Publishable Summary for 18SIB08 ComTraForce
Comprehensive traceability for force metrology services

Overview

Internationally competitive high-tech products, such as those in the automotive and healthcare sectors, use highly efficient materials including carbon fibre, high tensile steel and concrete. European industry needs an improved scientific infrastructure, which covers a large range of different construction types, to measure their performance for safety and ecological use. Currently, calibration for material testing is done statically and does not only disregard time and frequency influences but also lacks traceability. The project will develop methods and transfer standards for static, continuous and dynamic force calibration traceable to the SI in the range of 1 N to 1 MN. In accordance with the requirements of industry 4.0, force measuring devices will be developed and described by extended theoretical models which will result in digital replicas. This software, which includes uncertainty contributions, can then be implemented in calibration procedures and machines. Outputs from the project will be made available to force metrology services, such as accredited calibration labs, for their force transducers and testing machines in both quality control and science.

Need

In order to cover many different force measurement applications and to develop suitable calibration methods, for these applications, it is necessary to review the current state of the art of available machines, force measuring devices and standards. A roadmap detailing future requirements for improved force transfer standards and associated calibration methods for force testing machines which considers realistic uncertainties, needs to be developed. In modern manufacturing, to meet the demands of industry 4.0 and the factory of the future, virtual tools which consider sources of uncertainty that can be directly implemented into calibration procedures and testing machines are needed. For an improved understanding, the time and frequency behaviour of the force measuring devices also need to be investigated and described by suitable models for continuous and dynamic force measurement. These models will form a “digital twin”, which is the digital replica, in software format, of the real force measuring devices.

Previous EMRP projects SIB63 Force and IND09 Dynamic focused mainly on large forces and basic investigations of dynamic forces but did not consider the need their practical application and the implementation of a traceability chain for continuous and dynamic force measurement was not considered. For continuous forces a calibration procedure for testing machines needs to be developed to extend the traceability chain from static to continuous. For dynamic forces a calibration procedure for the traceability chain in the frequency range 0 Hz to 1000 Hz is required. There is a need for suitable and practical validated methods and guidelines which can be used for continuous and dynamic force calibration and can be applied by calibration laboratories. Currently there are no methods available.

Objectives

The overall aim of the project is to provide calibration services, in the field of mechanical and material testing, with the methods and guidelines needed for comprehensive traceability of static, continuous and dynamic force measurements.

The overall objectives of the project are:

1. To review all types of mechanical and materials testing machine standards and force calibration methods and their traceability chain to national standards and to produce a roadmap for new extended calibration methods and innovative force transfer standards considering the static force calibration method as well as the influence of continuous and dynamic force application.
2. To develop advanced models that accurately describe the influences in force measuring devices including the development of digital twins of force measuring devices according to the future

requirements for digitisation and industry 4.0 with a target uncertainty of 1 % up to 100 Hz and 2 % between 100 Hz – 1000 Hz.

3. To develop a force traceability chain for metrological services by implementing new improved methods to consider static, continuous and dynamic force calibrations across a frequency range of 0 Hz to 1000 Hz in a force range from 1 N to 1 MN.
4. To develop guidelines for force calibration of testing machines under consideration of continuous and dynamic force applications and parasitic influences from multi-component forces and temperature effects and to develop a strategy for offering calibration services from the established facilities to their own and neighbouring countries.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (e.g. National Metrology Institutes, National Accreditation Bodies), standards developing organisations (e.g. ISO, ASTM) and end users (e.g. testing machine manufacturers, test houses).

Progress beyond the state of the art and results

Review of machines and standards used in force metrological services

A widespread range of different testing machines are used in all areas of technology, research and quality control systems. Due to the differing technical applications, such as medical engineering, civil engineering, aviation industry or offshore technology, the existing testing machines cover a wide range of different concepts of force generation, force introduction and systems for the measurement of the applied force. As the material testing facilities often have a very low wear-out, machines are still in service which are several decades old. In addition, the dimensions of the machines are quite different, for example the size of machines needed for bioengineering is in the mN range, in contrast to the size of machines in civil engineering which go up to 100 MN in Europe. A knowledgebase on the individual requirements of different construction principles regarding the traceable dynamic calibration of the machines does not currently exist. This project will provide an overview of the measurement principles, technologies, and procedures currently used for force metrological services. It will result in a comprehensive description of the existing force calibration infrastructure, covering both physical and documentary standards. It will also highlight areas in which there are industrial force measurement applications whose traceability needs are not being fully met by the current arrangements. These needs will be incorporated in the development of a roadmap, planning how best to meet them in the future.

Modelling and development of digital twins for force measuring devices

Digitalisation is an important topic of tomorrow’s industry 4.0. Digitalised data processes will heavily influence the field of material testing and force and torque measurement. Currently systems for digital identification have already been implemented in the latest generation of force measuring devices. However, the use has not been specified and the theory for a digital twin is still missing. The digital twin is a software solution which helps to mimic the behaviour of an engineering phenomena such as a force measurement process. The project will progress beyond the state of the art by developing a digital twin which will deliver the output of a force measuring device as a function of the force spike including detailed investigation of the instantaneous response of the material behaviour of the load cell’s beam giving rise to corresponding changes in the readings recorded by the sensors.

Traceability chain for static and continuous and dynamic force

The force calibration of material testing machines is currently performed according to the ISO 7500-1 standard, which only considers the static axial calibration of the equipment. In the case of continuous or dynamic force application, which is required in many fields of material testing, there is the need for a suitable calibration procedure, since there are presently no European standards or recommendations available for such measurements. In addition, there are no CMC values available for non-static forces. Therefore, the traceability chain in all applications with continuous and dynamic forces is an unsolved problem for the users of metrology services. The focus of previous EMRP project SIB63 was mainly set on the measurement of large forces and that was considerably improved. However, not all different types of material testing machines could be considered. In previous EMRP project IND09, the focus was mainly on the traceability to the NMIs. The problem concerned with the application of dynamic force measurement in many different material testing machines was left as an open question.

This project will improve the traceability of force measurement by implementing new validated and traceable methods for the calibration of material testing machines and test stands. In addition to static forces, traceable methods and procedures for continuous and dynamic forces will be developed. In addition, the effects of multi-component force measurement for alignment influences, values of bending strain, associated percent bending, gripping and apparatus and the influences of temperature will be investigated and considered in the development, which are also addressed in the “Force” and “Dynamic” roadmaps of the EURAMET TC Mass and related quantities.

Recommendations and guidelines for force metrological services

At present, the calibration of all types of material testing facilities is performed in accordance with ISO 7500-1. This international standard focuses only on static procedures for calibrating the force indicator of a testing machine and the influence of dynamic effects has not been considered. This project will develop guidelines for the improved dissemination of the force unit especially in the field of material testing. These guidelines will be developed for at least two types of calibration (with continuous and dynamic force).

Impact

Impact on industrial and other user communities

The guidelines developed in this project will be made available to calibration laboratories. It is expected that these laboratories will then be able provide a service to end-users for continuous and dynamic force calibration traceable to the SI. Dissemination of traceability from NMIs for continuous and dynamic force measurement will provide access to improved capabilities for national and accredited laboratories in Europe and support consistency in measurement capabilities. PTB will introduce the two measurement traceability chains for continuous and dynamic force calibration into their calibration services. This will benefit industrial companies concerned with new material technologies such as the aviation and civil engineering industries as well as renewable energies that rely on such calibration services. This will be immediate through the involvement of industries and laboratories in the stakeholder committee. Information on the calibration services will be disseminated via accredited bodies (for force) in Europe, calibration laboratories or, in Germany, via the Deutsche Kalibrierdienst (DKD) committee of experts for force. To facilitate uptake of the project’s outputs there will be considerable engagement with industrial stakeholders including manufacturers of force measuring devices and material testing machines and test stands as well as end users and calibration laboratories. This will enable them to confidently demonstrate the performance of their products and ensure they remain internationally competitive. A stakeholder committee will also be established to ensure the project is aligned with industrial needs. In addition, workshops will be held to share project outputs and engage with the target user communities.

Impact on the metrology and scientific communities

One of the outputs of the project will be a worldwide review of all standards, measuring devices and material testing machines in force metrology as well as the establishment of an associated database, which will be available on the project website as a report and a roadmap. It will also be disseminated at national expert groups such as the DKD in Germany. The results will support industry in the area of material testing facilities for the implementation of the metrological traceability chain for continuous and dynamic forces including digital twin software for digital industry 4.0 solutions. For metrological services new calibration methods and guidelines for continuous and dynamic force calibration traceable to the SI will be developed. Based on the developed methods NMIs/DIs can extend their Calibration Measurement Capabilities (CMCs) from static to continuous and dynamic force calibration and calibration laboratories can gain accreditation for continuous and dynamic force calibration. Two sets of guidelines will be produced; one on the force calibration of testing machines under continuous forces and the other, for under dynamic forces. Both will consider parasitic influences from multi-component forces and temperature effects. These guidelines will be submitted to EURAMET TC-M for publishing as a EURAMET calibration guide on dynamic force. Research papers will also be submitted for publication in high impact peer-reviewed journals and presented at international conferences.

Impact on relevant standards

A roadmap including a worldwide analysis of all relevant existing standards that must be considered for the development of new standards for continuous and dynamic force calibration, will be produced during the first year of the project. The most relevant international standardisation and technical committees such as ISO TC164 and BIPM CCM as well as other committees will also be informed about the outputs of the project. New methods and guidelines will be developed for continuous force calibration which will be most relevant for ISO TC164/SC1 “Mechanical Testing – Uniaxial testing” and for dynamic force calibration it will be most relevant for ISO TC164/SC4 “Fatigue Testing”. Many project partners are involved in the work of these committees and will consider the feedback in the development of new methods.

Longer-term economic, social and environmental impacts

The project will provide an economic benefit to all future markets involved in force metrology, material testing and mechanical testing through the traceable and harmonised methods and procedures needed for the calibration of testing machines and test stands considering both continuous and dynamic forces. Test results will be more comparable because of these new methods. The unknown real uncertainties for continuous and dynamic forces will be quantified and this will result in a significant reduction in the known uncertainty compared to the currently assumed uncertainties. In respect to industry 4.0 and IoT, this project, for the first time will develop a digital twin of force measuring devices. All test results, in a large range of industrial applications, will become traceable with competitively low uncertainties. As a result material science will get better and reliable instruments to develop future, materials and to guarantee quality control.

Every year, societies and governments are expecting growing economies. But the resources are limited, as is the pollution load capacity of the environment. In order to grow future economies, whilst minimising negative impact on the environment, it is vital that Europe ‘builds more by using less’. This requires new improved materials. The development of new highly efficient materials has already had a beneficial impact on the environment, but material testing needs better traceability to the SI units.

Products from the automotive, aerospace, and healthcare and construction industries have a large impact on the quality of life for many people and are important for European trade and infrastructure. Improved force measurements in the continuous and dynamic regime will be socially important for improved product design.

<table>
<tr><td>Project start date and duration:</td><td colspan="2">1 September 2019, 36 months</td></tr>
<tr><td colspan="3">Coordinator: Dr. Rolf Kumme, PTB Tel: +49 531 592 1200 E-mail: rolf.kumme@ptb.de
Project website address: https://www.ptb.de/empir2019/comtraforce/project/overview/</td></tr>
<tr><td>Internal Funded Partners:
1. PTB, Germany
2. CEM, Spain
3. CMI, Czech Republic
4. INRIM, Italy
5. NPL, United Kingdom
6. RISE, Sweden
7. TUBITAK, Turkey
8. VTT, Finland</td><td>External Funded Partners:
9. CU, United Kingdom
10. USTUTT, Germany
11. ZAG, Slovenia</td><td>Unfunded Partners:
12. GUM, Poland
13. INMETRO, Brazil</td></tr>
<tr><td colspan="3">RMG: -</td></tr>
</table>