BIPM Capacity Building & Knowledge Transfer Programme

2025 BIPM - TÜBİTAK UME Project Placement

REPORT

Project Name	Enhancement and expertise exchange in torque metrology
Description	This project focuses on developing practical skills and technical expertise in torque metrology, learning and applying standardized calibration procedures, and improving torque measurement services to ensure traceability and support the national metrology framework.
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Motivation & Introduction

Malaysia's economic aspirations and global standing are closely tied to the quality of its industrial output. At the core of this quality assurance is the National Metrology Institute of Malaysia (NMIM), which provides the nation's industries with the highest level of measurement accuracy and traceability, ensuring Malaysia's competitiveness in the global market. Precision is particularly critical in key sectors such as the automotive industry, oil and gas, aerospace, precision manufacturing, and construction, where correct torque specifications safeguard safety, efficiency, and product performance. For example, the reliability of a car's engine or an aircraft's wing depends on fasteners being tightened to exact and verifiable torque values. From flight safety to automotive performance, precise torque measurement serves as the silent guardian of reliability, and any deviation can result in catastrophic failure, making NMIM's role in this area indispensable.

Recognizing this, NMIM is undertaking vital upgrades to its equipment and facilities, particularly its torque metrology laboratory, to provide more sophisticated and reliable calibration services. These improvements will enable the institute to deliver services with a level of confidence that meets and exceeds international benchmarks. This is not simply an operational enhancement, but a strategic step that allows Malaysian industries to comply with international standards. By establishing a credible and globally recognized calibration system, NMIM strengthens the competitiveness of local businesses, builds trust with international partners, and reinforces Malaysia's reputation for manufacturing excellence.

However, NMIM continues to face challenges in torque metrology where currently Malaysia lacks Calibration and Measurement Capabilities (CMC) in this field, as efforts have been largely focused on ensuring traceability rather than building full calibration services. This project directly addresses that gap by proposing strategies to improve technical skills of personnel and advance the laboratory's torque measurement facilities. By doing so, NMIM can boost operational efficiency, encourage innovation, and align with international best practices. The vision is to position NMIM as one of the leading national metrology institutes in the Asia-Pacific region, supporting Malaysia's industrialization and global competitiveness.

Malaysia's economic future depends heavily on the ability of its manufacturing sector to meet global quality standards. Advancing national capabilities in torque metrology is therefore essential, especially for industries such as automotive and aerospace. Guided by this vision, the project is structured around three core objectives. The first objective is to acquire expertise by gaining advanced technical skills and practical knowledge in torque metrology through learning from international experts, thereby establishing a strong foundation for future national capability. The second objective is to develop and implement standardized torque calibration methods and procedures, ensuring all measurements are accurate, consistent, and aligned with international benchmarks. The third objective is to expand torque calibration and measurement services, creating a robust and traceable framework that strengthens Malaysia's national metrology infrastructure and supports global competitiveness. By pursuing these objectives, this initiative aims to elevate Malaysia's standing in torque metrology, foster industrial excellence, and contribute directly to the nation's long-term economic growth.

Research

Traceability in torque measurement refers to the unbroken chain of comparisons that link an industrial torque tool to the International System of Units (SI). At the top level, the torque unit (Newton metre) is realized by national metrology institutes using primary torque standard machines, where torque is derived directly from the SI base units of mass, length, and time. These primary standards are then used to calibrate secondary standards such as torque transfer wrenches or high-precision torque transducers which act as portable reference devices. The transfer standards in turn are used to calibrate working standards like torque testers or reference torque wrenches, which finally verify and adjust the torque tools used in industry. Through this hierarchy, every torque value applied in a production or testing environment can be traced back step by step to the SI unit, ensuring international consistency, reliability, and confidence in measurement results. The traceability chart is illustrated in Figure 1.

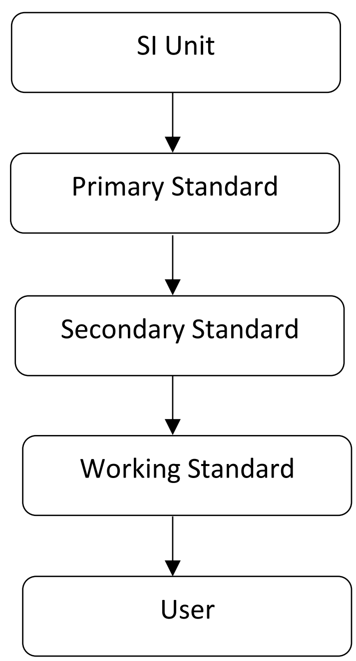

Figure 1 Traceability Chart

Calibration of Transfer Torque Wrench

Transfer torque wrenches which are used as transfer standards for the calibration of torque wrench calibration devices. Transfer torque wrenches are special torque measuring devices whose design enables the torque to be introduced via a lever arm (comparable to the design of torque wrenches) and in accordance with the requirement measurement uncertainty are insensitive to superimposed transverse forces and bending moments.

Calibration Process

I calibrated a 200 N.m transfer torque wrench using a Torque Calibration Machine(TCM), 1kN.m where this machine is designed to apply precise torque through a motorized system usually powered by an electric motor. I worked with the TCM-1kN.m model for my practical training in transfer torque wrench. In Figure 2, it shows the calibration setup by using TCM with transfer torque wrench and a reference torque transducer.

Figure 2 Calibration of Transfer Torque Wrench with Reference Torque Transducer

A reference torque transducer is the high accuracy torque transducer that serves as the reference standard in a torque calibration system for example in a TCM. The sensor being used is Static Torque Transducer, TN 1000 N.m with serial number is 40240012. It is specifically designed to provide stable, repeatable torque readings and high accurate that form the basis of traceability to the SI units. In the calibration setup, the reference torque transducer is mounted in line with the applied torque and generates an electrical signal proportional to the applied load. During the calibration, the applied torque is measured simultaneously with the reference torque transducer and the test item which is transfer torque wrench. The reference torque transducer with the amplifier provides the reference torque value against which the test item is compared such as transfer torque wrench which to determine the accuracy and establish the calibration results.

The calibration measurements were recorded using an automated data acquisition system. The reference torque values which acquire the electrical signal and convert it into the reference torque value were obtained from the MGCplus CP42, which was connected to the reference torque transducer, while the indication values of the test item were acquired simultaneously via the MGCplus CP32. Both instruments are synchronized and the data are automatically captured with time stamps. This ensures that the reference and test item values are directly comparable for each applied torque step. The procedure follows the requirements of DKD-R 3-7, which standardizes the measurement series, time intervals, and data recording to guarantee repeatability and traceability. Figure 3 shows the amplifier of MGCplus CP42 and MGCplus CP32 and the data acquisition system in the laptop.

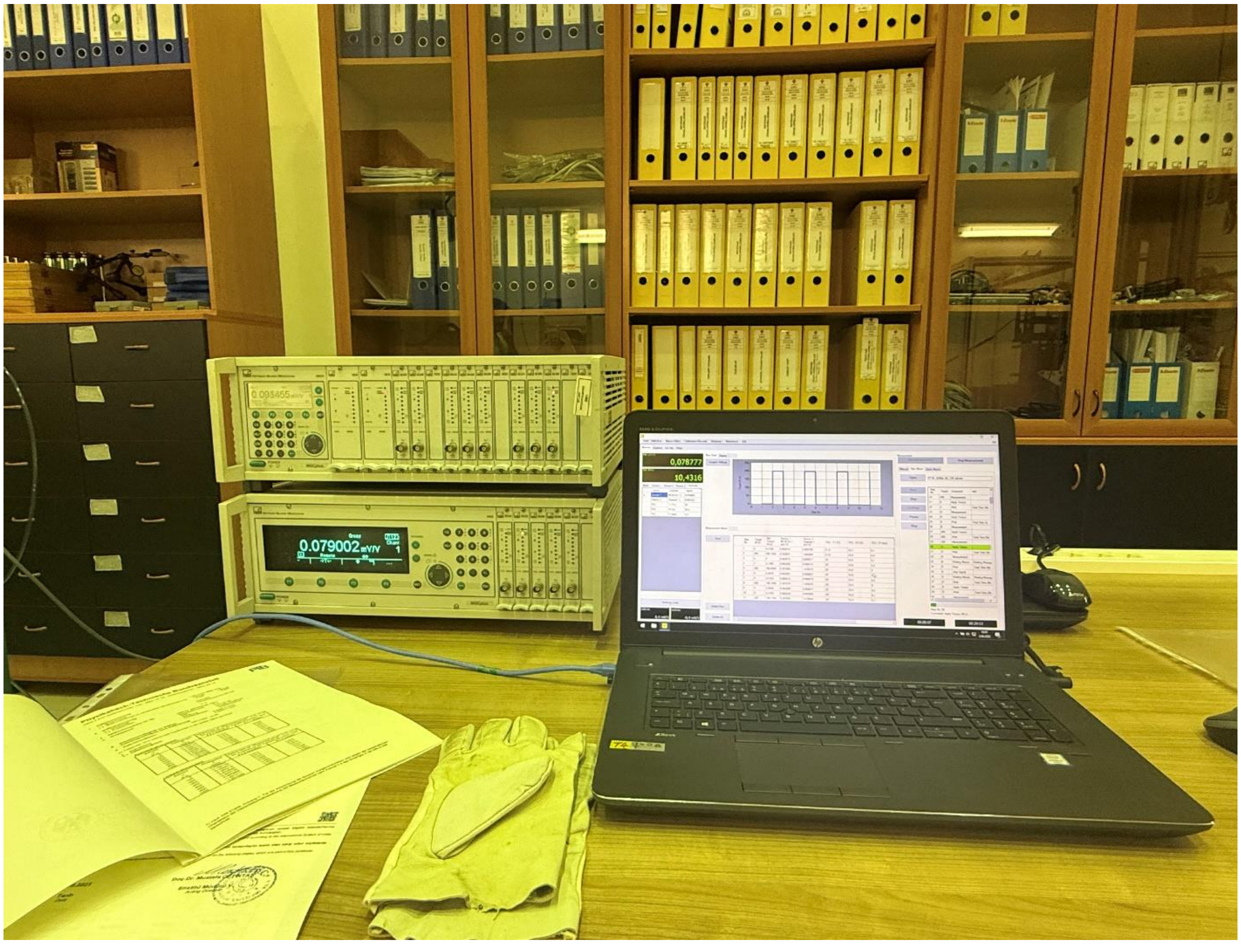

Figure 3 Data Acquisition System

Calibration Procedure of Transfer Torque Wrench

The procedures and requirements for the calibration of the torque transfer wrench is carried out in accordance with DKD-R 3-7 – Static calibration of indicating torque wrenches. The calibration is carried out separately for clockwise and counterclockwise torque. Figure 4 shows an example of calibrating a torque wrench for clockwise torque with five equidistant torque levels.

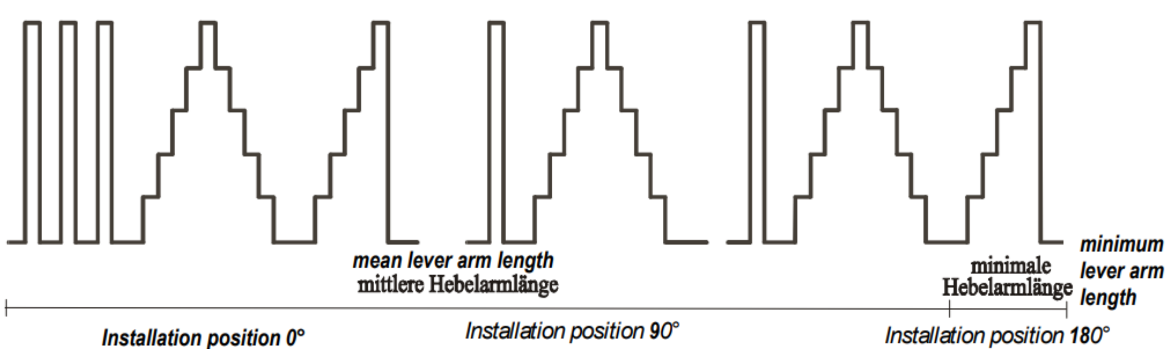

Figure 4 Preloading and Measurement Series for classes 0.05 to 0.5

a) Preload

The first measurement is the transfer torque wrench was subjected to preloading three times in the direction to be calibrated and once for each change in installation position of 90° and 180° with the final value of the measuring range ME to be calibrated. Transfer torque wrench was inspected free from physical damage and allowed to stabilize under laboratory environmental conditions 21.02° and 53.03%.

b) Measurement Series

After preloading, the calibration started with a series of torque applications in increasing steps at 0° with the same installation at 2 increasing and 1 decreasing. Next, for the other installation positions, the number of measurement series is 2 increasing and 2 decreasing. Meanwhile, for the minimum lever arm length is 1 increasing and 1 decreasing. In this calibration, I selected the measurement series based on the class of my transducer which is classified as 0.05. According to DKD-R 3-7, the classes 0.05 to 0.2 should be utilized (distributed appropriately across the measuring range) in increments of 10%, 20%, 30%, 40%, 50%, 60%, 80% and 100% of M_E and the arm length of the transfer torque wrench was selected according to the torque capacity.

Model Equation for Calibration Result

$$\boldsymbol{M = M_k \cdot \prod_{i=1}^{n}(1 - \delta M_i)}$$

a) For uncorrelated input variables, the relative standard measurement uncertainty, $\boldsymbol{w}$ to the torque M is given by the uncertainties propagation law for an introduces calibration torque $\boldsymbol{M_k}$.

$w(M_k) = \sqrt{w^2{}_{KE}(M_{K)} + \sum_{i=1}^{n} w^2\,(\delta M_i)}$ with $n = 7$

b) The relative expanded measurement uncertainty, $\boldsymbol{W\,(M_k)}$ of the torque value of the calibration item is calculated according to

$W(M_k) = k\,.w(M_k)$

c) For unnamed scale and application a linear compensation function, $\boldsymbol{W'(M_k)}$

$W'(M_k) = |f_a|(M_k) + k\,.w(M_k)\,,\, k = 2$

Results and Discussion

The results in Figure 5 illustrate the individual calibration outcomes for both clockwise and anticlockwise directions at different angular positions (0°, 90°, and 180°). The measurements were expressed as deviations referring to the full scale torque.

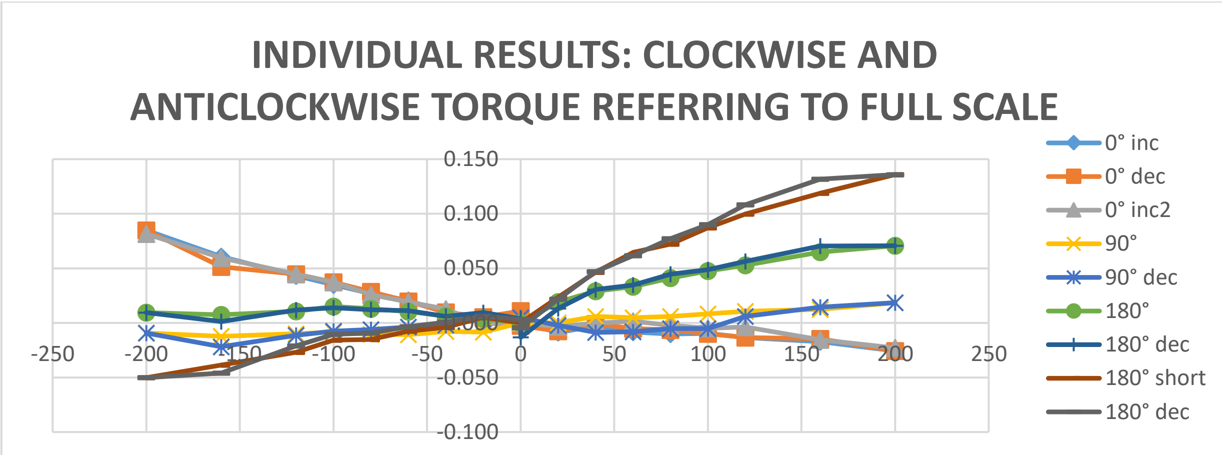

Figure 5 Individual results for Clockwise and Anticlockwise Torque Referring to Full Scale

The measurement results exhibit good linearity and symmetrical behaviour between both torque directions. The deviations remain within approximately ±0.15% of the full scale, indicating stable transducer performance over the measurement range. Minor differences observed between the increasing and decreasing series are attributed to the inherent mechanical hysteresis of the torque wrench and the elastic characteristics of the loading system. The results demonstrate good reproducibility and reversibility, confirming compliance with the requirements defined in DKD-R 3-7 which is static calibration of indicating torque devices. The small changes between different angular positions indicate the influence of mounting which is included in the uncertainty budget. Overall, the stable results show that the calculated expanded uncertainty correctly represents the performance of the transfer torque wrench and ensures reliable traceability to the national torque standard.

Calibration of Torque Transducer

Torque Transducer is a precision device used to measure the torque applied to a rotating or stationary system. In simple terms, it converts the mechanical quantity of torque into an electrical signal (mV/V) that can be recorded, displayed, or used for further analysis.

Calibration Process

The torque transducer of capacity 50 N.m was calibrated by using a deadweight system machine which is the 50 N.m Primary Torque Calibration Machine. It is mainly used for calibration of torque measuring devices (such as torque transfer standards, torque transducer, e.g.) with high accuracy and calibration of transducers with capacity 10 N.m, 20 N.m and 50 N.m torque transducer. Figure 6 shows the setup of calibration of process system of torque transducer with the dead weights system.

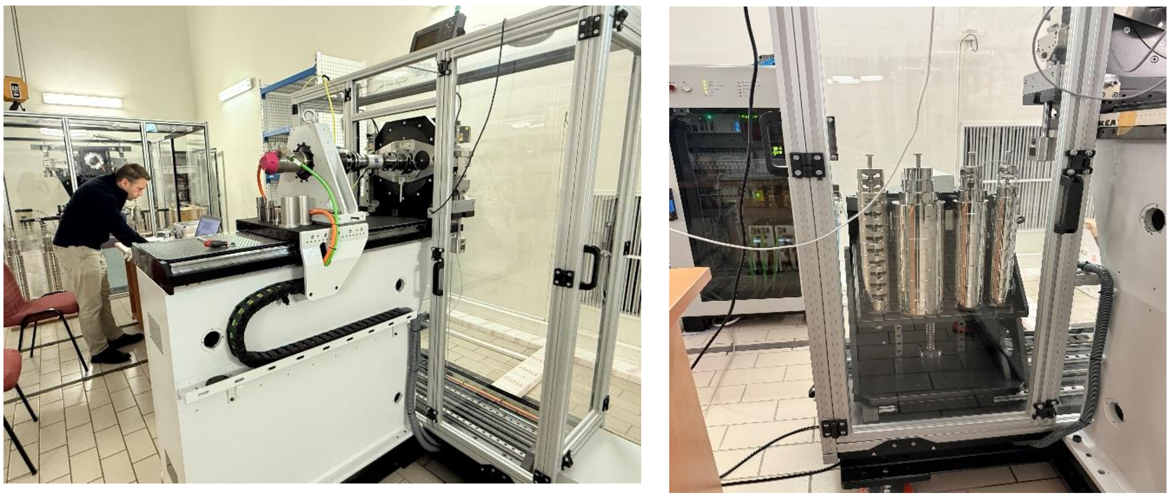

Figure 6 Calibration system of torque transducer with deadweight system

The machine can provide calibration according to the national and international torque calibration standards the measurement of torque is performed by a lever arm and dead weights system. The working range is from 0.2 N.m – 50 N.m. It has 3 set of mass that are traceable to the mass lab in Ume. The system applies torque by means of deadweights acting on a known lever arm length ensuring traceability directly to SI units (mass × length × gravity). A motorized drive system is used to apply torque smoothly and automatically in both clockwise and counterclockwise directions which eliminates operator influence and improves repeatability. This signal is then acquired by a data acquisition system which is HBM DMP40 for reference. The automation ensures that torque points, time intervals, and measurement series are standardized according to DIN 51309 allowing for precise, repeatable, and traceable torque calibration. Figure 7 shows the data collected by using automation that auto captured and the HBM DMP40 is connected with the high accuracy of torque transducer.

Figure 7 Data Acquisition System

Calibration Procedure of Torque Transducer

The procedures and requirements for the calibration of the torque transducer are carried out in accordance with DIN 51309 – Calibration of static torque measuring devices. The calibration is performed separately for clockwise and counterclockwise torque. Figure 8 illustrates version of the calibration procedure for class 0.05 and 0.1 at different mounting positions.

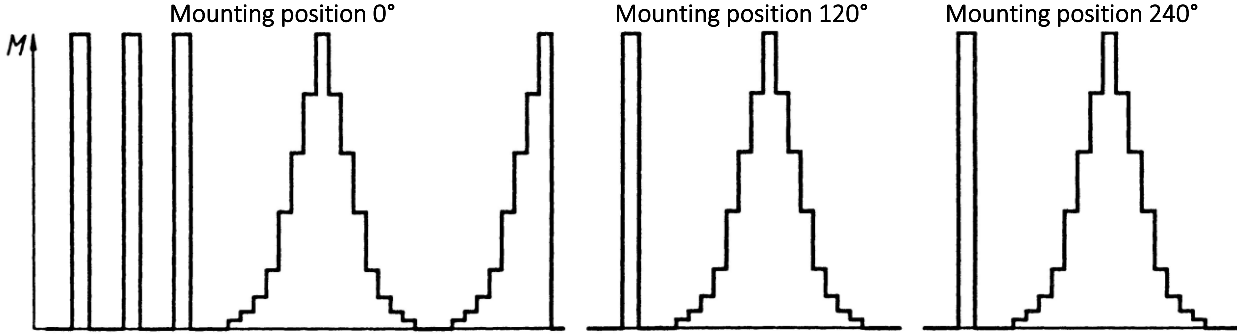

Figure 8 Preloading and Measurement Series for classes 0.05 to 0.5

a) Preload
After mounting the torque transducer in the calibration machine, it shall be preloaded three times and after each change of mounting position once in the calibration direction using the upper limit of the measurement range to be calibrated, M_E.

b) Measurement Series
The calibration of torque transducer is initially carried out in the same mounting position of the torque transducer with an increasing and decreasing series; subsequently the calibration is repeated for the classes 0.05 to 0.5 with an increasing series. After that, the mounting position is changed and a series of increasing and decreasing measurements are taken. During my practical session, the minimum number of torque steps (in addition to zero) for each direction are classes 0.05 to 0.1 which the number of sequences is 8 in steps of 10%, 20%, 30%, 40%, 50%, 60%, 80% and 100% of M_E .

Evaluation of the torque measuring device

According to DIN 51309, there are two different cases for evaluating the torque measuring device which is,

Case I: The calibration is performed using only the increasing torque series. The measurement values are taken during the application of torque in ascending steps, corrected to zero, and averaged across the mounting positions of the transducer. The evaluation of calibration results is carried out by applying a linear or cubic fitting function through the origin to determine the interpolation deviation. In this case, reversibility (hysteresis) is not included in either the classification of the transducer or in the uncertainty budget. Case I therefore provides a simplified calibration procedure that is less time-consuming but does not fully reflect the hysteresis behavior of the device. The calibration result $Y(M_K)$ is calculated for each calibration torque according to Equation below as a mean value for the different mounting positions determined from the increasing series of displayed values corrected for the zero value.

$$Y(M_K) = \frac{1}{n}\sum_{j=1}^{n}(I_j(M_K) - I_{0,j})$$

$$= \frac{1}{n}\sum_{j=1}^{n} X_j(M_K)$$

Case II: The calibration is carried out using both the increasing and decreasing torque series. The measurement values are taken during both loading and unloading steps, corrected to zero, and averaged across the mounting positions. The evaluation of calibration results $Y(M_K)$ is performed by applying a linear fitting function through the origin to the mean values obtained from both directions. Unlike Case I, reversibility (hysteresis) is included in the classification of the torque transducer and contributes to the uncertainty budget. Case II therefore provides a more comprehensive and realistic assessment of the performance of the torque transducer.

$$Y_h(M_K) = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{(I_j(M_K)+I'_j(M_K)}{2} - I_{0,j}\right)$$

$$= \frac{1}{n}\sum_{j=1}^{n}\left(\frac{X_j(M_K) + X'_j(M_K)}{2}\right)$$

In both cases, *n* is the number of increasing series for different mounting positions.

Measurement uncertainty budget

For uncorrelated input quantities, the relative standard measurement uncertainty is given by
For case I is

$$w\,(M_K) = \sqrt{w^2{}_{KE}(M_K) + 2.w^2{}_r(M_K) + w^2{}_b(M_K) + w^2{}_{b'}(M_K) + w^2{}_0(M_E) + w^2{}_{fa}(M_K)}$$

Meanwhile, for case II

$$w\,(M_K) = \sqrt{w^2{}_{KE}(M_K) + 2.w^2{}_r(M_K) + w^2{}_b(M_K) + w^2{}_{b'}(M_K) + w^2{}_0(M_E)}$$

Calibration of Hand Torque Tools

Hand torque tools are mechanical devices used to apply a controlled static torque to threaded fasteners, ensuring that joints are tightened to the required specification. These tools, which include indicating torque wrenches, setting torque wrenches, and torque screwdrivers, play a vital role in sectors where joint integrity is critical, such as automotive, aerospace, and heavy industry.

Calibration process

Hand torque tools can be broadly divided into two main types which is Type I: indicating torque tools meanwhile Type II: Setting torque tools. Indicating torque tools provide a direct reading of the applied torque through a mechanical scale, dial, or digital display, and are primarily used for checking or monitoring the torque value during fastening. In contrast, setting torque tools, often known as preset or click-type wrenches, are designed to apply a specific torque value without the need for continuous observation; once the preset torque is reached, the tool provides a signal such as a click or slip mechanism to prevent over-tightening. I performed the calibration on a Type II, Class A – Setting Torque Tools with a capacity 40 N.m. Figure 9 shows the hand torque tools and the torque calibration machine with capacity 100 N.m with reference transducer of 50 N.m.

Figure 9 Hand Torque Tools and The Torque Calibration Machine

Calibration Procedure of Hand Torque Tools

For the calibration of hand torque tools, the reference guidelines that I used is ISO 6789:2017 which consists of two parts.
ISO 6789-1 : 2017 – Requirements and methods for design conformance testing and quality conformance testing: minimum requirements for declaration of conformance.
ISO 6789-2: 2017 – Requirements for calibration and determination of measurement uncertainty
Before start the measurement, I have learned how to determine the calibration point according to the ISO 6789:2017. The wrench is a tool designed to be adjusted which has a scale and display to assist adjustment. After mounting the torque wrench on the torque calibration machine, I started my calibration with

a) **Preload**
After mounting the torque wrench in the calibration machine, it shall be preloaded five times at maximum torque value of the measurement range. The duration for measurement taken is not less than 30 seconds.

b) **Repeatability**
The repeatability of measurements in each calibration points for five times.

c) **Reproducibility**
The reproducibility of measurements in each calibration points for five times

d) **Geometric effect of output drive**
According to the standard, the tools with a square drive, four mounting positions are preferred meanwhile for the tools that has hexagon drive, the six sets of measurement need to be taken.

e) **Loading point**
Ten measurements are then recorded for each of two positions with changed force loading point at the lower limit value of the measurement range. The two force loading points was on 10mm on either side of the centre of the hand hold position or the marked loading point.

Determination of the relative standard measurement uncertainty, $\boldsymbol{w}$

The relative standard measurement uncertainty, w, assigned to the torque tool at each calibration point is given for uncorrelated input quantities.

For indicating torque tools:

$$w = \sqrt{\left(\frac{W_{md}}{2}\right)^2 + 2.w_r^2 + w_{rep}^2 + w_{od}^2 + w_{int}^2 + w_l^2 + w_{re}^2}$$

For setting torque tools:

$$w = \sqrt{\left(\frac{W_{md}}{2}\right)^2 + w_r^2 + w_{rep}^2 + w_{od}^2 + w_{int}^2 + w_l^2 + w_{re}^2}$$

Determination of the relative expanded measurement uncertainty, $\boldsymbol{W}$

The relative expanded measurement uncertainty, W, of the calibration result for the torque tool is calculated from the standard measurement uncertainty by multiplication by the coverage factor, k which the default value of k = 2.

$$W = k \times w$$

Determination of the relative measurement uncertainty interval, $\boldsymbol{W'}$

The relative uncertainty interval, W' of a calibration including all systematic and random components shall be calculated using the formula below

$$W' = |\overline{a_s}| + W + |b_{ep}|$$

Conclusions and Future Work

The training program has successfully achieved its primary objectives of enhancing technical capabilities and practical expertise in torque metrology. Through both theoretical and hands on sessions guided by experts, I have gained a comprehensive understanding of torque calibration principles, traceability, and uncertainty evaluation in accordance with international standards such as DKD-R 3-7, DIN 51309 and ISO 6789.

During the training, I performed calibration activities on various torque instruments, including hand torque tools, transfer torque wrenches and torque transducers. These practical exercises provided valuable insights into preloading procedures, measurement series execution, data recording, and uncertainty analysis. They also deepened my understanding of the mechanical characteristics and performance behavior of different torque measuring devices.

The skills and knowledge acquired will be applied to develop and implement standardized torque calibration procedures within my home laboratory. These efforts aim to enhance the existing torque calibration services, improve measurement reliability, and establish a robust traceability chain within the national metrology framework. The outcomes of this training will directly contribute to strengthening torque metrology capabilities and supporting the long-term development of the national measurement infrastructure.

In preparation for achieving accreditation in the torque calibration scope, it is essential to procure appropriate equipment and reference standards, including torque calibration machines and high accuracy reference transducers. These investments will enable the laboratory to perform precise, traceable, and repeatable calibrations in compliance with ISO/IEC 17025 requirements. In parallel, the implementation of a comprehensive uncertainty evaluation system and quality documentation will ensure the technical credibility of the laboratory’s services.

Furthermore, the knowledge and methodologies gained from this program will be shared with colleagues to promote internal capacity building and foster a culture of continuous technical improvement. Collaboration with international metrology institutes will also be sought to maintain alignment with emerging best practices in torque measurement.

In conclusion, conducting a detailed assessment of the laboratory’s resources and capabilities prior to the training would have further optimized the learning focus. Nevertheless, the training outcomes are highly valuable and will play a vital role in guiding the development, equipment upgrading, and accreditation preparation for torque metrology services in the National Metrology Institute.

Acknowledgements

I would like to express my sincere gratitude to the Bureau International des Poids et Mesures (BIPM) for providing this valuable opportunity to participate in the torque metrology training program. This initiative has significantly contributed to the development of my professional knowledge and technical capability, while also supporting the enhancement of torque measurement practices in my home institution.

My heartfelt appreciation also goes to Ms. Müge for her excellent coordination, management, and continuous support throughout the training. Her dedication in organizing the program, managing participants’ needs, and arranging transportation from TÜBİTAK UME to the airport ensured the smooth operation and successful completion of all activities. Her professionalism and attention to detail were truly commendable.

I would like to extend my deepest appreciation to Mr. Çetin and Mr. Semih for their exceptional mentorship, technical guidance, and willingness to share their extensive expertise in torque metrology. Their thorough explanations, practical demonstrations, and insightful discussions on various calibration techniques and technical issues have greatly enriched my understanding. They provided not only theoretical knowledge but also valuable hands-on experience, which has enhanced my ability to apply standardized methods in torque calibration and uncertainty evaluation.

Their patience, professionalism, and commitment to teaching were instrumental in helping me overcome technical challenges and develop confidence in performing torque calibration tasks independently. I am deeply thankful for their continuous encouragement, constructive feedback, and dedication to ensuring each participant gained meaningful learning outcomes from this program.