

THE COMMISSIONING OF THE FIRST UK NATIONAL STANDARD STATIC TORQUE CALIBRATION MACHINE

Andy Robinson

National Physical Laboratory, United Kingdom

ABSTRACT

At IMEKO - XV World Congress, the design of the first UK national torque calibration machine was described. Following the construction of the machine, this paper describes its commissioning, leading to the establishment of the first UK national static torque calibration standard. The novel vertical transducer orientation is made possible through several innovative sub-assemblies. This paper evaluates the performances of these critical sub-assemblies, and compares them against design specifications.

1. INTRODUCTION

The 2 kN·m machine, its design based on a vertically-mounted transducer, generates a symmetric pure torque via identical weightstacks located at either end of the lever beam (see figure 1). The machine can operate from 1 N·m to 2000 N·m, in clockwise and anti-clockwise modes, and can generate an asymmetric torque by simply using one weightstack. A second pair of smaller weightstacks gives the machine a secondary range from 1 N·m to 100 N·m. The lever beam can be mechanically locked and the reaction drive gearbox then used to generate a dynamic torque.

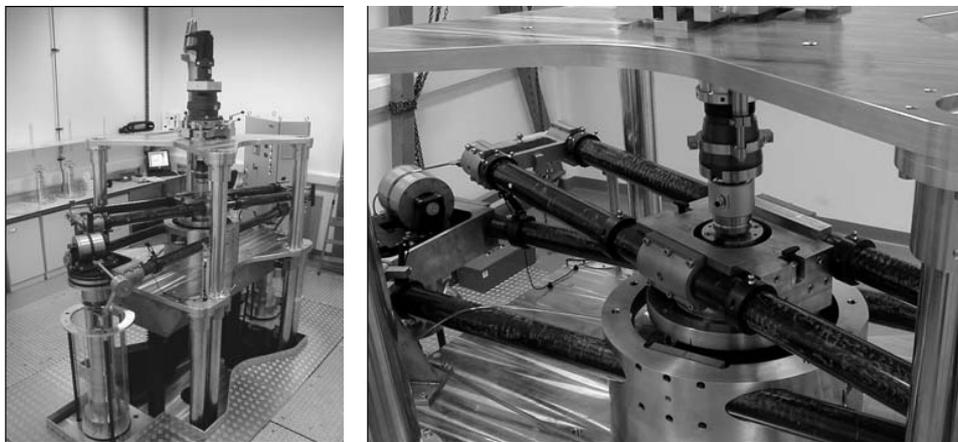


Figure 1: View of the NPL's static torque calibration machine

2. FORCE TRANSFER

The design of the machine, generating torque using a lever–deadweight system and accommodating a vertically mounted transducer, requires a change in the direction of the force. This is achieved via an arrangement of boron fibre tapes and a castor-pulley air bearing assembly that allows horizontal and vertical rotation. The boron tape transfers the force from the weightstack over a pulley to a 90°

coupling, connecting to a second tape passing around the radius of the lever beam (see figure 2). The horizontality of the tape as it connects to the lever beam is critical in ensuring that the full force is transferred. On using the machine, it soon became apparent that the titanium 90° connector and tape ends caused the tape to sag below the horizontal at the lower end of the torque range, as illustrated in figure 3.

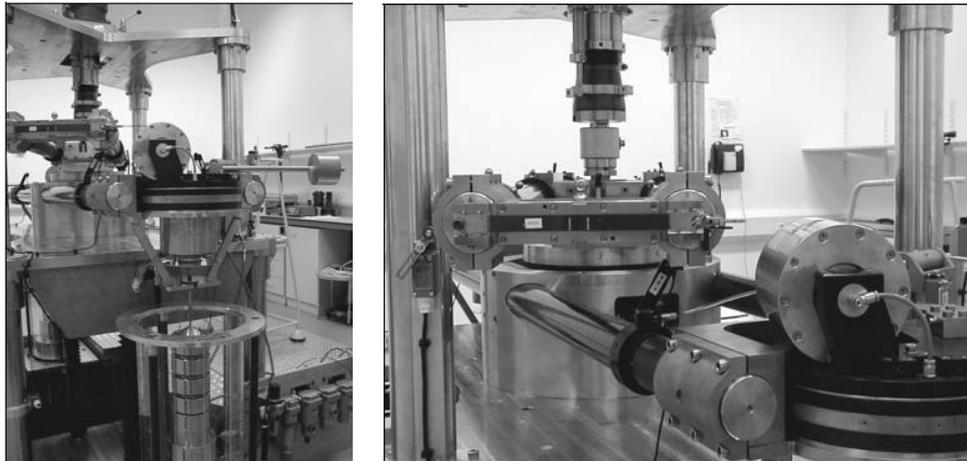


Figure 2: Views of the end of the machine showing the transfer of the force

The deviation was greatest at lower range of the small weightstack, although it also affected the zero position on the larger weightstack. To overcome the problem, the weight due to the connector needed to be removed or counterbalanced. In doing this, it was essential not to introduce friction into the system or to introduce any additional forces. The setup was modelled to provide an estimate of its contribution the uncertainty in the force. This is also shown in figure 3.

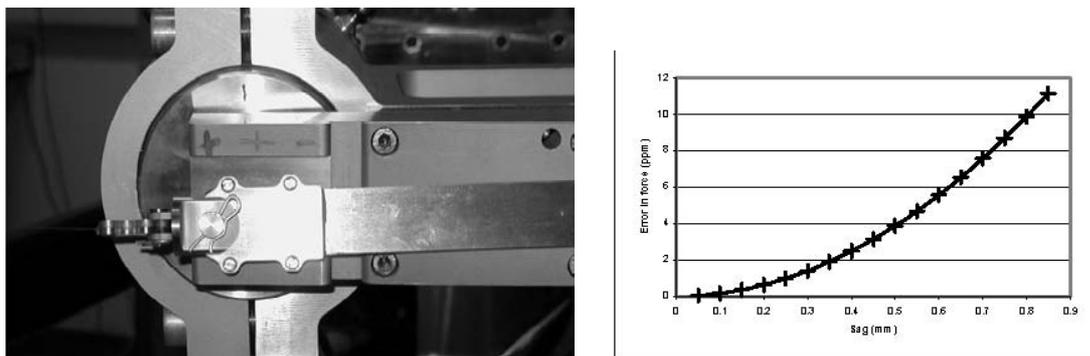


Figure 3: Deviation of tape, error in force caused by tape sag

From this model, the maximum allowable deviation was calculated and a target weight for the 90° connection was derived. The small weightstacks use a thinner boron fibre tape of 5 mm width. For this tape, a preformed 90° twist was put into the tape to eliminate the need for any sort of connector. The larger weightstacks use a wider tape of 20 mm width. Unfortunately the width of the tape prevented a twist being used because of a limit in the length over which the twist had to take place. An alternative was developed for the 20 mm tape whereby a small incision at the end of the two tape

lengths allowed them to be intersected perpendicular to each other. Bonding short lengths of carbon angle onto the area held the intersection length together.

In measuring the deviation in the tapes a second problem was discovered. As larger masses were applied it became apparent that the reaction beams were deflecting. The implication of this is that the height of the pulley over which the tape passes would change relative to the centre line of the tape passing around the radius. The setup is shown in figure 4. The effect is that the force would be introduced into the lever beam at an angle, with only the resolved horizontal component being transferred.



Figure 4. Force transfer, measuring deflection under load, measuring the initial alignment

The problem was quantified by measuring the change in height of the pulley with a plunger gauge mounted on the lever beam.

The effect of mass of the castor pulley assembly - approximately 130 kg - on the end of the reaction beams now needed to be reconsidered. The initial alignment of the top of the pulley with the centre line of the radius was measured, as any initial misalignment would be added to the deflection under load due to the weightstack. To make this measurement, the pulley and lever beam were centralised as shown in figure 4.

A cathetometer was used to measure the difference in height between the top of the pulley and the top of the boron fibre tape passing around the radius. The pulley was then removed and the distance between the top and bottom of the tape was measured to determine the centreline of the force passing around the radius. The relative height of the pulley, plus half the thickness of the boron fibre tape was compared to the relative height of the centreline of the force passing around the radius.

Table 1: Summary of measurements of the reaction beam deflection

	End A [mm]	End B [mm]
Deflection at rest	-0.48	-0.95
Additional deflection under load (1 kN)	-0.95	-1.31
Total deflection	-1.43	-2.26

A simple calculation shows that a misalignment of 2.3 mm will generate an error of 1.2×10^{-5} in the force. To keep the error below 5×10^{-7} the misalignment must be kept to within 0.5 mm. F.E. analysis had predicted a deflection of 0.9 mm [2].

4. COUPLINGS

A system of couplings and adapters enabling the machine to accommodate the widest range of torque transducers has been designed. The design, based around a hydraulic friction joint, is symmetrical and minimises the number of couplings and adapters. The system includes a flexible coupling containing a double disc pack, compensating for radial, angular, and axial misalignment. The coupling can be located on either side of the transducer, or removed entirely. The head of the machine can be moved to give up to 1 m of working space. The scheme is illustrated in figure 7, which shows the flexible coupling located in its upper position.

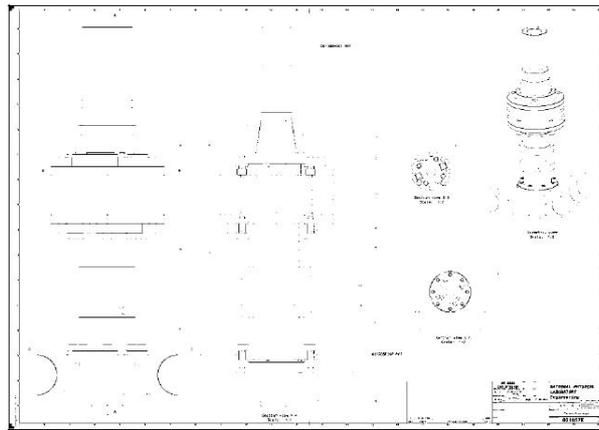


Figure 7: Design scheme for torque machine couplings

5. UNCERTAINTY

For the purposes of this paper the uncertainty is defined as that of the torque generated around the central axis of the machine. The target uncertainty for the machine during the design stage was 1×10^{-5} for a $k = 2$ coverage factor. The major contributions to the uncertainty are discussed below.

Force: The uncertainty of the force generated from the weightstacks is calculated to be 5.3×10^{-6} for a $k = 2$ coverage factor for the range 10 N·m to 2000 N·m which uses stainless steel weights [3]. For the range 1 N·m to 10 N·m aluminium weights used for machining purposes, increase the force uncertainty to 9.1×10^{-6} for a $k = 2$ coverage factor because of buoyancy effects.

Alignment of force: Using the screw jacks described the deflection of the lever beams under load can be limited to 0.1 mm. Using the screw jacks to align the system to within 0.4 mm under zero load, gives a total vertical misalignment of 0.5 mm. A simple calculation shows that the maximum uncertainty will be 5.4×10^{-6} . The contribution due to the deviation of the boron tape is 3.6×10^{-7} . The horizontal alignment should be negligible as the tape is left to find its own position across the surface of the pulley. In addition the radius on the end of the lever beam ensures that the tape always leaves the radius perpendicularly to a line passing through the central pivot point while maintaining the overall distance. The lever beam is also driven back to same position before each measurement to ensure the tape leaves the same portion of the radius. Consequently no contribution is included for horizontal misalignment.

Length: The length of the lever beam has been measured on a CMM with an uncertainty of 3.3×10^{-6} . The beam length including half the thickness of the boron fibre tape gives a nominal overall length of 1.000 000 m. The boron fibre experiences no deformation under the loads involved and so maintains its thickness. The carbon fibre lever beams have a coefficient of thermal expansion of $3 \times 10^{-7} \text{ } ^\circ\text{C}^{-1}$. To ensure the constancy of the length, a series of tooling balls mounted on the lever beam are measured monthly with a length comparator, which compares the distances to a reference standard. The comparator has an expanded uncertainty of 2.0×10^{-6} and results over an 8 month period show that the length has not changed by more than 3×10^{-6} m over a one metre length. This combines to give an expanded uncertainty for the length of lever beam of 5.3×10^{-6} .

Friction: Friction is minimised through the use of a central air bearing on which the lever beam sits. Air bearings also allow the pulleys to rotate freely while a castor bearing enables rotation around the axis of the weightstack. Turbine torque has been experimentally determined at 2.2×10^{-4} N·m. for a constant pressure in the central air bearing. As the air pressure is kept constant this error can be eliminated. The level of balance of the bearing is within 3.56×10^{-6} N·m. At the very lowest end of the torque range this contributes an uncertainty of 1.78×10^{-6} .

Overall: The contributions combine to give an overall expanded uncertainty ($k = 2$) of 1.03×10^{-5} for the range 10 N·m to 2000 N·m.

CONCLUSIONS

At the time of writing, several of the redesigns described in this paper are nearing completion. The work described in this paper has analysed the performance of many critical sub assemblies and where necessary modifications will allow the machine to meet its target uncertainty. An intercomparison is scheduled with PTB, which will help to demonstrate the capability of the machine. In 2005 the machine will take part in a 2 kN·m CIPM comparison.

ACKNOWLEDGEMENTS

The author would like to thank Mr P Bird of NPL's Engineering Services, Dr G Sims and Mr R Shaw for their involvement with the reaction beams and boron fibre tapes.

REFERENCES

- [1] Davis F A, The 1st UK National standard static torque calibration machine – new design concepts lead the way, Measurement Science Conference in Anaheim, USA, 2002.
- [2] Marks L, Greensmith B, Sangster R, & Davis F A, Design of the Lever and Reaction Beams for the UK Torque Calibration Machine, IMEKO XVI World Congress, Vienna, Austria, Sept 2000.
- [3] Knott A J, The accuracy of the NPL 1.2 MN deadweight force standard machine, Proceedings of the 14th IMEKO TC3 conference, Warsaw, Poland, Sept 1995.

Address of the author:

Force, Torque, and Hardness Standards, G7-A12, National Physical Laboratory, Hampton Road, Teddington, Middlesex, United Kingdom, TW11 0LW. andy.robinson@npl.co.