KEY COMPARISONS IN THE FIELD OF TORQUE MEASUREMENT

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ABSTRACT

One of the main tasks of the National Metrology Institutes (NMIs), besides the realization and improvement of standards for the different physical and other quantities, is to carry out comparisons between their own standards and those of other NMIs. At the highest level, the CIPM key comparisons involve at least the standards with the smallest uncertainties of measurement in the world and should cover - if possible - all geographical regions through the corresponding Regional Metrological Organizations (RMOs). It is also intended to compare different realization techniques of the given quantity and to make a statement of equivalence for the different calibration capabilities. This document deals with the recently agreed CIPM key comparisons in the field of torque measurement.

1. INTRODUCTION

In spring 2004, at the last meeting of the Force Working Group of the CIPM‘s Consultative Committee for Mass and Related Quantities (CCM), a decision on a first key comparison in the field of torque was made. In a first step it was necessary to get an updated overview of the measurement capabilities in the different countries. This will be the subject of section 2. On this basis, the participants of the comparison and the pilot laboratory had to be defined. Some details of the measurement procedure, the transducers, their transportation and adaptation in the machine had to be agreed upon and will be given in section 3. A brief summary follows in section 4.

2. TORQUE METROLOGY – AN OVERVIEW

There are different primary torque standard machines in the NMIs of the world: different in their principal techniques, capacities and (absolute or relative) expanded uncertainties. An overview of some of these devices is given in Table 1. The data shown there have been taken from the BIPM key comparison database, Appendix C [1], and contain the Calibration and Measurement Capabilities (CMCs) stated by the National Metrology Institutes. In some cases, different machines with adjacent or overlapping ranges have been combined to form one data set . Unfortunately, this database is not very up-to-date and does possibly not include machines which have been recently constructed and set into operation . Especially new machines using a lever-masssystem (dead weight type) in combination with an air-bearing support and a very small frictional influence on the transmission of the generated torque to the torque transducer are of interest for the key comparison. Nevertheless, the devices with the smallest uncertainty of measurement can be taken from Table 1. An updated list containing these machines and the newer devices together with their responsible laboratories is shown in Table 2. In case a laboratory is not a NMI or a CCM member laboratory (China), the corresponding designated national metrology institute must nominate the laboratory to participate in the key comparison. In Table 2, the Regional Metrological Organization is added for each of the countries in order to find out how these devices are distributed over the world. It can be seen that not all RMOs can be covered by a CIPM key comparison with high-precision torque standard machines. Figure 1 shows a geographical map of the countries from Tables 1 and 2 as well as countries with primary torque standard devices known to the author which are not mentioned in the tables.

Table 1: Calibration and Measurement Capabilities in the field of torque (BIPM key comparison database, 2004)

Country	NMI / CCM member	Range	Absolute (in N·m) or relative expanded uncertainty (*k* = 2, level of confidence 95%)
China	NIM (National Institute of Metrology)	0.5 N·m to 5000 N·m	$1 \cdot 10^{-4}\ T$, T in N·m
Czech Rep.	CMI (Czech Metrology Institute)	10 N·m to 1000 N·m	$5.0 \cdot 10^{-4}$
Finland	MIKES (Mittatekniikan Keskus, Centre for Metrology and Accreditation)	20 N·m to 2000 N·m	$5.0 \cdot 10^{-4}$
		4 N·m to 20 N·m	$8.0 \cdot 10^{-4}$
France	BNM (Bureau National de Métrologie)	1 N·m to 40 N·m	$(2.0 \cdot 10^{-4}\ M + 0.005)$, M in N·m
		5 N·m to 300 N·m	$(2.0 \cdot 10^{-4}\ M + 0.015)$, M in N·m
		5 N·m to 2000 N·m	$(2.0 \cdot 10^{-4}\ M + 0.04)$, M in N·m
		2 kN·m to 10 kN·m	$(2.0 \cdot 10^{-3}\ M + 2.0)$, M in kN·m
		10 kN·m to 200 kN·m	$2.0 \cdot 10^{-3}$
Germany	PTB (Physikalisch-Technische Bundesanstalt	0.1 N·m to 5000 N·m	$2.0 \cdot 10^{-4}$
		0.01 N·m to 1 N·m	$2.0 \cdot 10^{-4}$
		1 N·m to 20000 N·m	$2.0 \cdot 10^{-5}$
		0.01 N·m to 1000 N·m	$2.0 \cdot 10^{-3}$
Hong Kong, China	SCL (Standards and Calibration Laboratory)	0.05 N·m to 0.1 N·m	$2 \cdot 10^{-3}\ T$, T in N·m
		0.1 N·m to 0.5 N·m	$1 \cdot 10^{-3}\ T$, T in N·m
		0.5 N·m to 1000 N·m	$1 \cdot 10^{-3}\ T$, T in N·m
Japan	NMIJ (National Metrology Institute of Japan)	0.005 kN·m to 1 kN·m	$5 \cdot 10^{-4}$
Korea, Republic of	KRISS (Korea Research Institute of Standards and Science)	1 N·m to 100 N·m	0.001 T, T in N·m
		0.1 kN·m to 1 kN·m	0.54 T, T in kN·m
Mexico	CENAM (Centro Nacional de Metrologia)	1 N·m to 10 N·m	0.0005
		5 N·m to 50 N·m	0.0005
		20 N·m to 200 N·m	0.0005
		200 N·m to 2000 N·m	0.0005
Switzerland	METAS (Metrology and Accreditation Switzerland)	1 N·m to 9 N·m	$2.50 \cdot 10^{-4}$
		10 N·m to 1000 N·m	$5.00 \cdot 10^{-5}$

Table 2: Torque standard machines which should be included in a CIPM key comparison (updated)

Country	NMI / CCM member	Range	Uncertainty *)	RMO
China	NMI	500 N·m to 50 000 N·m	0.0005 [1)]	APMP
Finland	MIKES	20 N·m to 20 000 N·m	0.0005	EUROMET
France	BNM	10 000 N·m to 200 000 N·m	0.002	EUROMET
Germany	PTB	100 N·m to 20 000 N·m	0.00002	EUROMET
		2 N·m to 1 000 N·m	0.00002	
UK	NPL	1 N·m to 2 000 N·m	0.00002	EUROMET
Japan	NMIJ	5 N·m to 1 000 N·m	0.00005	APMP
		200 N·m to 20 000 N·m	0.00007	
Korea	KRISS	100 N·m to 2 000 N·m	0.0001	APMP
Mexico	CENAM	500 N·m to 20 000 N·m	0.0004	SIM
		200 N·m to 2 000 N·m	0.0005	
Spain	CEM [2)]	2 N·m to 1 000 N·m	0.00002	EUROMET
Switzerland	METAS	10 N·m to 1 000 N·m	0.00005	EUROMET

* Relative expanded uncertainty (*k* = 2, level of confidence 95%)
[1)] device located at SMERI, Shanghai Marine Equipment Research Institute
[2)] CEM = Centro Español de Metrologia

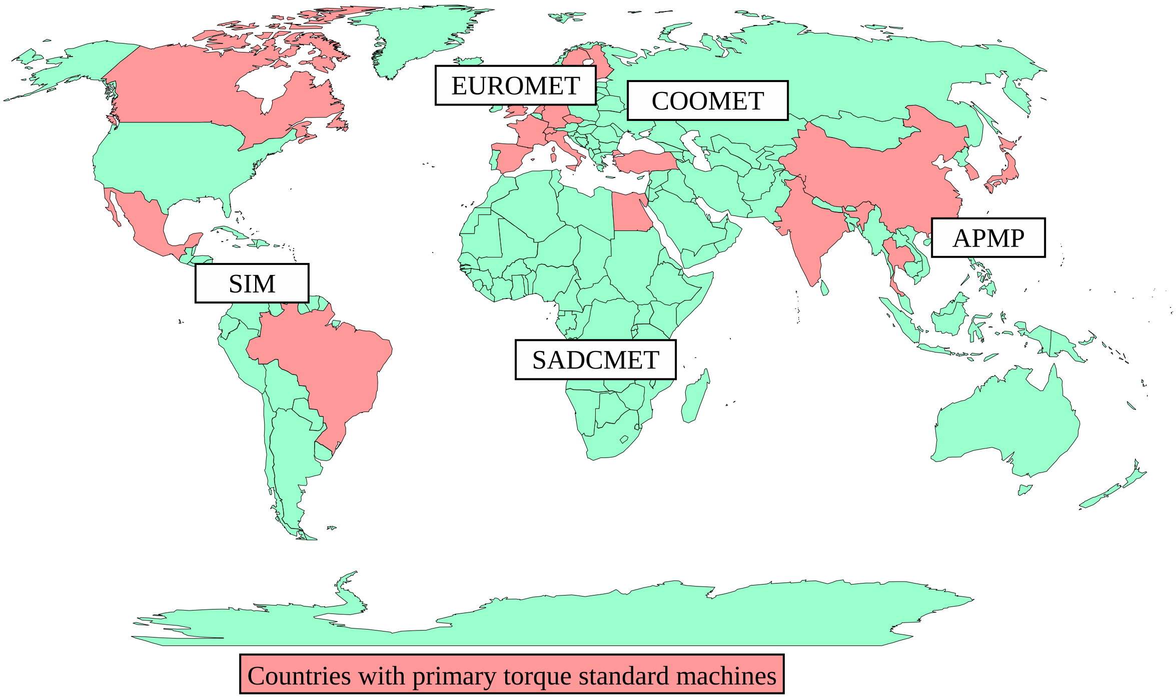

Figure 1: Countries with primary torque standard machines and corresponding RMOs

One conclusion can be drawn from Table 2: there are two important torque ranges of 1 kN·m and 20 kN·m and it was decided at the meeting to start the CIPM key comparisons for torque in these measuring ranges.

3. PARTICIPANTS AND DETAILS

The countries listed in Table 2 (except for Switzerland as there was no Swiss delegate at the meeting) agreed to take part in the comparison,. China will nominate SMERI as the Chinese participant in the upper range. One objection was raised regarding the measuring principle of the devices and their uncertainties for the 20 kN·m range. Only two of the devices (PTB/Germany, NMIJ/Japan) are dead-weight machines with air-bearing and able to attain a small uncertainty of a few 10^{-5}. The other machines are of the reference type and use a torque transducer as reference. The support is often made by counter-rotating ball bearings. The SMERI machine uses multiple knife-edge systems. These machines represent, however, the primary standards in their country. The delegates therefore decided to include them and turn the 20 kN·m key comparison into a combination of a bilateral comparison between PTB and NMIJ and a multilateral comparison between the other four participants. Table 3 shows the key comparisons and the participants of the corresponding RMOs.

Table 3: Torque standard machines which should be designated for a CIPM key comparison

Key Comparison	Range / Type	APMP	EUROMET	SIM
CCM.F-Kx[1)]	1 kN·m / dead-weight	NMIJ, KRISS	CEM, NPL, METAS[2)], **PTB**[3)]	CENAM
CCM.F-Ky[1)]	20 kN·m / dead-weight	NMIJ, SMERI	**PTB**[3)]	
	20 kN·m / reference		BLM-LNE, MIKES-RAUTE	CENAM

[1)] x and y stand for the number of the comparison and have not yet been defined
[2)] Switzerland; will be invited
[3)] pilot laboratory

Referring to the good results of the ongoing force key comparisons it was decided to apply the same procedures. In detail, the measurement sequence consists of three preloadings, one preloading and three measurement cycles for the 0° mounting position, followed by one preloading and one measurement cycle for each new mounting position with an intermediate rotation of the transducer about an angle of 60°. Two full rotations of the transducer must be carried out (mounting positions: 0°, 60°, 120°, ..., 300°, 360°/0°, 60°, 120°, ..., 300° and 360°). Each of the preloadings and measurement cycles consists in two steps: 50% and 100% of nominal load. There is no additional step for decreasing torque value. The time between the readings is 6 minutes. The long waiting time was chosen to reduce the influence of the creep. On the other hand there are some machines which take a longer time for torque application in comparison with other devices. Figure 2 shows the load-time diagram of the measurement sequence.

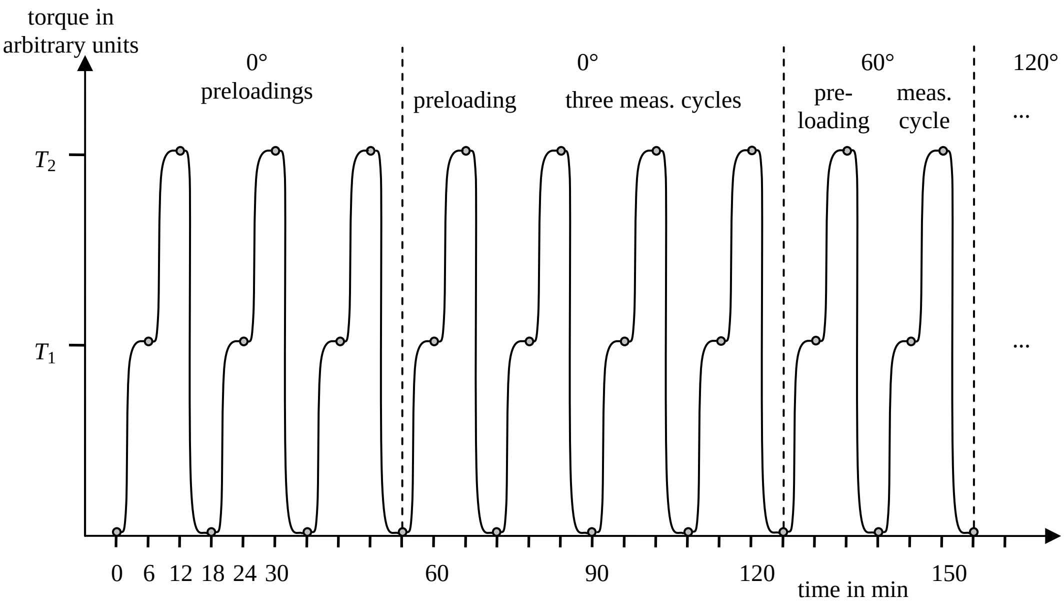

Figure 2: Measurement sequence

There is one difference between force and torque: in torque measurement it is possible to calibrate a transducer both in clockwise and anti-clockwise direction without changing the mounting of the transducer. The two directions correspond to tension and compression forces. In force standard machines it is, however, almost always necessary to change the transducers position in the machine or to even take another transducer type. This is a great advantage of the torque compared with the force. For clockwise and anti-clockwise torque, the measurement sequence can be the same (see Figure 2).

It is planned to perform the measurements with two transducers of different type, but with identical capacity. For 1 kN·m, there are cylindrical torque transducers of shaft type (TT1) and flange type (TB2) available. The long-term stability of the TT1 transducers is known, but the main influence on this parameter is expected to be caused by transportation. Especially changes in temperature and air humidity may affect the transducer’s properties. Therefore, the transducers will be transported in special temperature-controlled boxes. It is also expected that the TB2 transducers are less sensitive to these environmental conditions due to their special construction: the strain gauge application is located on the inner side of the hermetically closed hollow cylindrical body of the transducer.

The measurement temperature in the laboratories is (20 ± 0.2) °C. Data loggers will be provided by the pilot laboratory to record the temperature during transportation and measurement.

Regarding the mechanical adaptation and mounting it was decided to supply the transducers with cylindrical shaft ends. That means that the flange type transducer will be equipped with adapters. Hydraulic coupling elements (ETP) must be available on-site for mounting.

As amplifier, a DMP40 from the participant with 5 V supply voltage and appropriate settings for filter and resolution must be used. It should be calibrated with a bridge standard delivered by the pilot laboratory. Each transducer is equipped with a cable to connect it to the amplifier. In order to keep the strong time regime (see Figure 2), the work of the participants will be supported by a special software on a notebook computer also delivered by the pilot laboratory. This program shows the time schedule and gives an alert when loading must be carried out or reading be taken. Data acquisition is also supported by the software: by clicking on a button in the program, the measuring values will be transmitted from the amplifier to an Excel sheet.

The comparison will follow a star formation: the pilot laboratory has to repeat all measurements each time the instruments return to it. It is planned to start the key comparisons at the beginning of 2005 and to finish it at the end of 2005.

4. SUMMARY

The last decade represented a great step forward in the field of torque metrology. Some new high-precision torque standard machines were constructed and are available for measurements. Now is the time to compare the different realizations of the torque unit in these machines. We hope that we will be able to find good agreement between the different devices.

As longest period for the repetition of key comparisons, a time span of 15 years was considered for dead-weight devices. For the other machine types, a maximum interval of 10 years should be a good estimate.

REFERENCES

[1] BIPM key comparison database, Appendix C, Internet: http: //kcdb.bipm.org/AppendixC/,accessed in October, 2004.

[2] Guidelines for CIPM key comparisons, Internet: http://www.bipm.org/utils/en/pdf/guidelines.pdf, accessed in October, 2004.

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