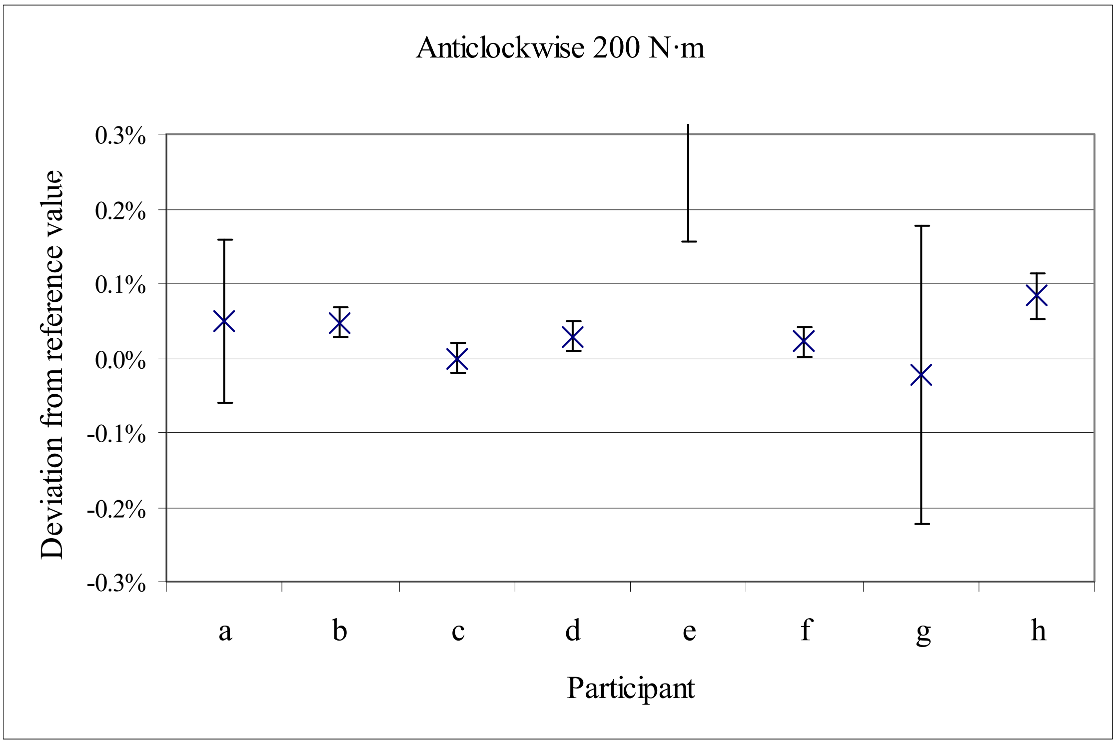

Figure 18. Percentage deviation from the reference value for a 200 N·m anticlockwise torque

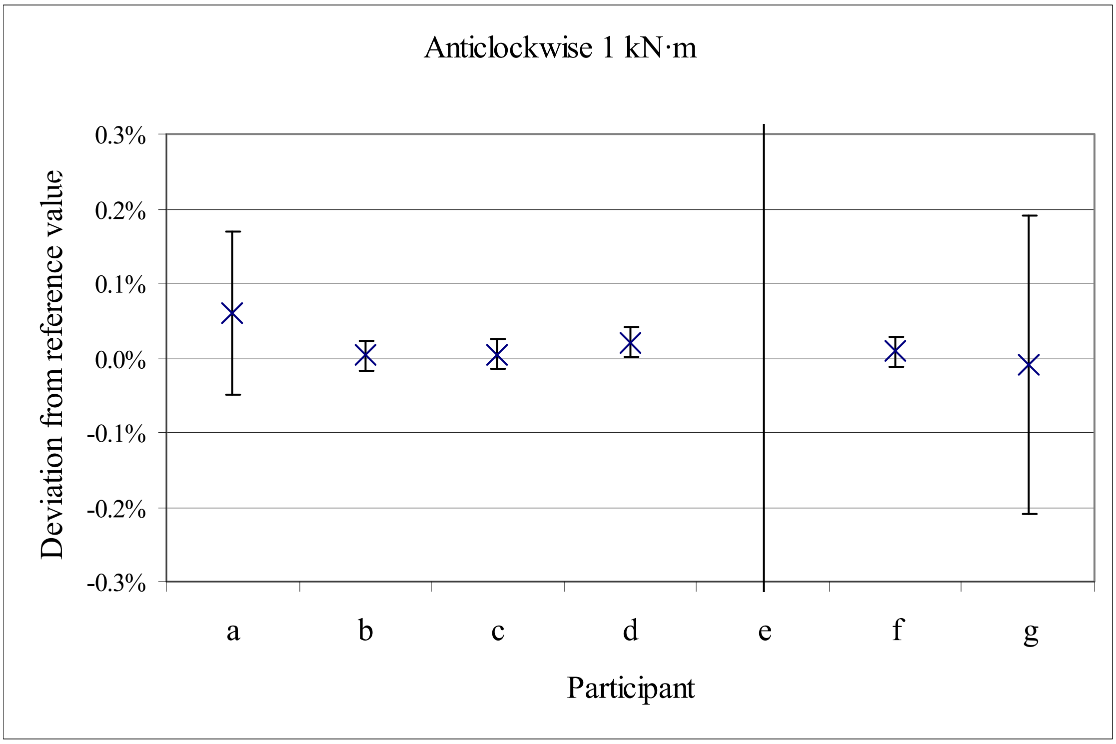

Figure 19. Percentage deviation from the reference value for a 1 kN·m anticlockwise torque

3.4 Temperature compensation and measurement uncertainty

3.4.1 Temperature compensation for participant results

In each calibration the temperature was recorded for every measurement series. From this, two mean temperatures were calculated - one for clockwise torque and one for anticlockwise torque. The difference between this value and the temperature corresponding to the NPL reference value gave a figure which was used to calculate the temperature compensation. The option of a more sophisticated approach to temperature compensation, adjusting each series or measurement point independently, was rejected because of the required assumptions.

3.4.2 Pilot (NPL) measurement Uncertainty

For the pilot measurement uncertainty, the following parameters were included; applied torque, reproducibility, residual deflection, resolution, temperature, and drift. The first five parameters were calculated according to the methods suggested in BS 7882:2008. There were two components to the temperature uncertainty, the temperature range throughout the calibration and the uncertainty of the temperature sensor, which in NPL's case was ± 0.5°.

The standard uncertainty due to drift was taken as one quarter of the difference between the deflections in the two NPL calibrations because the reference value is halfway between the two extremes, and the value will be multiplied by two in the expanded uncertainty. The uncertainty was calculated for both NPL calibrations. The largest uncertainty was used in the analysis. The uncertainty is based on a standard uncertainty multiplied by a coverage factor $k = 2$, providing a level of confidence of approximately 95%.

3.4.3 Participant measurement uncertainty

For the participant measurement uncertainty, the following parameters were included; applied torque, reproducibility, residual deflection, resolution, temperature, and temperature correction. The parameters were calculated as described above. In the absence of any knowledge about the temperature sensors used at each participant a constant value of ±0.5° was used for the uncertainty of the temperature sensor. The temperature sensitivity for the two transducers was +0.035%/°C. In consultation with the manufacturer an uncertainty of ±0.005%/°C was agreed for this sensitivity. Multiplying this uncertainty by each participants difference from the reference temperature, an uncertainty contribution for the temperature correction was calculated. In the 1 kN·m comparison for laboratory *b* where the data has been interpolated an uncertainty contribution for interpolation was included. Again the uncertainty is multiplied by a $k = 2$ coverage factor.

3.4.4 100 N·m transducer

The temperature adjusted calibration results are given below.

Table 5. Temperature compensated mean calibration results for the 100 N·m transducer - deflections given in mV/V

	Torque N·m	NPL	Lab a	Lab b	Lab c	Lab d	Lab e	Lab f	Lab g	Lab h
clockwise	20	-0.39656	-0.39598	-0.39587	-0.39972	-0.39601	-0.39961	-0.39700	-0.39603	-0.39766
	40	-0.79353	-0.79289	-0.79289	-0.79584	-0.79307	-0.80097	-0.79391	-0.79304	-0.79431
	60	-1.19061	-1.19003	-1.19006	-1.19254	-1.19074	-1.20203	-1.19203	-1.19023	-1.19233
	80	-1.58782	-1.58730	-1.58739	-1.58971	-1.58840	-1.60321	-1.59031	-1.58757	-1.58949
	100	-1.98506	-1.98457	-1.98475	-1.98702	-1.98609	-2.00420	-1.98843	-1.98494	-1.98482
anticlockwise	20	0.39588	0.39599	0.39598	0.39922	0.39606	0.40359	0.39674	0.39607	0.39460
	40	0.79256	0.79279	0.79292	0.79495	0.79293	0.80640	0.79340	0.79271	0.79093
	60	1.18952	1.18977	1.19002	1.19169	1.19006	1.20724	1.19075	1.18957	1.18798
	80	1.58662	1.58687	1.58725	1.58882	1.58737	1.60868	1.58793	1.58660	1.58487
	100	1.98374	1.98401	1.98458	1.98595	1.98481	2.00934	1.98527	1.98371	1.98186

The measurement uncertainties have been calculated according to the methods described in sections 3.4.2 and 3.4.3.

Table 6. Measurement uncertainties for the 100 N·m transducer

	Torque N·m	NPL	a	b	c	d	e	f	g	h
clockwise	20	0.148%	0.217%	0.319%	0.715%	0.291%	1.630%	1.326%	0.606%	0.311%
	100	0.038%	0.086%	0.116%	0.040%	0.220%	1.511%	0.356%	0.241%	0.469%
anticlockwise	20	0.085%	0.372%	0.575%	0.923%	0.605%	2.010%	0.690%	0.830%	0.540%
	100	0.023%	0.145%	0.203%	0.067%	0.248%	1.525%	0.152%	0.268%	0.482%

The departure of the temperature corrected mean values from the NPL reference value was calculated as a percentage of the NPL value. The results for applied torques of 20 N·m and 100 N·m in the clockwise and anticlockwise directions are shown in Figures 20 to 23. The error bars shown for each value correspond to the measurement uncertainty for each participant. The grey band corresponds to the measurement uncertainty of the pilot.

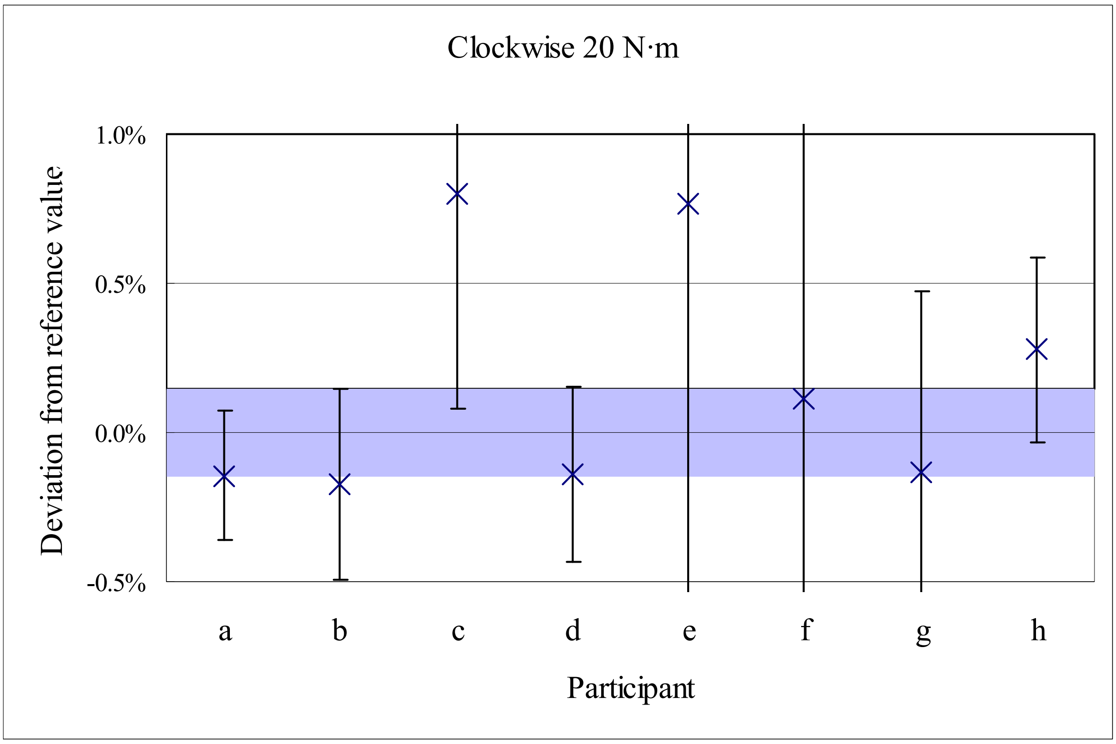

Figure 20. Percentage deviation of the temperature compensated results from the reference value for a 20 N·m clockwise torque

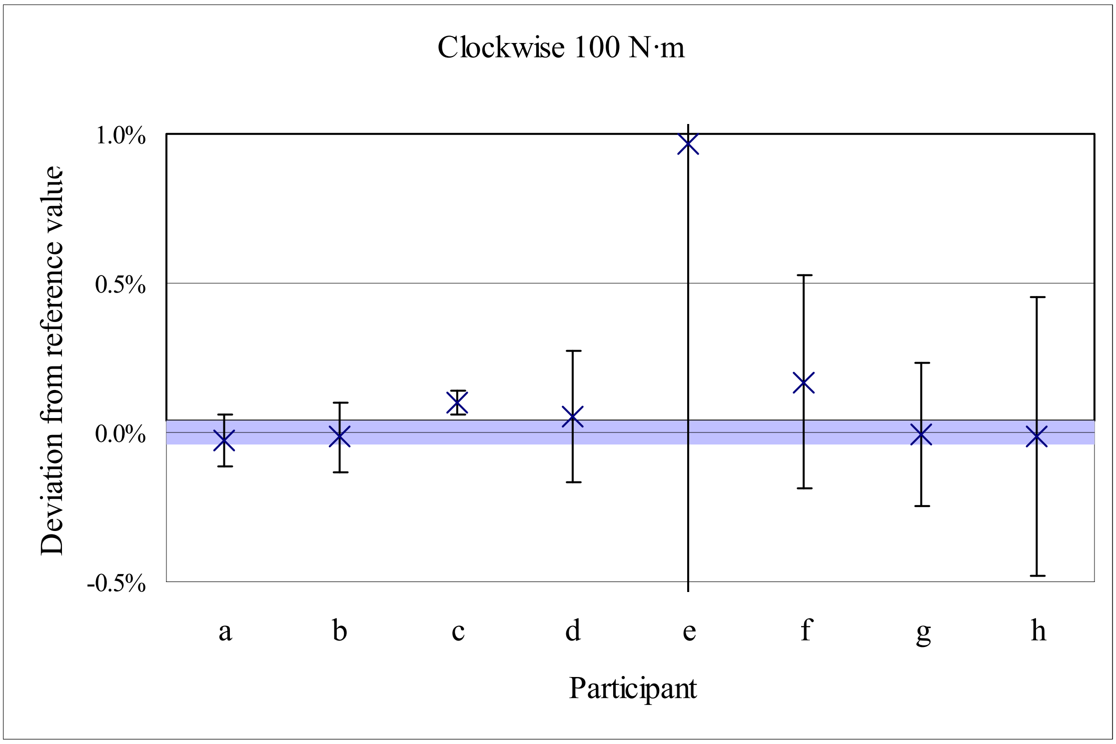

Figure 21. Percentage deviation of the temperature compensated results from the reference value for a 100 N·m clockwise torque

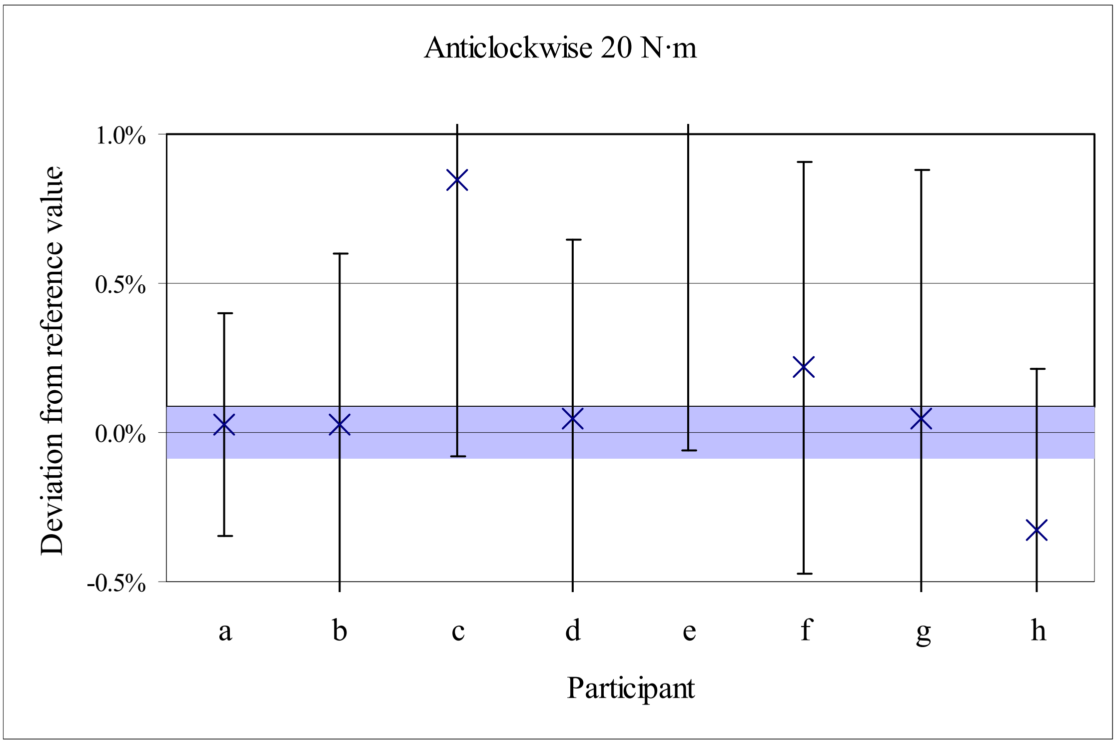

Figure 22. Percentage deviation of the temperature compensated results from the reference value for a 20 N·m anticlockwise torque

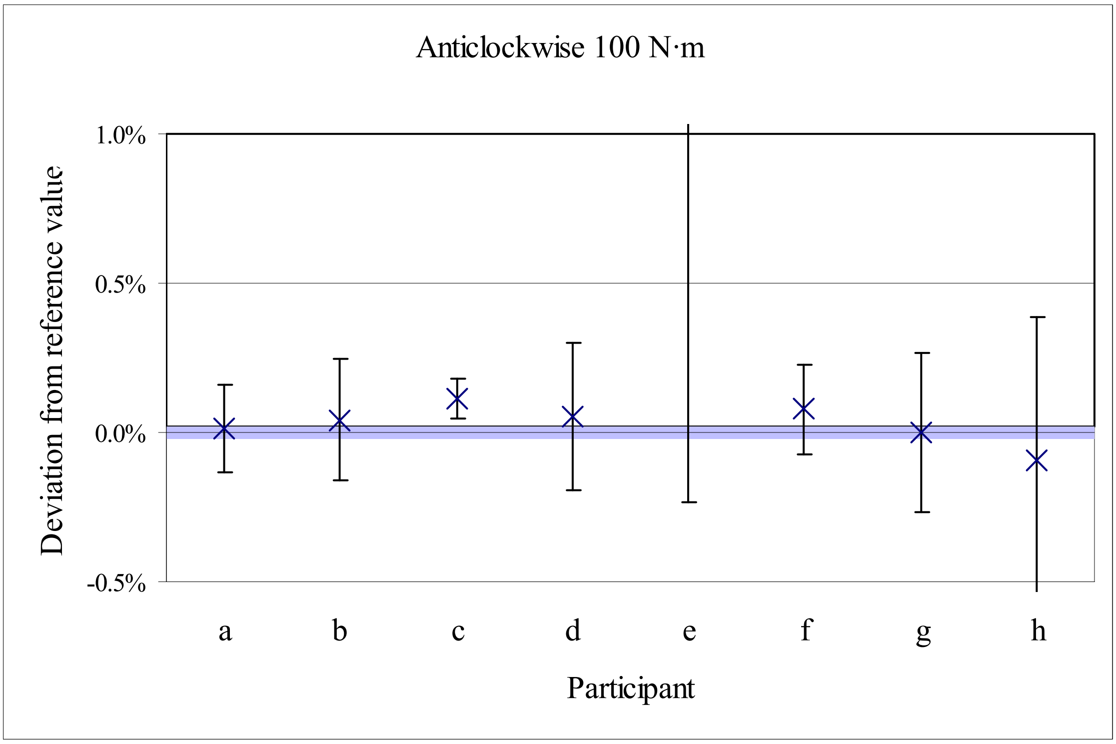

Figure 23. Percentage deviation of the temperature compensated results from the reference value for a 100 N·m anticlockwise torque

3.4.5 1 kN·m transducer

The temperature adjusted calibration results are given below.

Table 7. Temperature compensated mean calibration results for the 1 kN·m transducer - deflections given in mV/V

	Torque N·m	NPL	Lab a	Lab b	Lab c	Lab d	Lab e	Lab f	Lab g	Lab h
clockwise	200	-0.39678	-0.39692	-0.39634	-0.39636	-0.39698	-0.40067	-0.39675	-0.39703	-0.39676
	400	-0.79381	-0.79401	-0.79317	-0.79322	-0.79405	-0.80154	-0.79362	-0.79420	-0.79361
	600	-1.19095	-1.19126	-1.19032	-1.18974	-1.19129	-1.20247	-1.19064	-1.19141	
	800	-1.58819	-1.58867	-1.58764	-1.58666	-1.58866	-1.60346	-1.58784	-1.58876	
	1000	-1.98547	-1.98621	-1.98495	-1.98321	-1.98609	-2.00451	-1.98507	-1.98616	
anticlockwise	200	0.39697	0.39708	0.39715	0.39667	0.39707	0.40339	0.39695	0.39693	0.39702
	400	0.79402	0.79426	0.79426	0.79357	0.79415	0.80382	0.79387	0.79513	0.79391
	600	1.19117	1.19152	1.19136	1.19034	1.19134	1.20435	1.19091	1.19194	
	800	1.58839	1.58891	1.58850	1.58717	1.58860	1.60510	1.58806	1.58833	
	1000	1.98563	1.98642	1.98570	1.98425	1.98597	2.00541	1.98530	1.98570	

The measurement uncertainties have been calculated according to the methods described in sections 3.4.2 and 3.4.3.

Table 8. Measurement uncertainties for the 1 kN·m transducer

	Torque N·m	NPL ref	a	b	c	d	e	f	g	h
clockwise	200	0.030%	0.120%	0.159%	0.110%	0.042%	1.503%	0.045%	0.203%	0.140%
	1000	0.012%	0.117%	0.060%	0.063%	0.042%	1.501%	0.042%	0.201%	
anticlockwise	200	0.017%	0.114%	0.381%	0.058%	0.039%	1.506%	0.047%	0.215%	0.149%
	1000	0.012%	0.113%	0.082%	0.068%	0.044%	1.501%	0.048%	0.205%	

The departure of the temperature corrected mean values from the NPL reference value was calculated as a percentage of the NPL value. The results for applied torques of 200 N·m and 1 kN·m in the clockwise and anticlockwise directions are shown in Figures 24 to 27. The error bars shown for each value correspond to the measurement uncertainty for each participant. The grey band corresponds to the measurement uncertainty of the pilot.

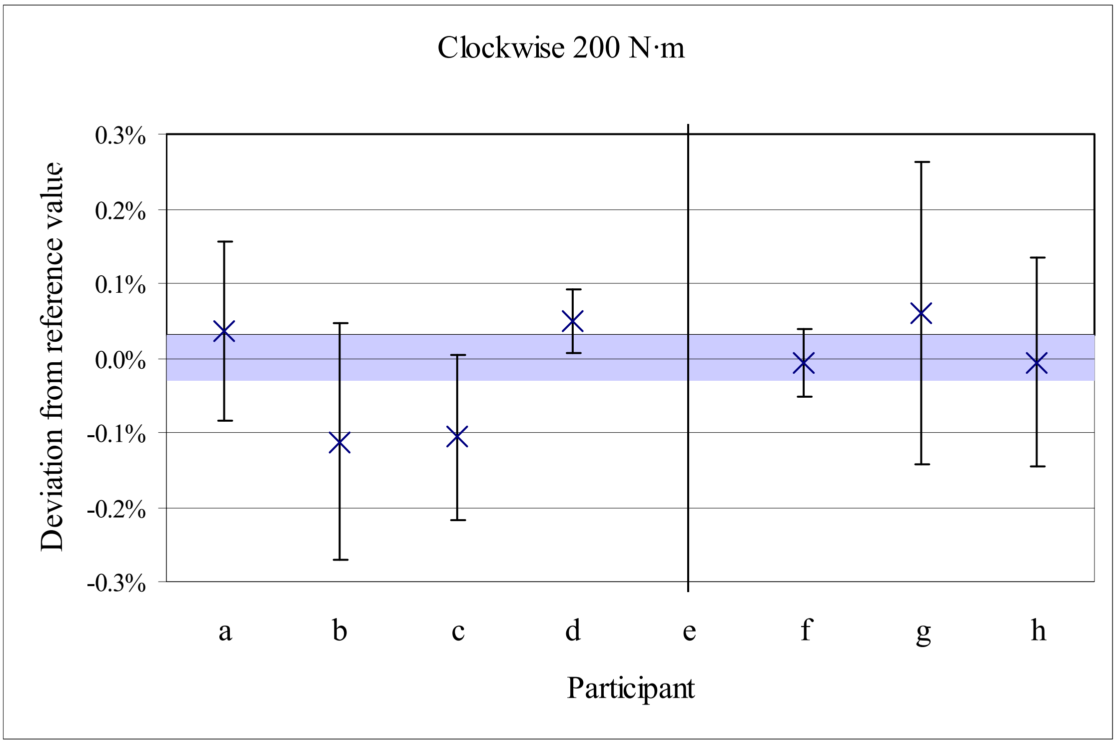

Figure 24. Percentage deviation of the temperature compensated results from the reference value for a 200 N·m clockwise torque

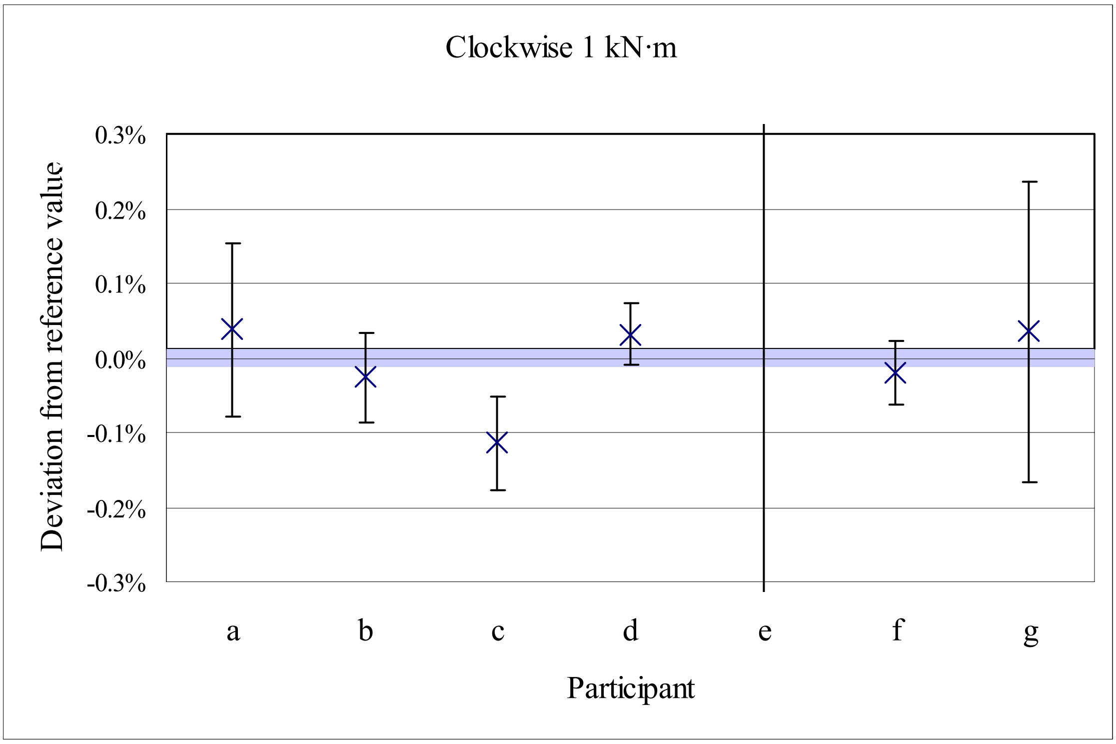

Figure 25. Percentage deviation of the temperature compensated results from the reference value for a 1 kN·m clockwise torque

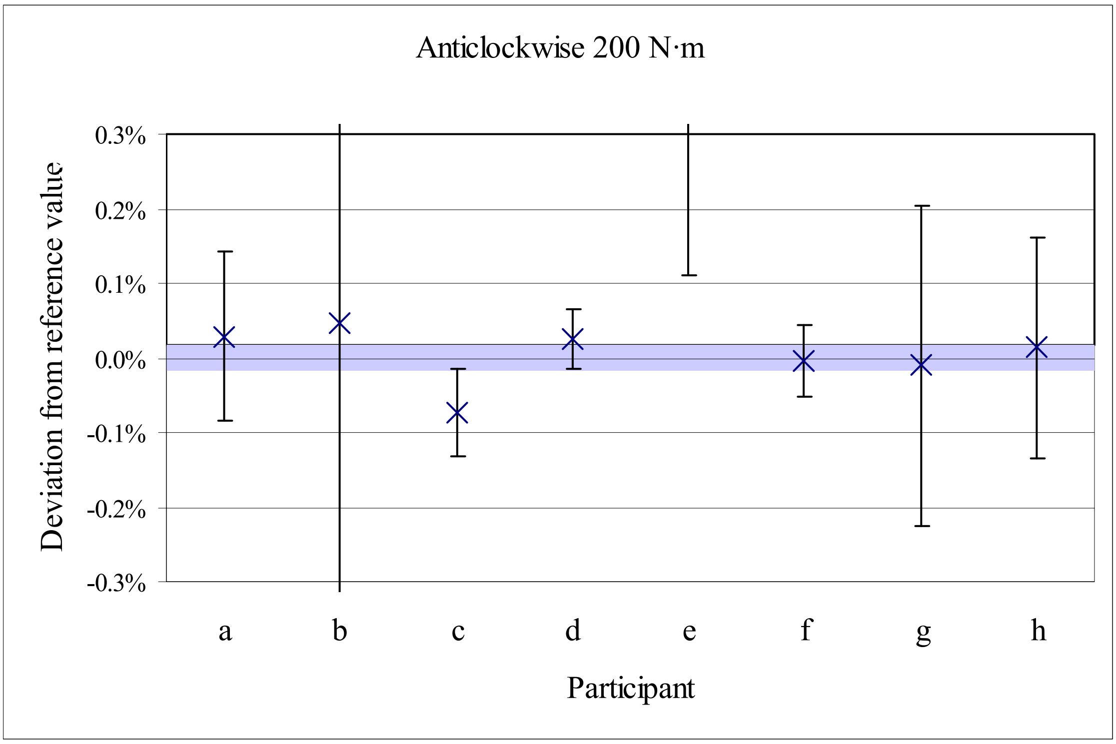

Figure 26. Percentage deviation of the temperature compensated results from the reference value for a 200 N·m anticlockwise torque

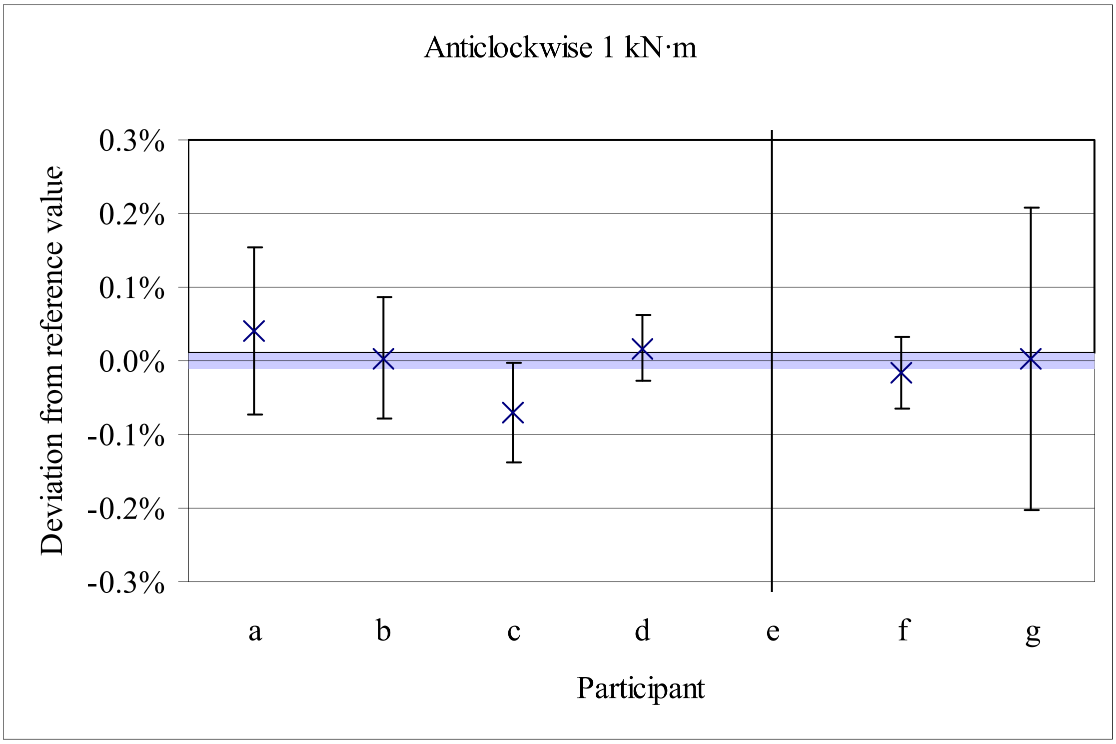

Figure 27. Percentage deviation of the temperature compensated results from the reference value for a 1 kN·m anticlockwise torque

3.5 Analysis of transducer parameters (Repeatability, reproducibility and reversibility)

3.5.1 100 N·m transducer

The repeatability, reproducibility and reversibility of the 100 N·m transducer as measured by each participant is shown in Figures 28 to 30.

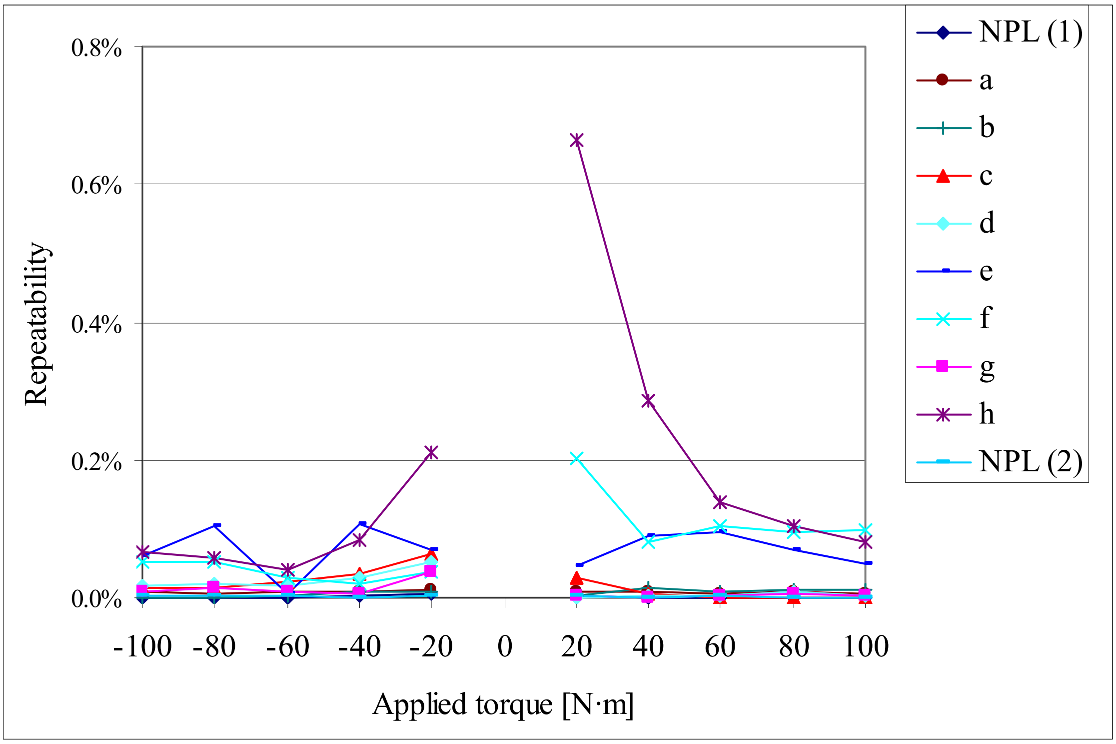

Figure 28. Repeatability for the 100 N·m transducer

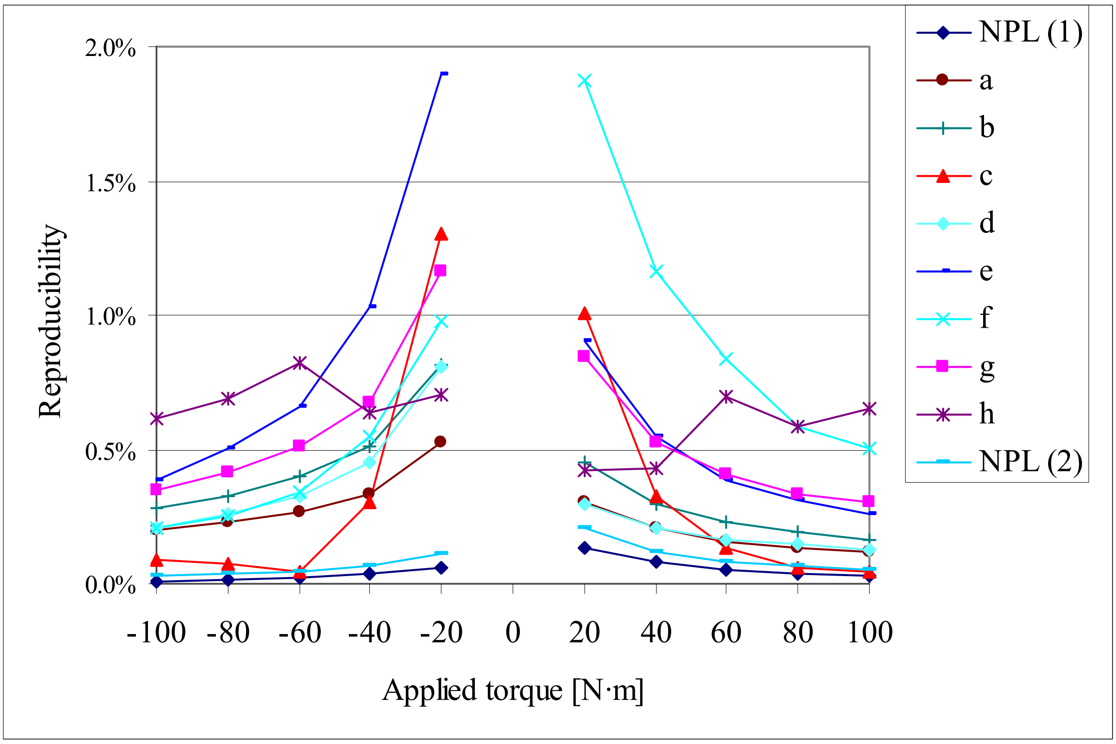

Figure 29. Reproducibility for the 100 N·m transducer

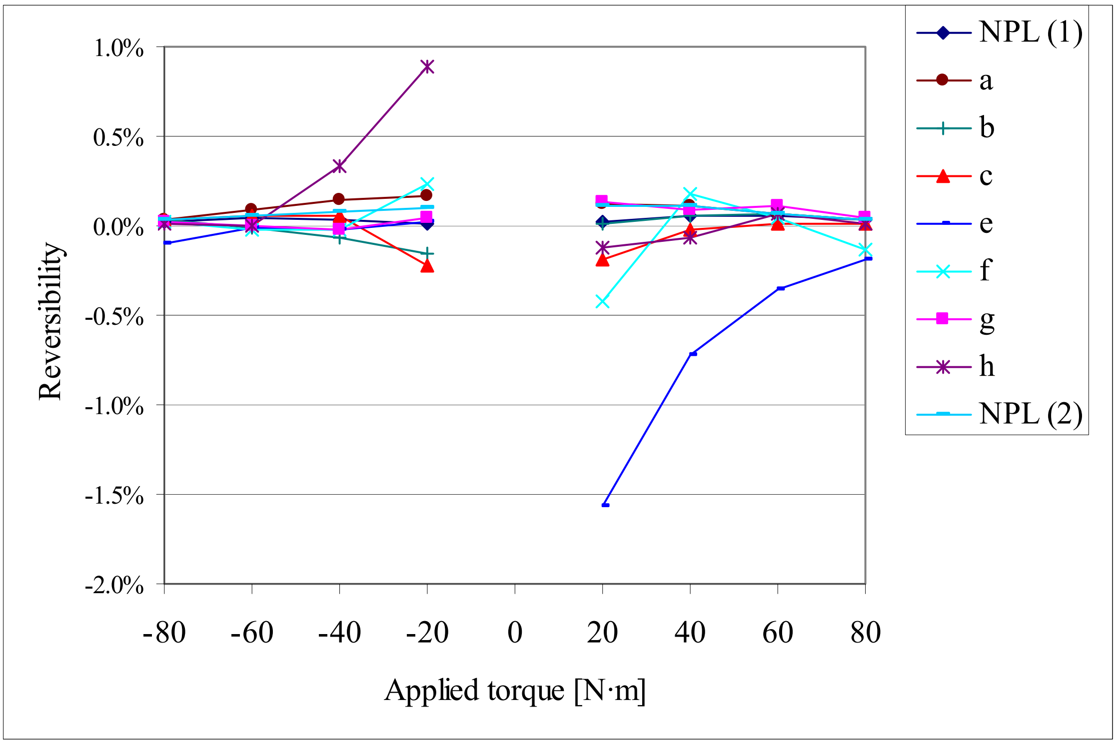

Figure 30. Reversibility for the 100 N·m transducer

3.5.2 1 kN·m transducer

The repeatability, reproducibility and reversibility of the 1 kN·m transducer as measured by each participant is shown in Figures 31 to 33.

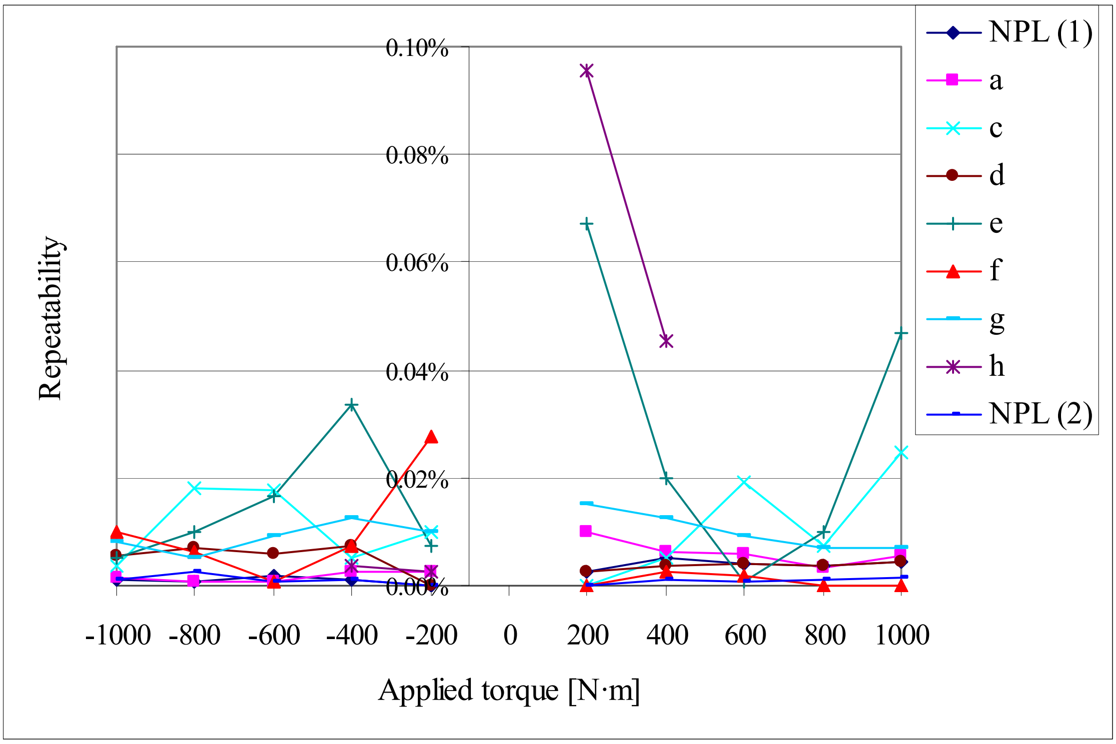

Figure 31. Repeatability for the 1 kN·m transducer

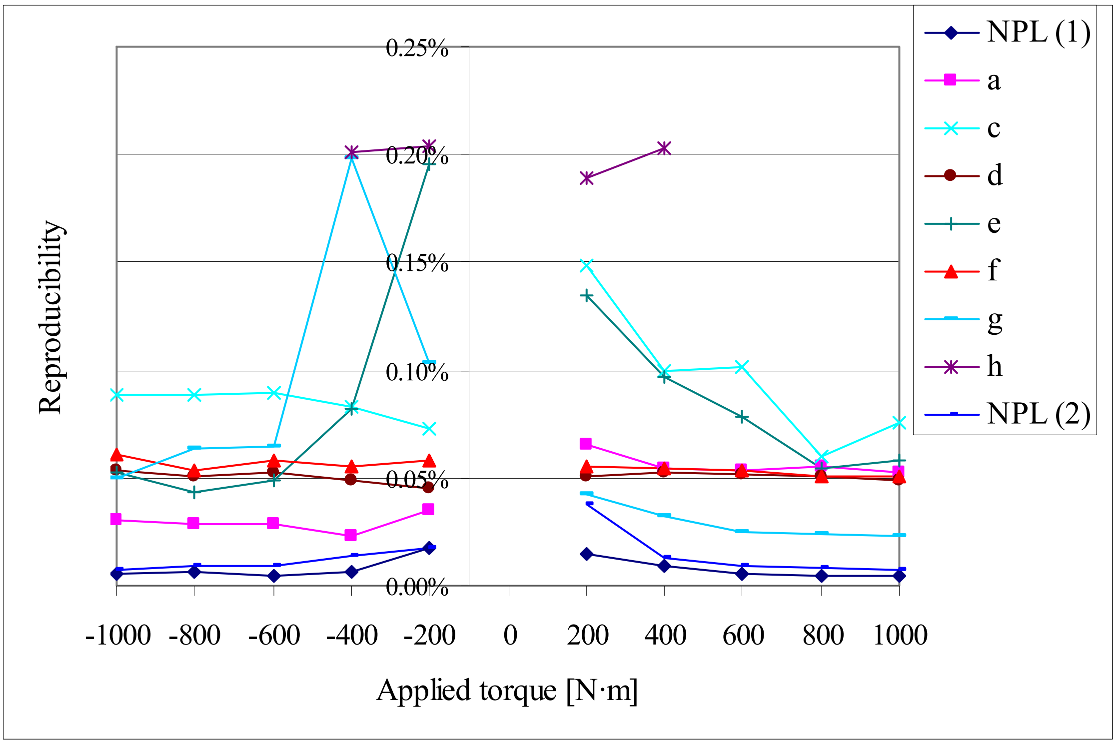

Figure 32. Reproducibility for the 1 kN·m transducer

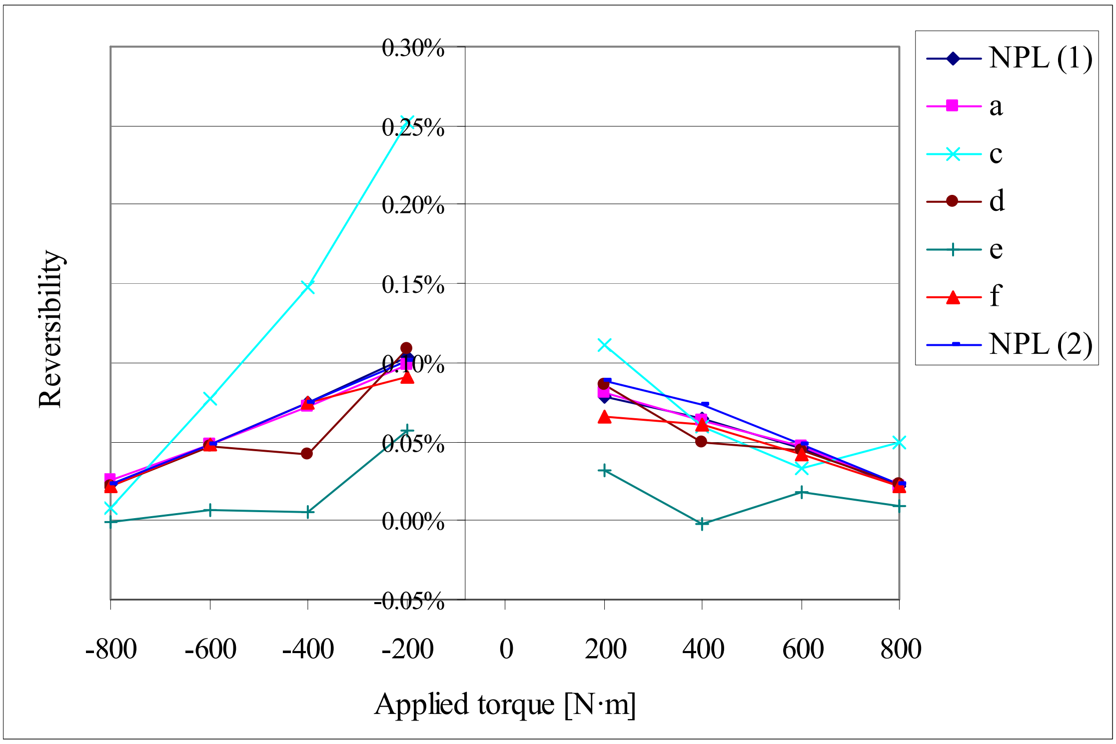

Figure 33. Reversibility for the 1 kN·m transducer

4. Conclusions

The round robin comparison has provided an opportunity for participants to compare their torque rigs against the NPL national standard via a calibrated transfer standard. Following a review of the results, each laboratory should determine whether any further action is required. For the 100 N·m transducer there are some large deviations from the reference value, particularly at the lower end of the measurement range. However the reproducibility for this transducer was, in many cases, the dominant factor in the measurement uncertainty, and in most cases the deviations were covered by this uncertainty. In the case of laboratory *c* a combination of the transducer's high reproducibility and the ability only to measure in 3 orientations put a large skew on the mean measurement results. In most cases, because the uncertainty of applied torque is only a small fraction of the measurement uncertainty, it is difficult to infer much about the particular torque rig from the measurement result. In the ideal case the transducer should have a negligible influence so that any differences in the comparison results can be directly attributed to the performance of the torque rig.

For the 1 kN·m transducer the reproducibility is less than a fifth of the value for the 100 N·m transducer. Consequently the measurement uncertainty is much lower and the uncertainty of applied torque now forms a significant part of it. As the transducer influence on measurement uncertainty is much less, more can be inferred from the measurement results. Most laboratories' results agree with the NPL reference values.

One unforeseen area of influence was the temperature sensitivity of the transducer, +0.035% per degree. This value was higher than expected and only became known partway through the comparison. Aside from using another transducer, with hindsight the measurements would have benefited from a more rigorous approach to temperature measurement including the use of a travelling temperature sensor.

It should be noted that there was no minimum criterion for entry in the comparison and that laboratories were encouraged to participate for their own benefits. As such, drawing comparisons between laboratories should be avoided as the torque rigs represented cover a broad range of industrial applications requiring different levels of accuracy. The important comparison is between the individual laboratory and the reference value incorporating the associated uncertainties – this is what determines whether the particular rig can be deemed fit for purpose. There are a few discrepancies amongst the results and these should be followed up by the laboratories concerned according to their perceived importance. Conversely some laboratories have results well within their uncertainty range that suggest the applied torque uncertainty budget for those laboratories could be re-evaluated and improved if there was a benefit to be gained.

The project has been a success both organisationally and in providing, in most cases, a first opportunity for laboratories to compare to a national standard. From NPL's perspective the project has been an efficient and cost effective way of disseminating the unit of torque to a broad range of beneficiaries. It is up to the individual laboratories to make best use of the measurement results. A periodic repeat of the exercise every few years would be a useful way of assessing the UK's torque measurement capabilities.

5. Acknowledgements

The author would like to thank UKAS for their financial support of this project, the loan of equipment, and for organising the logistics of the comparison, in particular Trevor Steward, Noel Burgher, and Derek Bergmann. The author would also like to thank Norbar Torque Tools for their swift response in repairing damaged equipment minimising any time delays.
Finally the author would like to acknowledge the financial support of the National Measurement System Directorate of the UK Department of Innovation, Universities and Skills.

6. References

[1] Robinson A, 2007 The Design, Development and Commissioning of a 2 kN·m Torque Standard Machine. *CalLab, Jan – Mar*.

[2] Debnam R, Hewitt R, Sangster R, Thompson G, 1996 Calibration and Classification of torque measuring devices. *Proceedings of the 15th Imeko TC3 Conference, Madrid, Spain pp 265-272*

[3] BS 7882:2008; Calibration and classification of torque measuring devices.

Appendix

Figures 11 to 14 and 16 to 19 are reproduced as Figures A1 to A4 and A5 to A8 respectively with a larger scale to show the results that did not appear in the main report due to scaling.

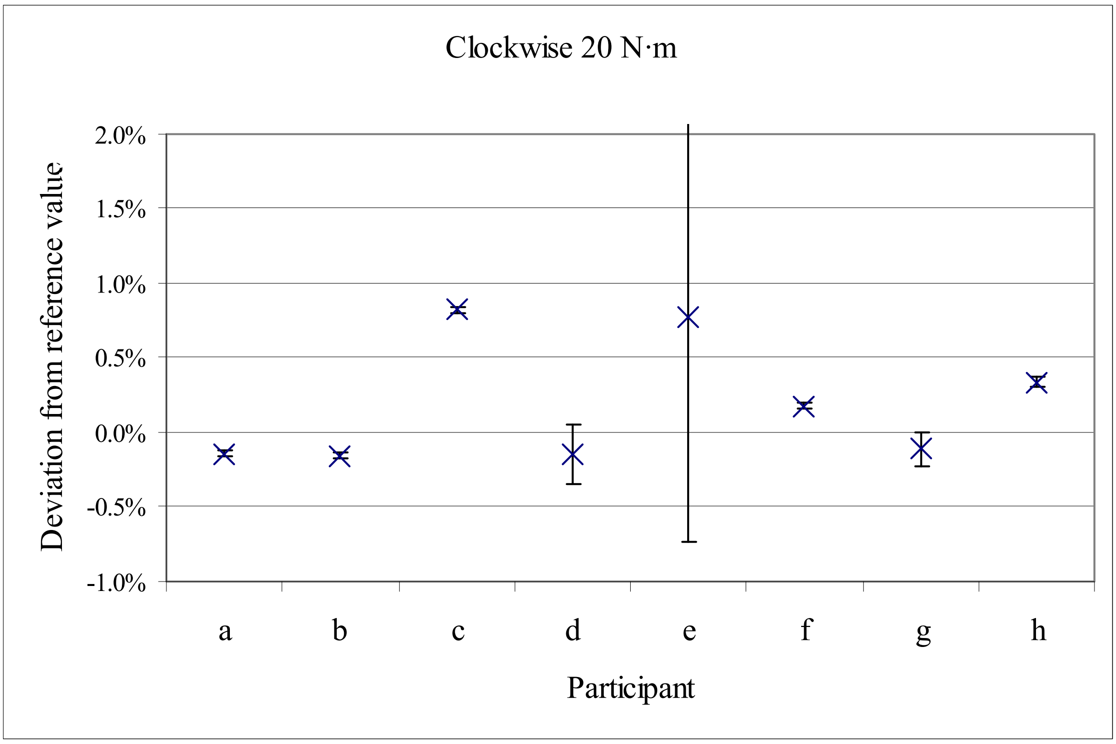

Figure A1. Percentage deviation from the reference value for a 20 N·m clockwise torque

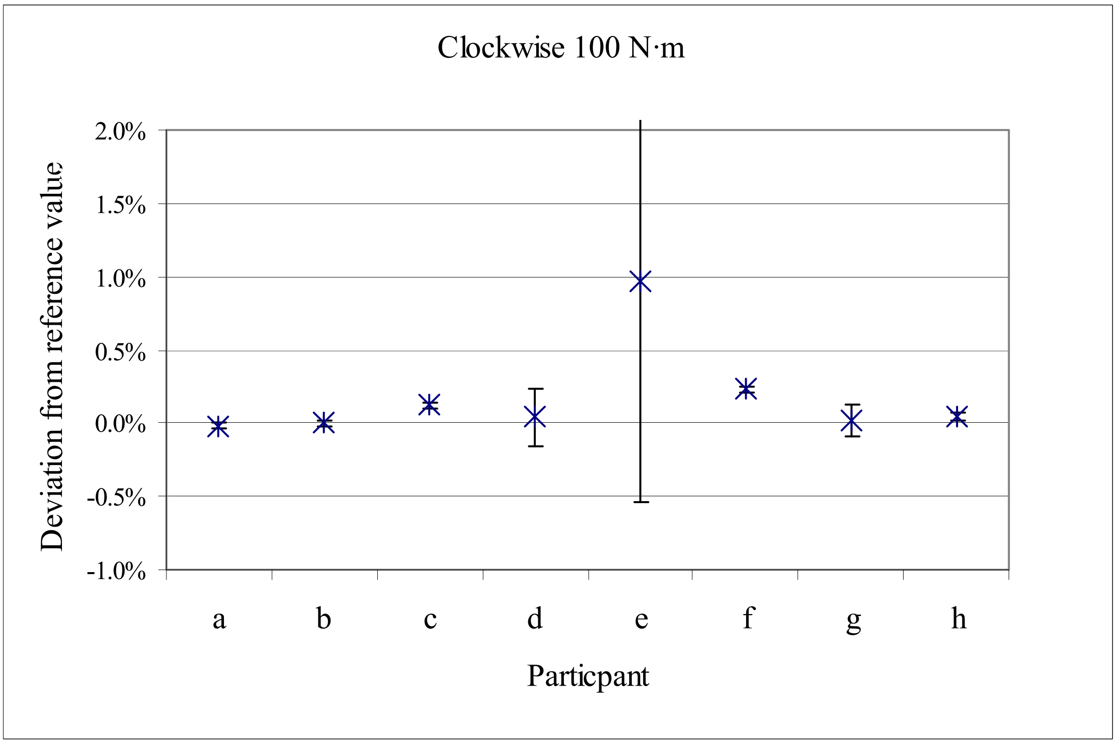

Figure A2. Percentage deviation from the reference value for a 100 N·m clockwise torque

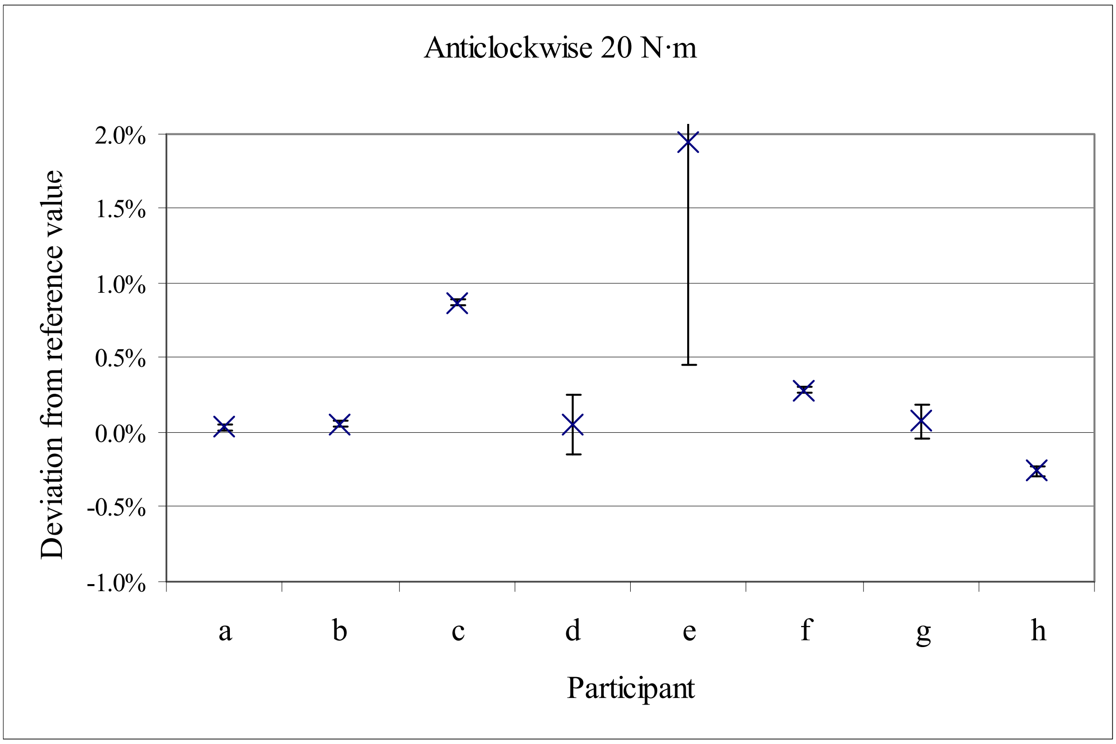

Figure A3. Percentage deviation from the reference value for a 20 N·m anticlockwise torque

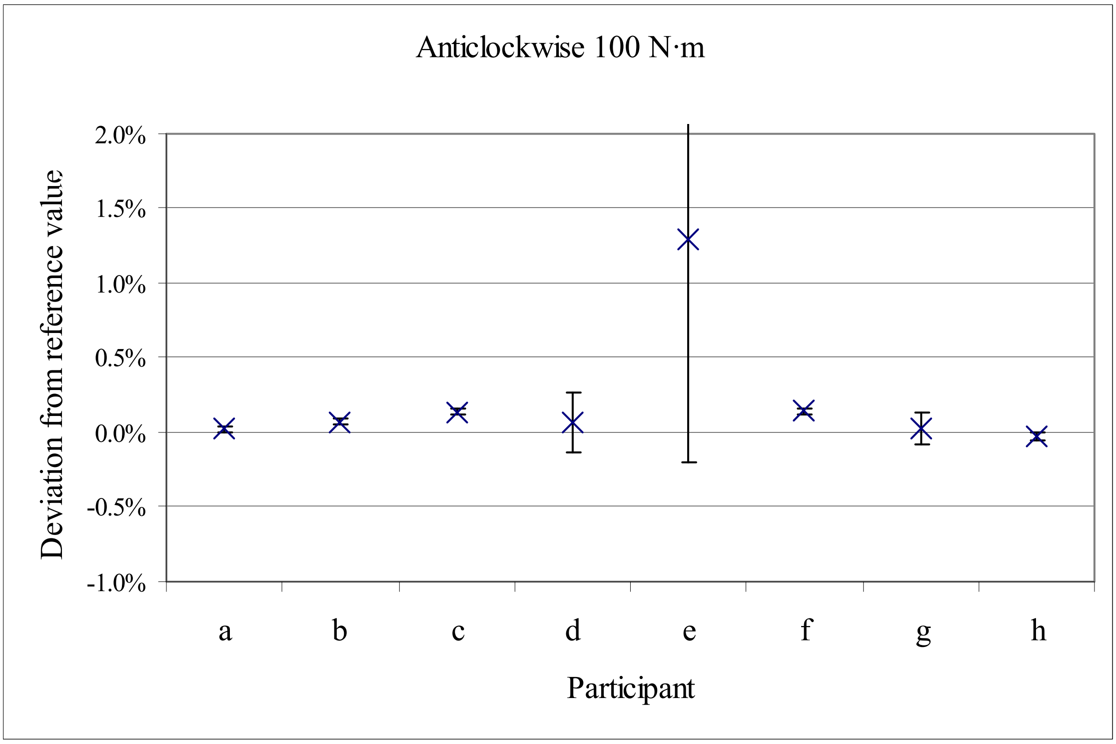

Figure A4. Percentage deviation from the reference value for a 100 N·m anticlockwise torque

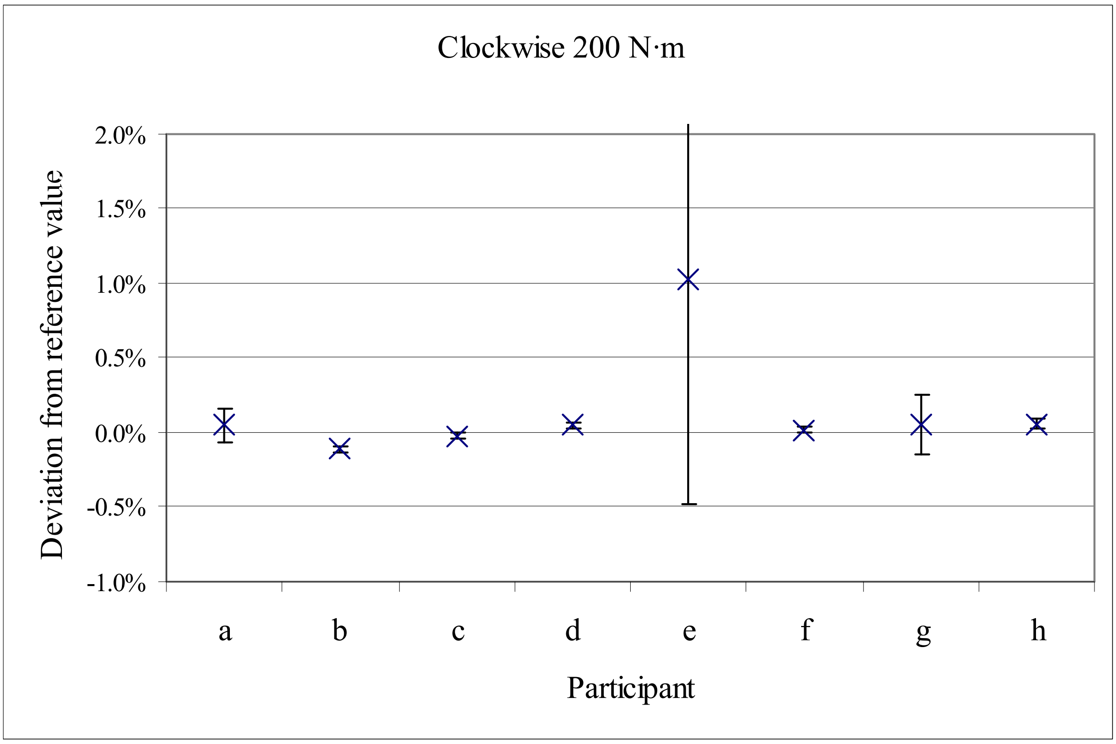

Figure A5. Percentage deviation from the reference value for a 200 N·m clockwise torque

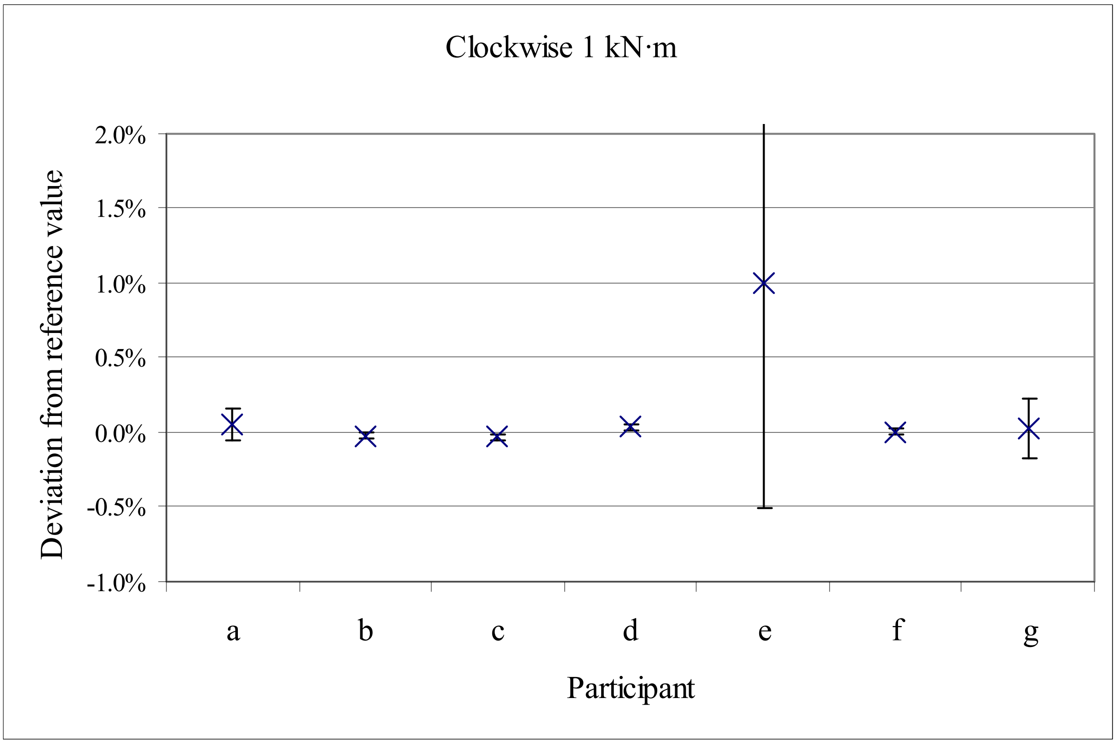

Figure A6. Percentage deviation from the reference value for a 1 kN·m clockwise torque

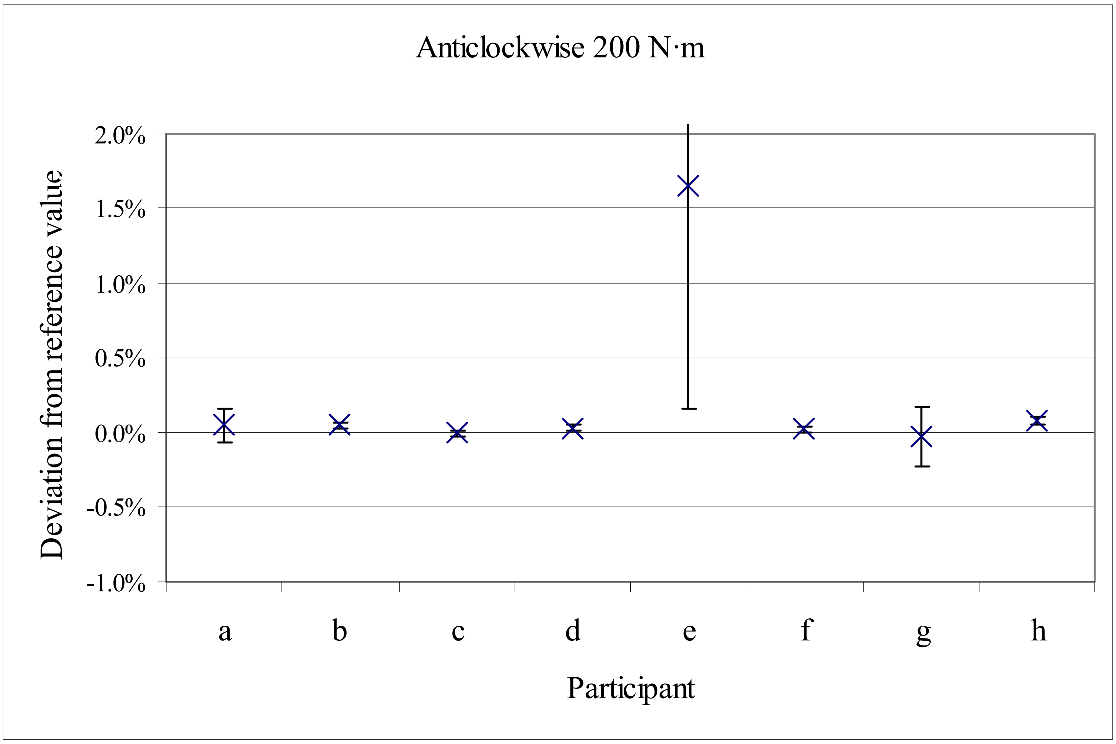

Figure A7. Percentage deviation from the reference value for a 200 N·m anticlockwise torque

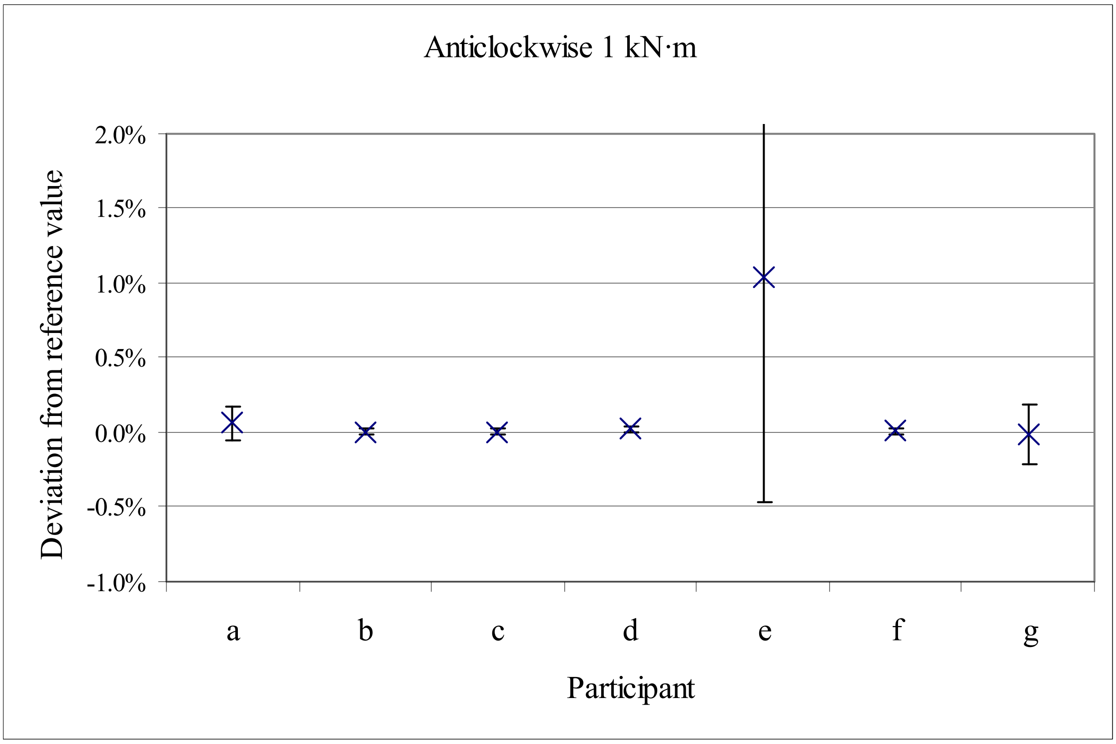

Figure A8. Percentage deviation from the reference value for a 1 kN·m anticlockwise torque