EURAMET TC-M, Force Area Roadmap

Background

Force metrology is a key metrology for industry, research and society because of extremely wide range of force relating applications. It plays an important role in the following areas:
- Material testing and safety engineering, car industries, aerospace, off-shore industrie, aviation industry, mechanical engineering, micro- and nanotechnologies
- Energy production processes in power plants, off-shore industries require measurement of force and torque. Traceability of force and torque measurements is important to improve energy efficiency and savings.
- In medicine as a diagnostic and therapeutic parameter of human body the traceabilty for smaller forces is required.
- In aviation, aerospace and road transport forces are important control and safety parameters.

On a primary standard level the quantities force and torque are based on well established static single-component calibrations. The high accuracy of these calibrations, however, cannot be applied for multicomponent applications, alternating loads and continuous loading. It is well-known from the experiences in the field of torque that these effects can significantly influence the measurement result and can cause incorrect force and torque values. The uncertainty of measurement for static and quasistatic force and torque is secondly based on the knowledge of the used transducers and parasitic effects which have to be taken into account.

Traceable single and multicomponent measurements of static force and torque play a more and more important role for industry, research and society to assure, for example, the quality and safety of products, the reliability of measurement results and the health of people. Typical examples are sensors to be used for measurements in materials testing, robotics, automotive and aerospace industries, manufacturing and assembling technology as well as machine monitoring and control. Further applications are torque wrenches in safety relevant screw connections and torque measurements in automated production lines, power stands or ergometers.

It is well known, that in many cases a single component stepwise static calibration alone is not appropriate - especially if the application conditions are different to the situation during the calibration. Consequently there is an increasing demand of industry and authorities for single and multicomponent measurements of force and torque with a reliable traceability to the SI-units in accordance with internationally accepted written standards. Such traceable measurements should cover the milli-range (mN forces and mN·m torques), single and multicomponent measurements as well as stepwise and continuous, alternating and non-alternating measurements.

Progress of the force and torque metrology will be based on currently available:
- primary force and torque standards utilising static and continuous forces,
- force and torque transfer standards with reduced uncertainties
- force and torque transfer standards with extended ranges up to the higher MN and MN·m range,
- theoretical methods including analytical and finite element analyses.

Further improvements will be achieved by developments and application in the field of smaller forces down to pN:

Small probing forces become increasingly important in quality assurance of micro- and nanosystems. Two aspects are important: tactile dimensional measurements with scanning probe instruments, stylus instruments and nano-CMMs and the handling and assembly of parts.

A new generation of tactile micro and nano probing systems enter into the measuring labs of researchers and developers. In order to measure in small bore holes and trenches small probing elements and even smaller and more flexible probing pins have to be used leading to probing forces from some pN to some µN. One challenge is their traceability because the parts to be measured have to be globally exchangeable. The well known traceability of forces by using small masses and the gravitational constant is limited to forces > 10 µN.

Another challenge follows from the usage of polymers and other soft materials as a base material in order to mass produce cheap parts by injection moulding or nanoimprinting. When measuring these parts by tactile methods great care has to be taken not to scratch the surface and to measure completely wrong results. The nano hardness of these materials is completely different from the well known silicon and a lot of consequences follow which complicate the manufacturing of these systems.

Common to both fields is another challenge: interaction forces between the probing element and the workpiece or between the handling element (gripper) and the part. The ultimate challenge of nanotechnology is to design and assemble new molecules atom by atom.

Triggers and Targets in this area are:

1. Traceable nano-force measurements: the trigger “Instability/traceability problems with the artefact kilogram” should be changed to “Traceability problems of nano-forces due to the instability of small masses”
2. The trigger “Force spectroscopy for analytics” should be inserted
3. The target “Probing forces for Nanotechnology (10^{-12} N)” should be added (details see below)
4. The target “Small forces for Biotech area (10^{-15} N)” should be extended by the medical area: “Small forces for Medical and Biotech area (10^{-15} N)
5. The experimental realisation “Traceable nano-probing systems” should be added.
6. The metrological application of basic science and technology “Dimensional micro- and nano-metrology” should be added
7. Enabling science and technology: “Small mass, sub-micro balance, µmanipulation” should be extended by “micro- and nano-probing systems, handling and assembly of micro parts”

Basic Science: Metrology

A great variety of micro- and nano-probing systems is currently under development in dimensional metrology of micro- and nanosystems. The growing demand for more powerful and hence smaller systems leads to increasing problems with interaction forces during handling and assembly of the parts. Thus the interaction forces like capillar forces due to water layers, electrostatic forces and van-der-Waals forces have to be experimentally studied. Models describing the dominating forces have to be developed and experimentally verified. Methods to overcome handling problems due to strong interaction forces will have to be developed.
Nano-probing systems will have to be developed which minimize the disturbing effects of interaction forces. The effects of conducting and non-conducting probes, grippers and parts to be measured or handled have to be investigated. The influence of material properties, environmental conditions (humidity), cleanliness and surface roughness on interaction forces needs to be studied.

Grand Challenges: Environment, Health, Energy

Force and torque metrology are important quantities for many areas of trade and industrial and scientific research and require traceability up to the higher MN and MN·m and down to the nN and mN·m range. The lowest and highest values are not yet covered by the Calibration and Measurement Capabilities (CMCs) of the European NMIs [1]. To meet the requirements of force and torque metrology in Europe the ranges of the national standards and of the transfer standards have to be extended according the future needs down to lowest values [2].

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Innovation (for industrial applications)

One direction towards improved traceable measurements of force and torque is the investigation of principles to realize force/torque in low range, in multicomponent and in alternating loading. Based on these investigations new facilities and improvements have to be designed for standards in the future. The experimental realisation are first traceable facilities for calibration of measurement devices with alternating load, second traceable facilities for calibration of measurement devices for low range and third traceable facilities for calibration of measurement devices for multicomponent techniques.
The other direction towards traceable measurement of force and torque is the development and investigation of new transfer standards and measurement procedures. Analytical and numerical modelling of transducers including interaction with mechanical structures are the bases for new or improved devices for measurement of force and torque. Measurement devices which use compensation techniques, which have to be developed for compensation of parasitic effects, can improve the uncertainty. This needs also the development of traceable multicomponent data acquisition and processing systems with appropriate algorithms.

This results in improved transfer standards for traceable static and quasistatic measurements. Finally improved and new procedures for single and multicomponent calibration of measurement devices have to be developed which should result in written standards.
The facilities for multicomponent measurements should cover a range up to at least 100 kN and moments up to 10 kN·m. The required uncertainty for the calibration of multicomponent sensors are less than 0.01% for the main axial component and less than 0.1% for the others. In the milli-range uncertainties of less than 0.01% are necessary to improve the uncertainty in the field of material testing of small structures. The influences of continuous loading, alternating and non-alternating measurements have to be determined with uncertainties of less than 0.01%. Therefore traceable facilities and measurement devices have to be developed with appropriate uncertainties.

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References

[1] BIPM, Calibration and Measurement Capabilities, http://kcdb.bipm.org/appendixC/
[2] Co-Nanomet, Co-ordination of Nanometrology in Europe, http://www.euspen.eu/content/Co-nanomet%20protected%20documents/publications%20area/European%20Nanometrology%202020.pdf