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UK TORQUE INTERCOMPARISON - 2007

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Abstract – This paper gives details of a round robin torque comparison involving the National Physical Laboratory (NPL) and nine other UK laboratories. The comparison covered two ranges: 20 N·m to 100 N·m and 200 N·m to 1 kN·m. The work was an effective way of disseminating the unit of torque to industry via the UK's new national torque standard, giving assurance to laboratories and customers and identifying areas for possible improvement.

Keywords torque, intercomparison

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 initiative between NPL and the United Kingdom Accreditation Service (UKAS), with NPL acting as the pilot laboratory. In addition to UKAS-accredited torque laboratories, the comparison was open to other UK-based laboratories with a suitable torque facility. All measurements were carried out at their own cost by the participants and the pilot laboratory. UKAS made the arrangements for the transportation of the equipment and also covered the associated costs.

Figure 1. NPL national torque standard machine.

This comparison was made possible through the recent development of the UK national torque standard. It was decided that 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.

While NPL was primarily concerned with the technical performance of each torque rig, UKAS was 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-accredited laboratories were encouraged to provide calibration certificates.

2. PROTOCOL

2.1. Participants

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. This resulted in nine participants, as well as NPL, spanning a wide range of laboratories and industries. The participants' torque rigs included both supported and unsupported beams.

2.2. Equipment

The measurement equipment was provided by UKAS. The transducers were commercially available square-drive transducers, which are in widespread use in industry (Table 1 and Figure 2). An NPL-owned indicator was chosen to ensure that 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 commonly undertaken in industry. The exercise would provide information on each torque rig but would also highlight more generic calibration issues.

The coefficient for the temperature sensitivity of both transducers was given by the manufacturer as +0.035 % °C^{-1}, with an uncertainty of ±0.005 % °C^{-1}.

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Table 1. List of equipment

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

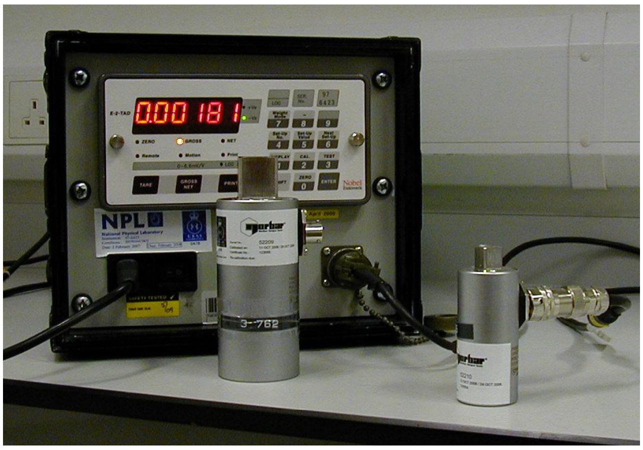

Figure 2. Transducers and indicator.

2.3. Timetable

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, both 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 damage had had no effect on the transducers' outputs, the equipment was then returned to NPL. On both occasions, a check calibration was performed and, as the results showed good agreement with the initial calibration, it was determined that there was no significant influence and that the exercise could continue.

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.

The measurement protocol is illustrated in Figure 3.

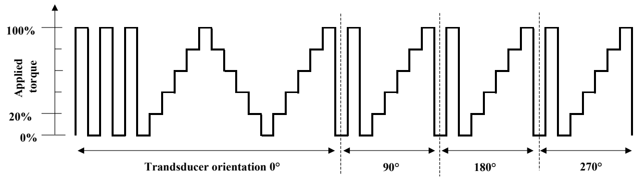

Figure 3. Calibration protocol for both clockwise and anti-clockwise calibrations.

2.5 Results and information policy

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

3. RESULTS

3.1. NPL calibrations

The graphs in Figures 4 and 5 show the calibration parameters for the two transducers calculated using the methods specified in BS 7882:2008. The clockwise results are plotted against positive torques and the anticlockwise results are plotted against negative torques. 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 the performance of both transducers prior to analysing the comparison results.

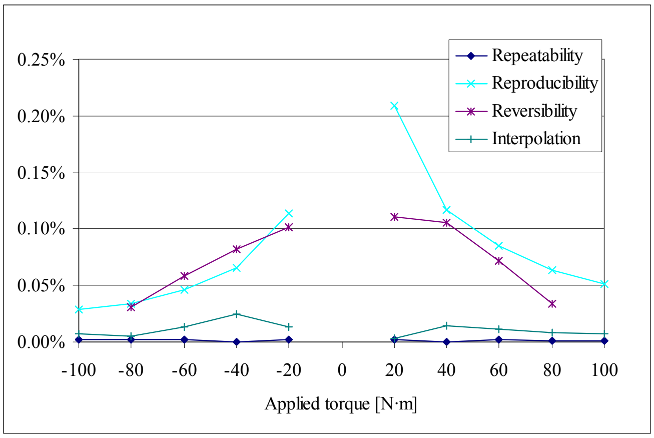

Figure 4. Calibration parameters for the 100 N·m transducer calibrated at NPL.

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

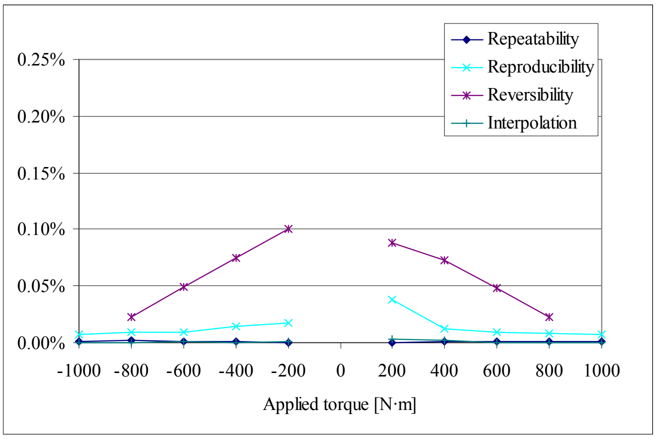

Figure 5. Calibration parameters for the 1 kN·m transducer calibrated at NPL.

3.2. Reference value

The NPL torque machine was used as the 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.

Figures 6 and 7 show the drift in the calibration value between the two NPL calibrations for the 100 N·m and 1 kN·m transducers respectively. The first calibration was in May 2007 and the second calibration in November 2007.

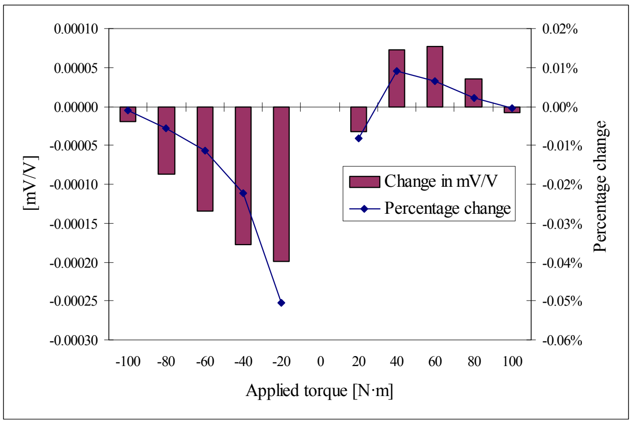

Figure 6. Drift of 100 N·m transducer between the two NPL calibrations, in both absolute and relative units.

The 1 kN·m transducer showed 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.

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.

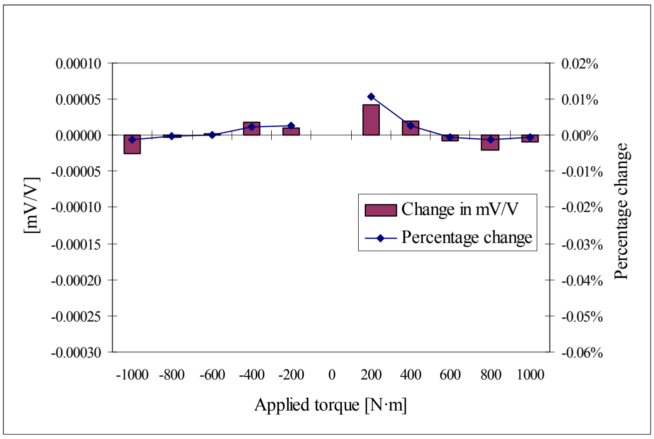

Figure 7. Drift of 1 kN·m transducer between the two NPL calibrations, in both absolute and relative units.

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 6 and 7 showed that the drift was minimal in relation to other uncertainty contributions. 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 sections 3.5 and 3.6 due to scaling, the graphs have been reproduced in the full report with a larger scale [4].

For the 100 N·m transducer results, Laboratory *c* was only able to calibrate in three orientations because of physical limitations. In this case the mean value was calculated from the three measurement series. The possibility of using the data from just two series, 0° and 90°, was considered as this is 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, 0° and 90°, and the mean value and measurement parameters were calculated from these two series. Laboratory *d* was also unable to apply a decremental series of torques.

The mean deflections were divided by the applied torque to give a sensitivity at each applied torque in units of $mV \cdot V^{-1} \cdot (N \cdot m)^{-1}$. The values are plotted in Figures 8 and 9, but with the clockwise and anticlockwise sensitivities both displayed as positive values, to aid comparison.

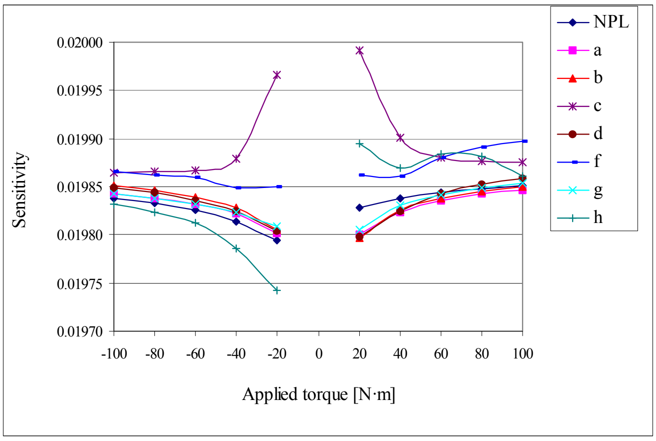

Figure 8. Sensitivity of the 100 N·m transducer for each participant.

For the 1 kN·m results, Laboratory *g* calibrated the transducer in just two orientations, 0° and 90°. Laboratory *h* only measured two points, at 200 N·m and 400 N·m. Laboratory *b* calibrated the transducer in units of pounds feet - a cubic equation was fitted to this data and interpolated values corresponding to the applied torques required in the comparison were calculated.

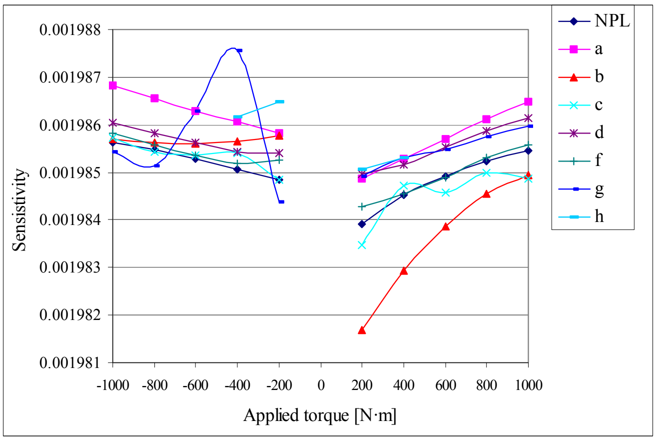

Figure 9. Sensitivity of the 1 kN·m transducer for each participant.

3.4. Temperature compensation and measurement uncertainty

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 each 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.

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 °C.

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 with the largest uncertainty being used in the analysis. The expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor $k = 2$, providing a level of confidence of approximately 95 %.

For each participant's 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 °C was used for the uncertainty of the temperature measurement. By multiplying the uncertainty of the temperature sensitivity (±0.005 %·°C^{-1}) by each participant's 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 was multiplied by a $k = 2$ coverage factor.

3.5. 100 N·m calibration results

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 10 to 13. The error bars shown for each value correspond to the expanded measurement uncertainty for each participant. The shaded band corresponds to the measurement uncertainty of the pilot.

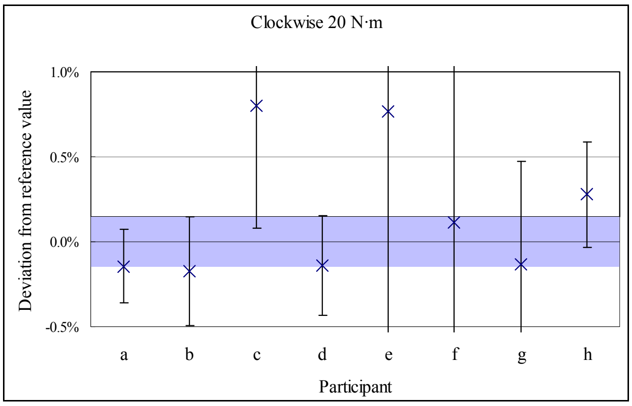

Figure 10. Percentage deviation of the temperature compensated results from the reference value for a 20 N·m clockwise torque.

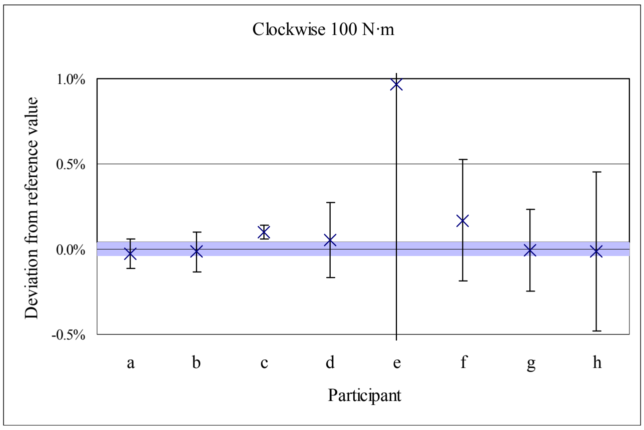

Figure 11. Percentage deviation of the temperature compensated results from the reference value for a 100 N·m clockwise torque.

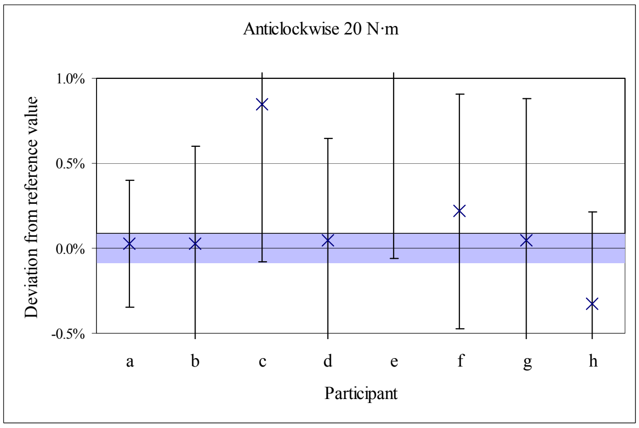

Figure 12. Percentage deviation of the temperature compensated results from the reference value for a 20 N·m anticlockwise torque.

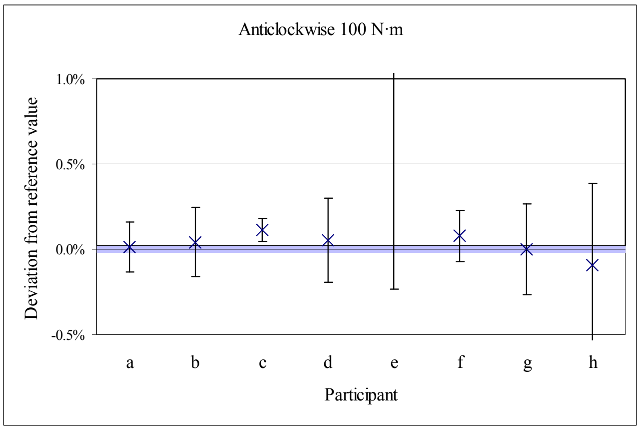

Figure 13. Percentage deviation of the temperature compensated results from the reference value for a 100 N·m anticlockwise torque.

3.6. 1 kN·m calibration results

The results for applied torques of 200 N·m and 1 kN·m in the clockwise and anticlockwise directions are shown in Figures 14 to 17.

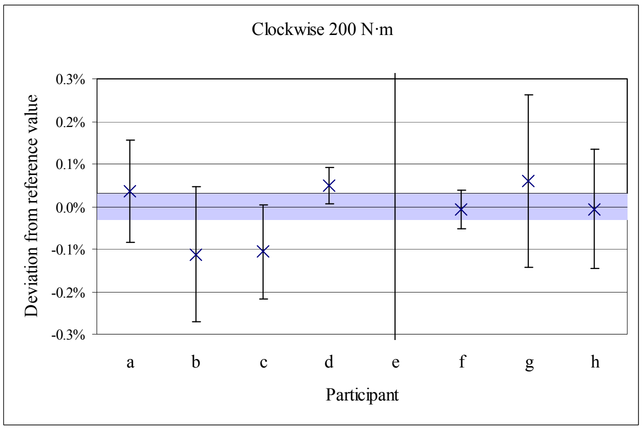

Figure 14. Percentage deviation of the temperature compensated results from the reference value for a 200 N·m clockwise torque.

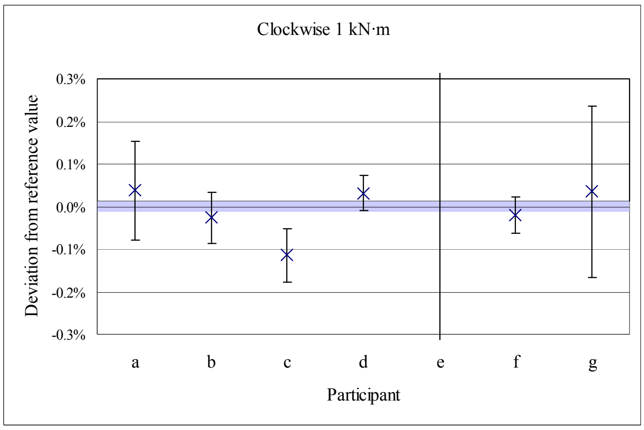

Figure 15. Percentage deviation of the temperature compensated results from the reference value for a 1 kN·m clockwise torque.

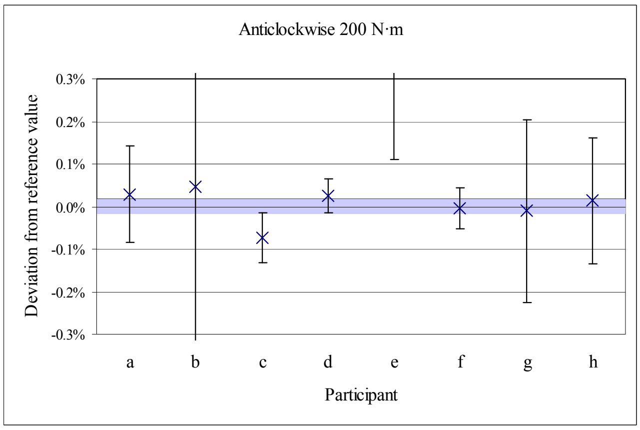

Figure 16. Percentage deviation of the temperature compensated results from the reference value for a 200 N·m anticlockwise torque.

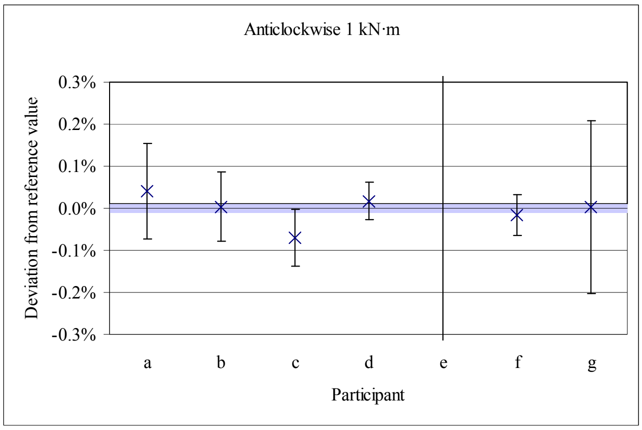

Figure 17. Percentage deviation of the temperature compensated results from the reference value for a 1 kN·m anticlockwise torque.

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 to measure only at three 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 $\%\cdot°C^{-1}$. 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 were no minimum criteria 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.

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