European Association of National Metrology Institutes

Title: Traceable dynamic measurement of mechanical quantities

Abstract

The measurement of force in fatigue testing machines or during crash testing; torque in the drive shafts of engine power test stands and in-cylinder pressure within combustion engines; the use of quality supervised automated screwdrivers in assembly lines; and the determination of cargo mass loaded on ships are a few examples of the diverse range of applications that require measurement of non-static (dynamic) parameters. For dynamic measurements of mechanical quantities such as force, torque or pressure, the provision of traceability is still based on static calibrations. Although the specific need for a dynamic characterisation of the respective measurement equipment is indisputable, this situation has improved only slightly over the last decade.

Proposals for Joint Research Projects (JRPs) submitted for this topic should aim to address the development of a metrological infrastructure and associated methods and algorithms for measurement of key dynamic mechanical quantities.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP 2008, sections on "*Metrology R&D for applied and fundamental metrology"* related to *Industry* on page 12 and *"Innovative set-ups for new industrial and societal needs" on p37*.

Keywords

Dynamic measurement, dynamic system analysis, error compensation, input prediction, measurement uncertainty, mathematical modelling

Background to the Metrological Challenges

Many applications of the measurement of quantities like force, torque and pressure are of a dynamic type, i.e. the measurand shows a strong variation over time. The transducers are however in most cases only calibrated by purely static procedures due to a lack of commonly accepted procedures or documentary standards for the dynamic calibration of mechanical sensors. On the other hand, it is a well-known and accepted fact that mechanical sensors exhibit distinctive dynamic behaviour that shows an increasing deviation from the static sensitivity characteristic as the frequency increases. Additionally the deficiencies in the knowledge of the transducers and the lack of calibration standards also apply to the electrical conditioning part of the measurement chain. The amplifiers used to complete the measurement chain are known to have a distinctive frequency dependence in their response, which has to be taken into account in order to achieve a precise and reliable measurement result. Commonly accepted calibration procedures and measurement uncertainty budgets have not been established so far and, in some cases (bridge amplifiers), a reliable dynamic calibration device still has to be developed.

These limitations lead not only to inaccurate measurement results but in some case culminate in an almost complete ignorance of the magnitude of the measurement uncertainty. Symptomatic of these limitations are passages in important international standards like ISO 6487 "Road Vehicles – Measurement techniques in impact tests – Instrumentation" [1] which include a footnote stating "*3) No method for the evaluation of the dynamic response during calibration of data channels for forces and displacements is included in this international standard since* ***no satisfactory method is known at***

present. The problem will be reconsidered later." An equivalent statement is given in the SAE J211/1 "Instrumentation for Impact Test part1 – electronic instrumentation" [2] in section 4.6.2.2.2.

Thus the main metrological challenge is:

- Lack of traceability for the measurement of dynamic mechanical quantities including
  - Traceability of the transducer response to dynamic stimuli
  - Traceability of the electrical part of the measuring chain to dynamic stimuli

These limitations impact the automotive, aerospace and transport industries, manufacturers of measurement equipment, accredited calibration laboratories and the materials and components testing community. Areas that would benefit from improvements in dynamic measurements include car safety through measurements for crash testing, engine development with the aim of increased drive efficiency and reduced carbon dioxide emission, the dynamic mechanical testing of materials and components for reduction of weight (and thus fuel consumption and environmental impact) without compromising road or air safety, or the monitoring of automated assembly line processes while e.g. screw mounting the components of a car brake system and the dynamic weighing of bulk materials at cargo ship terminals in order to determine the price of the shipped cargo.

Currently, the traceability from the NMI-level to the industrial application for the calibration of torque, pressure or force transducers (including load cells) is in most cases only available on a static basis. For static calibrations by primary methods, the expanded relative uncertainty is, for the three listed measurands, in the order of some parts in 10^5. For the few existing facilities in Europe where research in the field of dynamic calibration is performed, rough estimates of the relative uncertainties in the order of one percent to several percent are discussed. Verification of the dynamic measurement capabilities on the basis of key comparisons is a long way off, due to a lack of validated methods and accepted procedures. Repeated measurements in the field (e.g. in automotive crash testing) currently rely solely on the reproducibility, when using identical device types, and on the comparability of results by using identical set-ups (same dummy type all over the world) - this puts strong restrictions on the market for measurement and testing equipment.

The relevant industry seeks support from the metrological community to provide the infrastructure in facilities, methods, documentary standards and primary calibration services in order to move a substantial step further towards proper traceability for their dynamic measurements. Thus the JRP proposal should be considered as part of a wider, longer-term approach of the metrological community.

Scientific and Technological Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them, in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the JRP protocol.

The core objective is to develop novel metrological methods and tools for dynamic measurement of key mechanical quantities as needed in industrial applications.

The specific objectives are:

1. Development and validation of algorithms and development of appropriate measurement tools for dynamic measurements of mechanical quantities, addressing the various parts of a measurement consisting of the sensor, the signal conditioning and where applicable the signal correction components.
2. Development of methods for the input prediction, i.e. the calculation of the actual value of the measurand and its uncertainty, taking into account the results of the dynamic characterisation.
3. Application of the developed methods to the analysis and characterisation of more complex dynamic measurement systems.

Proposers shall give priority to work that meets documented industrial needs and that which supports transfer into industry e.g. by cooperation and/or by standardisation.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links with the “end user” community. This may be through the inclusion of unfunded JRP partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the “end user” community (eg letters of support) is encouraged.

Where a European Directive is referenced in the proposal, the relevant paragraphs of the Directive identifying the need for the project should be quoted and referenced. It is not sufficient to quote the entire Directive per se as the rationale for the metrology need. Proposals must also clearly link the identified need in the Directive with the expected outputs from the project. In your JRP submission please detail the impact that your proposed JRP will have on any Directives.

You should also detail other impact of your proposed JRP as detailed in the document “Guidance for writing a JRP”.

You should detail how your JRP results are going to:

- feed into the development of urgent standards through appropriate standards bodies or other organisations, such as ISO, CEN or WELMEC
- transfer knowledge to a range of sectors such as the automotive, aerospace, traffic and manufacturing sectors.

You should also detail how your approach to realising the objectives will further the aim of the EMRP to develop a coherent approach at the European level in the field of metrology. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development to be increased
- outside researchers & research organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of 3 years duration.