BIPM Capacity Building & Knowledge Transfer Program

2024 BIPM - TÜBİTAK UME Project Placement

REPORT

Project Name	Enhance skill development and improve the Torque-measuring laboratory capability of the Ethiopian Metrology Institute.
Description	This Project aims to build the capacity the system required to carry out calibration of torque measuring devices using torque standard machines to make a suitable measurement set-up, identify standards and equipment necessary for this purpose, to draft the specification of the standards, to carry out measurements, prepare calibration procedures and to be perform accredited torque calibration
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Motivation

The Ethiopian Metrology Institute (EMI) plays a crucial role in ensuring the accuracy and reliability of measurements across various sectors, including industry, trade, and scientific research. As Ethiopia continues to develop its economy and integrate into the global market, the demand for precise measurement standards becomes increasingly vital. Torque measurement is particularly significant in industries such as manufacturing, automotive, and construction, where accurate torque specifications are essential for safety and performance.

Enhancing skill development within the EMI's workforce is paramount to achieving these goals. A well-trained staff equipped with advanced skills in torque measurement techniques will not only improve the laboratory's operational capabilities but also foster innovation and adaptability in an ever-evolving technological landscape. Furthermore, investing in skill development aligns with national objectives to build a competent workforce capable of supporting Ethiopia's industrialization efforts.

Improving the torque-measuring laboratory's capabilities will enable EMI to provide more reliable calibration services, which are essential for maintaining quality control in production processes. This enhancement will also facilitate compliance with international standards, thereby boosting Ethiopia's competitiveness on a global scale. By focusing on both skill development and laboratory capability improvement, the EMI can position itself as a leader in metrology within the region.

Introduction

The importance of metrology cannot be overstated; it is foundational to scientific inquiry, industrial processes, and regulatory compliance. In Ethiopia, where economic growth is closely tied to advancements in technology and industry, the role of institutions like the Ethiopian Metrology Institute becomes even more critical. The EMI serves as the national authority responsible for establishing measurement standards that ensure accuracy across various applications.

Torque measurement is a specialized field within metrology that requires precision instruments and skilled personnel. The ability to accurately measure torque is essential for numerous applications ranging from mechanical assembly to quality assurance in manufacturing processes. However, many laboratories face challenges related to outdated equipment, insufficient training programs, and a lack of resources dedicated to skill enhancement.

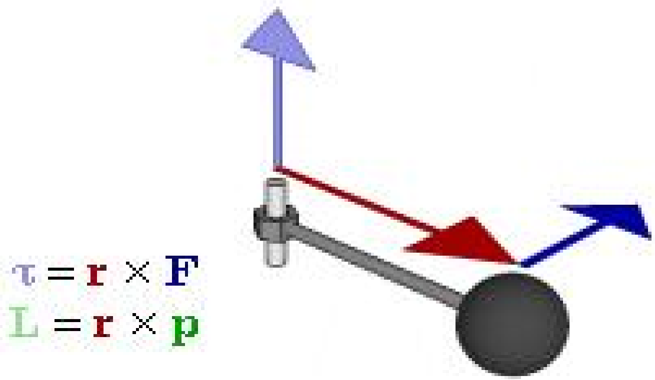
This research aims to address these challenges by proposing strategies for enhancing skill development among EMI staff while simultaneously improving the technical capabilities of its torque-measuring laboratory. By identifying current gaps in knowledge and infrastructure, this study will provide actionable recommendations that can lead to improved measurement accuracy and reliability.

This initiative aligns with broader national goals aimed at fostering innovation and enhancing technical expertise within Ethiopia's workforce. By investing in both human capital and laboratory infrastructure, the EMI can significantly contribute to advancing Ethiopia's metrological standards while supporting local industries' growth.

Enhancing skill development alongside improving laboratory capabilities at the Ethiopian Metrology Institute represents a strategic investment in the nation's future—one that promises not only immediate benefits but also long-term sustainability in an increasingly competitive global environment.

Research

Torque measurement is crucial in various engineering applications, particularly in ensuring that fasteners are tightened to the correct specifications. This is where torque transducers and hand torque tools come into play. A torque transducer measures the torque applied to an object, while hand torque tools (like wrenches) are used to apply a specific amount of torque. Torque is a measure of the force that can cause an object to rotate about an axis



Relationship between force F, torque T, linear momentum p, and angular momentum L in a system that has rotation constrained to only one plane (forces and moments due to gravity and friction not considered).
Common symbols T, M
SI unit: N.m Other units: pound-force-feet, lbf· inch, ozf· in

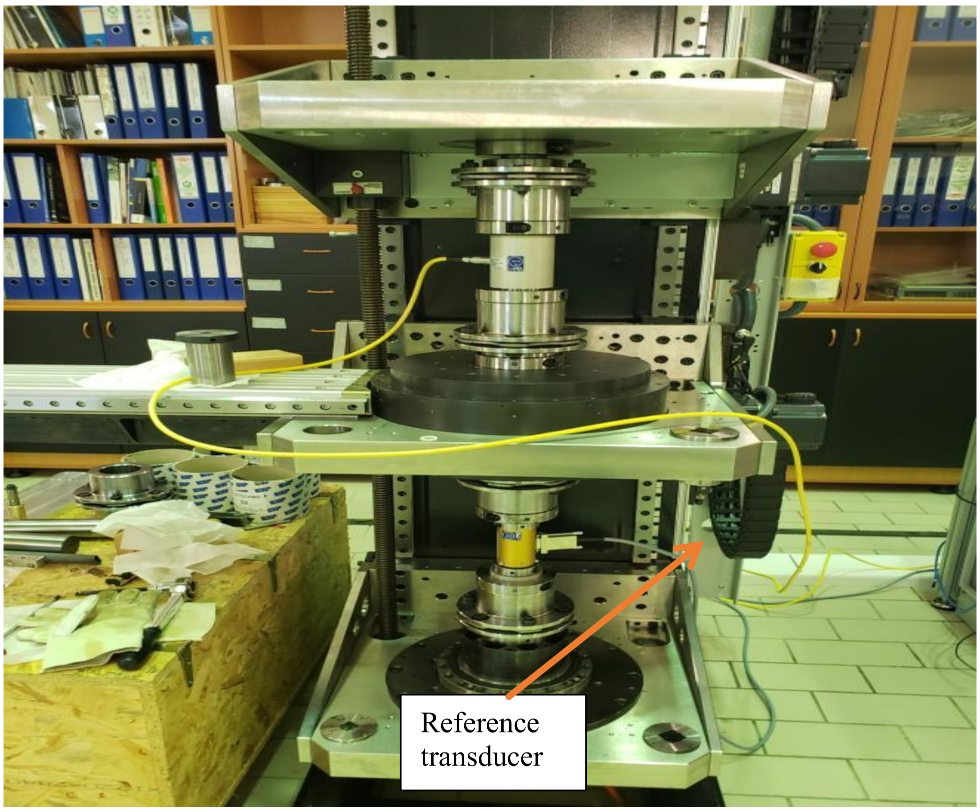
Calibration method of static torque measuring devices

1. **Understanding Torque Transducers**:

- Torque transducers convert mechanical torque into an electrical signal. They typically use strain gauges or piezoelectric sensors.
- Torque sensors, also known as torque transducers, are specialized devices designed to measure the torque applied to a rotating object, such as a shaft or a wheel. They convert the mechanical energy associated with torque into an electrical signal that can be measured and analyzed. This conversion is typically achieved through the use of strain gauges, which detect the deformation (strain) of the material when torque is applied.

2. Calibration Process:

Torque Calibration Machine: This is a specialized device that can apply precise torque levels. It typically consists of a motorized system that can generate controlled torque, often using electric motor. I used TCM-1kNm machine for may practical training of torque transducer calibration .



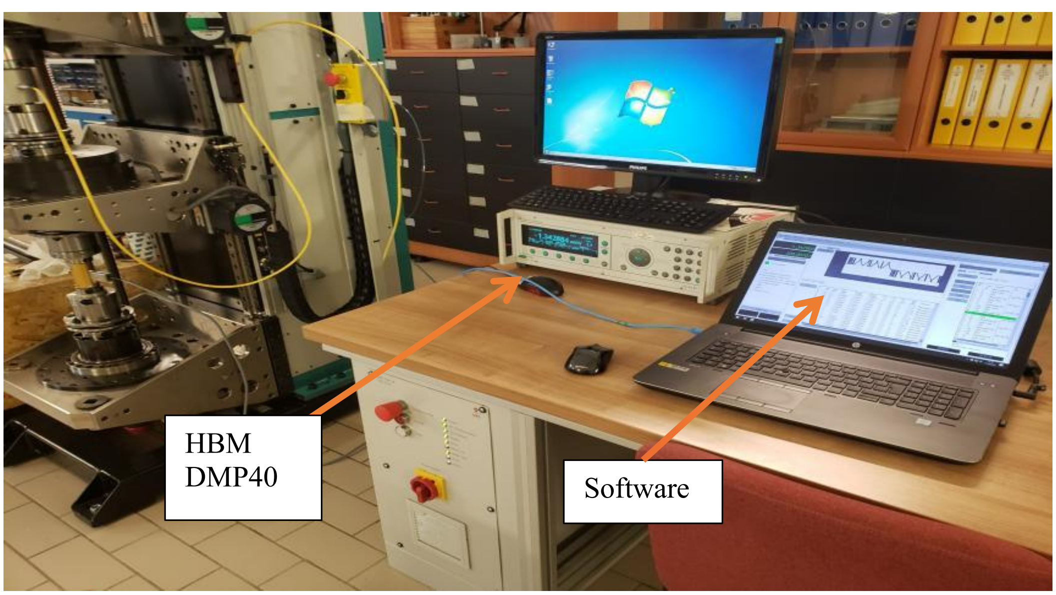
Reference Torque Standard:

A reference standard is crucial when it comes to calibration processes as it serves as a point of comparison. in the field of torque measurement, using a certified torque wrench or another calibrated torque sensor with known accuracy is essential to ensure the reliability of the measurements. It is imperative that the chosen reference standard is traceable to national or international standards to guarantee its accuracy and reliability. In my study, I utilized a Type DmTN torque sensor with a 1000 Nm nominal load and serial number 62112. This particular sensor is part of a transfer torque standard that has been calibrated and verified to meet the required accuracy levels. By using a traceable reference standard torque sensor, the calibration process becomes more robust and trustworthy. This ensures that the measurements taken are accurate and consistent, leading to reliable results.

Data Acquisition System:

To record the output from the torque sensor being calibrated, a data acquisition system is required. This system collects data from both the sensor under test and the reference standard, allowing for real-time analysis and recording.

In this particular scenario, I utilized software that assists in my calibration data collection, analysis, and reporting. This software help me and automate the process and ensure consistency of my calibrations data and I utilized the HBM DMP 40 device to showcase the measurement signal effectively. This device not only displays the measurement signal but also facilitates the seamless transfer of data. Additionally, I utilized specialized software designed for recording purposes to meticulously document each calibration sequence of signals. This software ensures that every detail of the calibration process is accurately captured and stored for calculating measurement uncertainty. when using the HBM DMP 40, I was able to monitor the changes in the measurement signal in real-time, allowing for immediate adjustments if needed. The software used for recording not only captures the calibration sequences but also provides a comprehensive overview of the entire calibration process. This level of detail is crucial in ensuring the accuracy and reliability of the measurement data obtained. by incorporating the HBM DMP 40 and the recording software into the calibration process, I was able to streamline the entire operation and enhance efficiency. The seamless integration of these tools not only simplifies the calibration procedures but also minimizes the margin of error, ultimately resulting in precise and consistent measurement results. The combination of the HBM DMP 40 and the recording software proved to be instrumental in achieving reliable and accurate calibration outcomes.



Calibration Procedure Steps

In this scenario I used the following methods for my calibration of torque transducer

Pre-loading: According to DIN 51309:2017, I preloaded my calibrated torque sensor thrice in the direction to be calibrated, and once after each alteration of the mounting position with the final value of the measuring range to be calibrated, denoted as ME.

Mounting position: I calibrated the transducer in three distinct mounting orientations by rotating the transducer by 120° around the measuring axis.

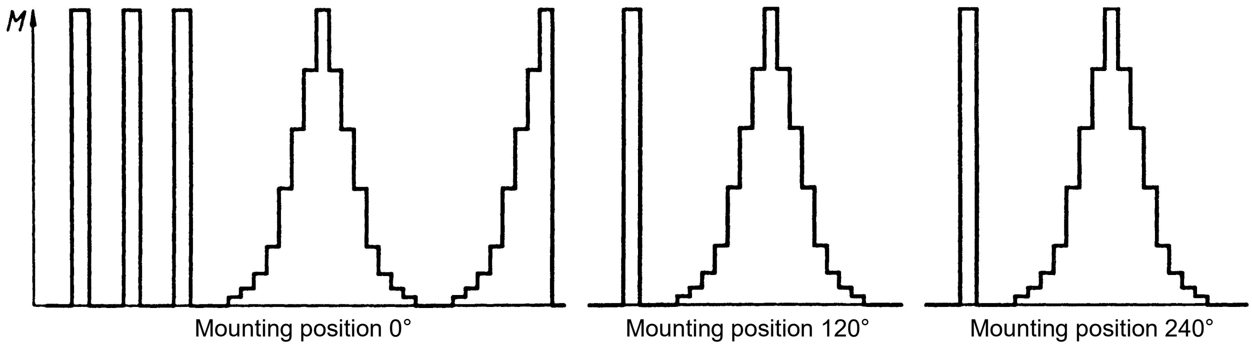


Figure: pre-loadings and measurement series for classes 0.05 and 0.1

Number of measurement series: In this scenario, I select my measurement series based on the class of my transducer, which is classified as 0.05. According to DIN 51309, classes 0.05 and 0.1 should be utilized (distributed appropriately across the measuring range) in increments of 10%, 20%, 30%, 40%, 50%, 60%, 80%, and 100% of M_E.

Loading conditions: The time interval between consecutive torque increments remains consistent. During the calibration process in discrete increments, the recorded values are transmitted once the display unit has returned to its initial position. The calibration was conducted under stable ambient temperatures fluctuating within ±1 K and falling within the range of 18 °C to 28 °C, with a preference for 22 °C.

Evaluation of the torque meter: in this case we have two options CASE I and CASE II.

Case I: The measuring device is used for increasing load. Calibration is done with displayed values from increasing series, averaged over mounting positions and corrected for zero point. A smoothing function is computed using origin point and interpolation deviation. Reversal error is not considered in classification or relative measurement uncertainty. Interpolation deviation is always considered.

Case II: Measuring device is used for torque measurements with unknown load directions. Calibration is done with mean values of increasing and decreasing series, averaged over mounting positions and corrected for zero point. A linear smoothing function is computed using origin point and interpolation deviation. For instruments with fixed scale, indication deviation is used instead of interpolation deviation. Reversal error and interpolation/indication deviation are considered in classification or as a contribution to relative uncertainty interval.

In my calibration process, I made sure to utilize both cases to gain a better understanding and to estimate the uncertainty more accurately. I carefully examined the data from both scenarios to compare and contrast the results. By doing so, I was able to identify any discrepancies or patterns that emerged, which helped me refine my analysis. by incorporating both cases into my calibration, I was able to account for any potential variations or errors that might have occurred if I had only relied on one case. This comprehensive approach allowed me to mitigate any potential biases and ensure that my estimates were robust and reliable.

Model equation for Calibration result *Yh(M$_K$), Y(M$_K$)*

Case I: The calibration result Y(MK) is calculated for each calibration torque according to the following Equation as an average over the different mounting positions of the displayed values of the increasing series, corrected for the zero point.

$$Y(M_K) = \frac{1}{n}\sum_{j=1}^{n}\left(I_j(Mk) - I_{o,j}\right)$$
$$= \frac{1}{n}\sum_{j=1}^{n}\left(X_j(Mk)\right)$$

Case II: The calibration result *Yh(MK)* is calculated for each calibration torque according to the following Equation as an average over the different mounting positions of the displayed values of the decreasing and increasing series, corrected for the zero point.

$$Y_h(MK) = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{I_j\,(Mk) + I_j(Mk)}{2} - I_{o,j}\right)$$

$$= \frac{1}{n}\sum_{j=1}^{n}\left(\frac{X_j\,(Mk) + X_j(Mk)}{2}\right)$$

Measurement uncertainty budget

I used the following mathematical equation for estimation of my measurement uncertainty

- For non-correlated input quantities, the relative standard measurement uncertainty is determine using

$$w(M_k) = \sqrt{w_{kE}^2(M_k) + 2 * w_r^2(M_k) + w_b^2(M_k) + w_{b'}^2(M_k) + w_o^2(M_E) + w_{fa}^2(M_k)} \qquad \text{for Case I}$$

$$w(M_k) = \sqrt{w_{kE}^2(M_k) + 2 * w_r^2(M_k) + w_b^2(M_k) + w_{b'}^2(M_k) + w_o^2(M_E)} \qquad \text{for Case II}$$

Hand Torque Tool Calibration Methods

During my study, I learned about various terms and methods associated with the use of hand torque tools, which include understanding the principles of torque measurement, the significance of applying the correct torque settings to prevent damage to fasteners, and the different types of hand torque tools available, such as torque wrenches and screwdrivers, along with their specific applications in mechanical assemblies.

Hand torque tools can be categorized into two main types: indicating torque tools (Type I) and setting torque tools (Type II).
Indicating torque tools are designed to show the amount of torque being applied during use. They are further classified into several classes. Class A includes wrenches that utilize a torsion or flexion bar mechanism to indicate torque. Class B consists of wrenches with a rigid housing that feature a scale, dial, or digital display for reading the applied torque. Class C encompasses wrenches with rigid housing that provide electronic measurement capabilities. Class D refers to screwdrivers equipped with a scale, dial, or display to indicate the applied torque, while Class E includes screwdrivers that offer electronic measurement features.
On the other hand, setting torque tools are used to apply a specific amount of torque to fasteners. This type is also divided into various classes. Class A includes adjustable wrenches that are graduated or equipped with a display for precise settings. Class B comprises wrenches with fixed adjustments that do not allow for variability in torque application. Class C features adjustable wrenches that are non-graduated, meaning they do not have markings for specific torque values. In terms of screwdrivers, Class D includes those that are adjustable and either graduated or equipped with a display, while Class E consists of screwdrivers with fixed adjustments. Class F refers to adjustable screwdrivers that lack graduation markings, and finally, Class G includes adjustable graduated flexion bar wrenches.

Calibration Procedure

for my research I used the following methods for calibration of hand torque tools

Pre-loading: The hand torque tool preloaded three times in the direction to be calibrated, applying the maximum torque value, T_E, of the measurement range of the measurement device and once after each change of the mounting position. The duration of the application of preload should be not less than 30 s. The indicator reading is taken before each preload and after each preload has been removed for not less than 30 s.

Mounting position: according to standard For torque measurement devices with a square drive, four mounting positions are generally preferred; however, depending on the device's performance and customer needs, two positions may suffice. For devices without a square drive, calibration should occur in three different mounting positions, rotating the transducer or its mechanical coupling by 120° each time around the measurement axis.

Range of calibration: The recommended number of calibration steps shall be a minimum of three approximately equally spaced from 20 % to 100 % of T_E.

Loading conditions: our Calibration temperature must stable to ±1 K. This temperature should be in the range between 18 °C and 28 °C (preferably between 20 °C and 22 °C) and recorded.

Determination of the calibration result: The relative standard measurement uncertainty, w_{md}, assigned to the measurement device at each calibration point is given for uncorrelated input quantities is calculated using the following formula

$$W_{md} = \sqrt{(\frac{w_{ref}}{2})^2\ 2w_r^2 + w_z^2 + w_{re}^2 + w_{rep}^2}$$

The expanded standard measurement uncertainty, W_{ref}, can be obtained from the certificate of reference measurement standard. Because readings are taken twice (at the scale's zero point or minimum, respectively, and at the calibration value), the measurement uncertainty of the resolution, r, appears in the result twice. These two random fractions are added up geometrically.

Overview of the seminar on CIPM MRA

During my training at UME, I had the privilege of participating in a webinar focused on the CIPM Mutual Recognition Arrangement (MRA) and its significance in the field of metrology. This session provided comprehensive insights into the origins, objectives, and operational functions of the CIPM MRA.
The webinar covered essential aspects such as the rationale behind the establishment of the CIPM MRA and its critical role in enhancing international metrological cooperation. I gained an understanding of how National Metrology Institutes (NMIs) can engage in comparisons under the CIPM MRA framework. Specifically, I learned about the process for NMIs to have their Calibration Measurement Capabilities (CMCs) published in the Bureau International des Poids et Mesures (BIPM) Key Comparison Database (KCDB).
Review Processes for CMC Publication: An important part of this process involves undergoing rigorous peer reviews prior to publication. The reviews include both intra-regional assessments and inter-regional evaluations conducted by the Joint Committee of Regional Metrology Organizations (JCRB). These reviews ensure that NMIs meet established standards before their capabilities are recognized internationally.
It was emphasized that NMIs must establish and maintain a Quality Management System (QMS) that aligns with CIPM MRA requirements. This QMS must be subject to review, approval, and ongoing monitoring by their respective Regional Metrology Organizations (RMOs), ensuring compliance with international standards.
Lastly, the webinar highlighted the critical importance of metrological traceability and discussed methods for maintaining it effectively within measurement systems.

Conclusions and Future Work

Perform calibration of hand torque tools and torque measuring devices by using a torque standards machine.Develop Ethiopian metrology institute torque calibration laboratory CMCs to post in the future in the BIPM KCDB database. Get accreditation for torque calibration laboratory Improve the EMI torque laboratory staff skills through training.
Develop and implement torque calibration methods and procedures, including uncertainty budget, Technological & knowledge transfer in the field of torque Metrology, Build an equivalent knowledge with other country torque laboratory of NMI.
Performing calibration of hand torque tools and torque measuring devices is crucial to ensure accuracy and reliability in various industries. This process involves using a torque standards machine to verify the precision of these tools. For example, calibrating a torque wrench used in automotive repair ensures that it tightens bolts to the correct specifications, preventing potential mechanical failures.
Developing EMI torque calibration CMCs (Calibration and Measurement Capabilities) to be included in the BIPM KCDB database is essential for establishing international

recognition and comparison of torque calibration standards. This step involves detailed documentation of calibration procedures, measurement uncertainties, and traceability to national standards.

Acquiring accreditation for a torque calibration laboratory demonstrates compliance with recognized quality standards and boosts confidence in the calibration services provided. This accreditation signifies that the laboratory meets specific criteria for competence, impartiality, and consistent performance.

Enhancing the skills of EMI torque laboratory staff through training programs is key to maintaining proficiency in torque calibration techniques and staying updated with industry advancements. Regular training sessions on new technologies and methodologies ensure that staff members are well-equipped to handle diverse calibration requirements.

Developing and implementing torque calibration methods and procedures, along with establishing an uncertainty budget, is fundamental for ensuring the accuracy and reliability of torque measurements. This includes documenting the sources of uncertainty and their impact on measurement results, thus enhancing the credibility of calibration reports.

Facilitating technological and knowledge transfer in the field of torque metrology is essential for fostering collaboration and sharing best practices among torque calibration laboratories globally. This exchange of expertise and resources contributes to the development of standardized approaches and promotes consistency in torque measurements.

Building an equivalent level of knowledge and expertise with other country torque laboratories of National Metrology Institutes (NMI) is crucial for harmonizing calibration practices and ensuring compatibility in torque measurements. This collaboration enables bench marking against international standards and facilitates mutual recognition of calibration results.

Acknowledgement

I would like to express my sincere gratitude to all those who contributed to the successful completion of the Torque measuring device Laboratory project. This work would not have been possible without the support, guidance, and encouragement from various individuals and institutions.

Institutional Support

I extend my heartfelt thanks to the Bureau International des Poids et Mesures (BIPM) for providing an excellent framework and resources that facilitated our research. Their commitment to ensuring accurate measurements worldwide has greatly influenced our approach in this laboratory.

I am grateful to TÜBİTAK UME for their invaluable assistance and collaboration throughout this project. Their expertise in metrology has enriched our understanding of torque measurements, allowing us to achieve precise results.

Mentorship

I would like to acknowledge my mentor, Semih Tunacı, his guidance was instrumental in navigating the complexities of this laboratory work. His profound knowledge in the field of physics and engineering provided me with a solid foundation upon which I could build my understanding of different torque principles. he encouraged critical thinking and fostered an environment where innovative ideas could flourish.He insights into experimental design helped streamline our processes and attention to detail ensured that we maintained high standards throughout our experiments. his mentorship has not only enhanced my technical skills but also inspired a passion for scientific inquiry.

Conclusion

I would like to formally acknowledge the significant contributions made by Mr. Anderson Maina, Mr. Chingis Kuanbayev, and Dr. Enver Sadıkoğlu during the recent webinar. Their presentations provided valuable insights into the CIPM MRA and its functions, greatly enhancing our understanding of this important topic. Additionally, I extend my sincere gratitude to Ms. Müge Atam for her exceptional management of our accommodation and transportation arrangements throughout my stay. Her timely provision of relevant information was instrumental in ensuring a smooth experience.I would like to thank Mr. Cihan Kuzu (head of force laboratory) for the explanation he gave me at the hardness laboratory and I would like to thank Dr.Cafer Kirbas for sharing his precious time with me from his endless wealth of knowledge about acoustic & vibration laboratory. I also wish to express my appreciation to the Ethiopian Metrology Institute and the prime minister office for granting me this opportunity, as well as to our institute General Director, Dr. Mulugeta Derebew, for his endless kind support. I am eager to apply the knowledge and experiences gained from this event to foster improvements within my country.

Life in turkiye beyond the project

My stay in Turkiye was incredibly enjoyable, and the Turkish people were exceptionally hospitable and warm-hearted, making me feel as though I was at home. The staff at UME were particularly outstanding; they generously shared their knowledge and provided us with valuable insights about Turkiye's rich culture and history.

In addition to the welcoming atmosphere created by the people, I encountered numerous campus cats that added a unique charm to my experience. These affectionate cats would follow us around and seek our attention as we explored the campus, providing moments of joy and companionship.

Another highlight of my trip was engaging in table tennis, which not only served as a fun activity but also contributed to our physical well-being. It was a great way to stay active while enjoying time with friends.

Throughout our vacation, my friends and I spent most of our days exploring the vibrant city of Istanbul. This magnificent city is filled with an abundance of tourist attractions and historical monuments. I feel fortunate to have had the opportunity to witness such remarkable sights, which left a lasting impression on me.

During my stay, TÜBİTAK UME significantly enhanced my experience by providing accommodations that rivaled those of a five-star hotel. The room was not only comfortable but also impeccably clean, creating an inviting atmosphere for relaxation. Each day, I was treated to exquisite hand-cut meals through their catering service, which offered me a wonderful opportunity to explore the diverse diet and culinary traditions of Turkiye.

One of the highlights of my visit was experiencing authentic Turkish tea. Tasting it in person allowed me to appreciate its rich flavor and cultural significance far beyond what I had known before. This experience deepened my understanding of Turkish hospitality and cuisine.