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# Development and metrological characterization of a 1000 Nm Torque Comparator Machine for calibrating Torque Wrench Testers

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**Abstract**

The National Physical Laboratory, India NPL(I) has established torque scale up to 2000 N.m with calibration and measurement capability up to 0.01%, which has demonstrated a degree of equivalence in the BIPM CCM-T.K.1.1 key comparison. A torque comparator machine has been designed and developed at NPL, India for providing the national traceability of torque scale to the users without much degradation in the accuracy of measurement for certain industrial applications. This paper describes the salient features of the machine and the performance evaluation of the machine up to 1000N.m. The expanded uncertainty associated with torque generated by this machine is found to be within ± 0.1% which is adequate for performing the calibration of industrial type torque wrench testers.

**Key words**: Torque standards, comparison calibration, measurement uncertainty,

## 1. INTRODUCTION

Precision measurement of torque is in great demand among industries like automobile, aviation, heavy engineering, pharmaceutical, food processing, etc. for improvement in quality of products and processes. The torque measurement is important for precision tightening of bolts, rotary power of turbines, generators, motors; torsion testing of materials and products; torque sensing in robotics, prosthetic medical appliances; etc [1-4].

The realization of accurate torque scale and its dissemination to users is one of the prime mandates of National physical Laboratory (NPL) which is the NMI of the country. At NPL, the torque scale comprises of two torque standard machines, of which one of them has an elastic hinge supported lever arm with a torque drive to generate the precision torque and the other one has an unsupported lever arm with a balancing weight coupled to the torque transducer using a suitable adapter for generating the required torque on the transducer. These two torque standard machines use calibrated dead weights for generating the required torque with the associated uncertainty of ± 0.01% and ± 0.05% respectively. The detailed description about these machines and the determination of the uncertainty associated with these machines are described elsewhere [5]. The associated uncertainty of the supported lever torque primary machine has been reaffirmed in the CCM-TK1.1 key comparison, the results are shown on the BIPM website [6].

Recently, we have developed a simple, economic, user friendly comparator type torque machine for generating precision torque up to 1000 N.m. The torque comparator machine is based on the direct comparison of the output of the torque measuring device against that of a reference torque transducer having lower uncertainty calibrated on the primary machine. This machine was characterized using a 1000 Nm torque transfer standard for its calibration and measurement capability (CMC). The design and the metrological performance of the torque comparator machine (TCM) and the process of transferring the measurement standard from NPL to the shop floor level are presented here.

## 2. DESCRIPTION OF THE TORQUE COMPARATOR MACHINE

The comparator torque machine comprises of a two metre long rectangular rigid frame made from square section beam. Very smooth and heavy railings are fixed on the frame of the machine, as shown in Fig1.

Figure 1 A view of the torque comparator machine

A rigid vertical angle plate is fixed at one end of the frame for appropriately integrating a precision torque transducer and to the other end of the frame a hand operated planetary gear box is mounted on the rails. The rails facilitate easy adjustment of torque driving gear with respect to the transducers, the flexible coupling and the rigid angle plate. The device under calibration can be appropriately mounted between this precision torque transducer and the drive side using flexible coupling for minimizing the bending effects and other axial misalignments. The required calibration torque can be slowly applied by the hand operated gear system and the applied torque can be monitored from the read-out of the precision torque transducer connected to a high resolution digital indicator. The precision torque transducer integrated to the system was separately calibrated on the primary torque standard machine and the uncertainty associated with the torque measured by this transducer was determined prior to its use on the machine.

Metrological characterization of the comparator machine was performed up to 1000 N.m using a reference transfer torque transducer having a capacity of 1000 N.m following a standard procedure. This reference torque transducer was independently calibrated against the primary standard machine to obtain its reference torque values and the uncertainty associated with the same. The reference torque transducer was mounted with the flexible coupling on the torque comparator machine. Several calibration torque series were applied in different mounting position following a recommended procedure, NPL-T-02 based on BS 7882, for calibrating the torque calibration machine. The experimental measurements procedures and the results obtained are described in the following section of the paper.

## 3. CALIBRATION METHOD

The 1kN.m torque reference transfer standard was calibrated on the primary standard machine using the procedure NPL T 01 based on BS7882 and DIN [7,8]. The transducer was mounted on the primary machine using the ETP couplings with suitable adapters and flanges and a high resolution digital indicator was connected to the transducer for taking the measurement. The indicator was switched on 30 minutes before starting the calibration for attaining proper stabilization and thermal equilibrium. The transducer was preloaded three times before staring the calibration and once at the every changed position. At zero degree position two series of calibration torques were applied in the increasing order and one series of calibration torque was applied in the decreasing order. Further, at 120 and 240 degree positions one series of calibration torque in increasing order and one series of calibration torque in decreasing order was applied to the transducer. From these measurements the relative deviation due to various components such as repeatability, reproducibility, reversibility, zero, etc. are determined and the overall uncertainty associated with measurement was estimated including the uncertainty associated with the application of torque by the primary machine. The same calibration procedure was adopted to evaluate the average torque values and the uncertainty associated with the torque measured by the precision torque transducer permanently integrated to the comparator machine.

After performing the calibration, having determined the reference values and the uncertainty associated with the 1kN.m torque reference transducer, the same transducer was mounted on the torque comparator machine for evaluating its performance. Proper alignment in mounting the transducer was ensured with a use of flexible coupling and suitable flanges as shown in fig1. After making the experimental arrangement, sufficient time was allowed for the system to attain proper stabilization and thermal equilibrium.

The reference torque transducer was calibrated in different mounting positions at $0^o$, $90^o$, $180^o$ and $270^o$ about the measurement axis. The calibration series are as follows; at $0^o$, two series of torque in increasing values & one series of calibration torque in decreasing order and at $90^o$, $180^o$ & $270^o$, one series of torque in increasing values in each position. The time interval between two successive application of torque is maintained as uniform as possible. A minimum stabilizing time of 30 seconds is given at each calibration torque step before recording the data. The residual indication of the torque transducer, at no load after each series of calibration, is noted after waiting for 30 seconds. The indication of the measuring device is tared to zero at the beginning of each measurement series. The resolution of the digital indicator (DK 38) is taken to be one increment of the last active number on the digital indicator, as the indication does not fluctuate by more than one increment under no applied torque.

## 4. RESULTS AND DISSCUSSION

From the measurement results obtained on the torque comparator machines, the deviations due to various uncertainty components are calculated following the standard procedure. Figure 2 depicts the relative repeatability and reproducibility deviations shown by the 1kN.m torque transducers, indicating a maximum repeatability deviation of 0.035% and reproducibility deviation of 0.055% in the entire range of measurement.

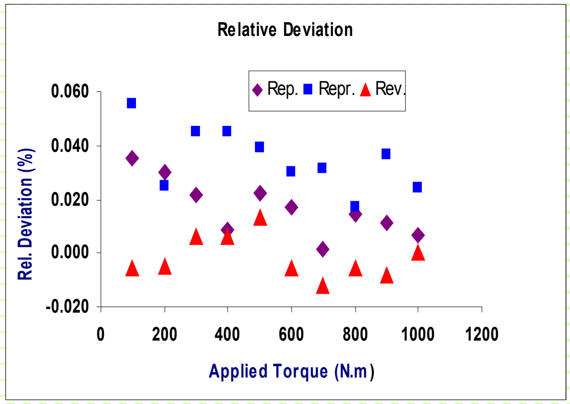


Figure 2 Relative deviation of Repeatability (Rep.) Reproducibility (Repr.) and Reversibility (Rev.) with the applied torque

The maximum relative deviations observed in the average values measured by the torque transducer with respect to the average reference values measured in primary standard machine is found to fall within the range of 0.1 %. The overall uncertainty in the torque measurement by the comparator machine was estimated considering all these components, repeatability, reproducibility, reversibility, etc., including the uncertainty associated with the reference torque values obtained from the primary torque machine. Figure 3 depicts the variation of the average deviation and the estimated uncertainty with the applied torque. It can be seen from the figure 3 that the maximum estimated overall uncertainty is found to be 0.06%. The estimated CMC of the machine is thus claimed on conservative basis as 0.1%.

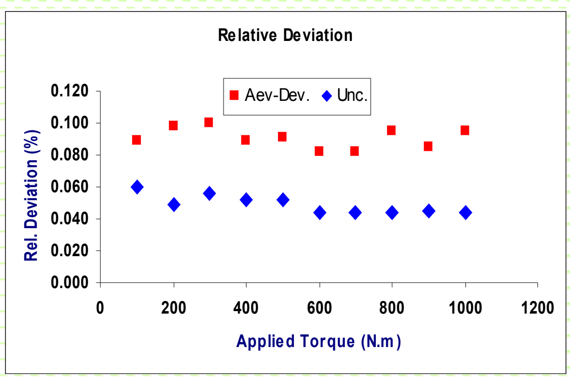


Figure 3 Relative deviation of average (Ave-Dev.) torque and the uncertainty (Unc.) in measurement with the applied torque

For establishing the degree of equivalence of this 1kN.m comparator machine, the En ratio was calculated with the claimed CMC of the machine which is found to be less than one. Table 1 shows the En ratio calculated at different applied torque steps.

Table 1 The uncertainty associated with each torque step and the estimated En ratio

| Applied Torque N.m | W % | En |
|---|---|---|
| 100 | 0.060 | 0.09 |
| 200 | 0.049 | 0.10 |
| 300 | 0.056 | 0.10 |
| 400 | 0.052 | 0.09 |
| 500 | 0.055 | 0.09 |
| 600 | 0.044 | 0.08 |
| 700 | 0.044 | 0.08 |
| 800 | 0.044 | 0.09 |
| 900 | 0.045 | 0.08 |
| 1000 | 0.044 | 0.09 |

## 5. CONCLUSION

A torque comparator machine of 1kNm developed at NPL (I) is described and is shown to possess a CMC of 0.1% (k = 2). It is expected that the torque comparator machine would provide a simple and economical solution to the user industries for calibration of torque transducers used as reference standard in torque wrench calibrators.

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