Standards and Software to Maximize End-User Uptake of NMI Calibrations of Dynamic Force, Torque and Pressure Sensors: a Follow-Up EMPIR Project to EMRP IND09 "Dynamic"

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The aim of this new project is to maximize uptake by industry end users and the Joint Committee for Guides in Metrology (JCGM) of outputs of EMRP JRP IND09 (*Traceable dynamic measurement of mechanical quantities*) by providing concrete, specific and directed advice on how to make best use of the results of dynamic calibrations provided by NMIs.

The project's primary supporter is Rolls-Royce who recognize that dynamic measurements are a key class of problems for high-value manufacturing and are providing data from measurements of unsteady pressure and vibration for the project team to demonstrate the methods developed in EMRP project IND09 in action.

Many applications of the measurement of quantities such as force, torque and pressure are dynamic, i.e. the measurand shows a strong variation over time. Transducers are in most cases calibrated by static procedures owing to a lack of commonly accepted procedures or documentary standards for the dynamic calibration of mechanical sensors. However, it is well known that mechanical sensors exhibit distinctive dynamic behaviour that shows an increasing deviation from static sensitivity characteristics as frequency increases. This lack of dynamic calibration standards also applies to the electrical conditioning components of the measurement chain.

The key output of JRP IND09 was the establishment of primary and secondary NMI-level traceability for the mechanical quantities; dynamic force, dynamic torque and dynamic pressure. However, effective dissemination of dynamic calibrations requires specific advice to be provided to industrial end users on how to use calibration results to correct measurements for dynamic effects and to demonstrate compliance with the *Guide to the expression of uncertainty in measurement*. Although JRP IND09 (i) developed general dynamic models for the complete calibration measurement chain, (ii) developed procedures for uncertainty evaluation in line with uncertainty evaluation for static measurements, and (iii) established general procedures for correcting measurements for dynamic effects, these were not able to be embodied in documentary standards and international guidance documents or in software that can be used in industrial applications to correct measurements and provide GUM-compliant uncertainty evaluations during the lifetime of the project.

Calibration certificates and associated information provided for dynamic quantities by NMIs and accredited calibration laboratories can take several forms, such as parameterized models of the sensors and measuring systems that are calibrated, or frequency response data that describes the amplitude and phase response of the calibrated system as a function of frequency. In addition, sensors alone may be calibrated, so that the end user has to understand how the remainder of the measuring system (amplifiers, filters, digital acquisition systems) affects the performance of the calibrated system.

The calibration methods may also be based on a variety of input signals, sine waves, chirps, steps and impulses, and the choice of signal determines what calibration information may be obtainable and how it may be used. Therefore, industrial end users require (i) guidance on what calibration information to request from NMIs and accredited calibration laboratories, (ii) guidance on how to use this information in their own dynamic measurement applications to ensure compliance with the GUM, and (iii) software that demonstrates the guidance in action.

The specific technical objectives of this project are concerned with providing detailed practical guidance in measurement uncertainty evaluation for industrial end users of the outputs from JRP IND09:

- To provide written advice and guidance to end users, that demonstrates (by means of case studies applied to end-user data) methods to evaluate reliable estimates of dynamic mechanical quantities and their associated uncertainties, taking into account the various forms that calibration results may take as well as correlation effects.

- To make publicly available, validated and tested software for industrial end users to implement the methods described in point 1 above.

- The project will undertake two activities, one associated with each of the project's objectives.

- The preparation and submission of a paper to Metrologia (the main international metrology journal) that describes the application of the methods developed in JRP IND09 to industrial end-user data made available by two key JRP IND09 stakeholders, Rolls-Royce plc and Hottinger Baldwin Messtechnik GmbH (HBM). The data will be for quantities studied in JRP IND09 (dynamic force, torque and pressure). The Metrologia paper will also be used as the basis for input to JCGM Document 103 on building and using measurement models and to Document 110 giving examples of uncertainty evaluations in metrology. Both JCGM documents are currently in the early stages of preparation.

- The production, validation and testing of software that demonstrates the methods developed in JRP IND09 in action on end-user data as well as the production of case study material for inclusion in the publications/contributions in the first activity. The software will be made available for public downloading, therefore marketing and end-user awareness activities will be undertaken by means of targeted end-user emails and the use of the PTB and NPL public websites to advertise the software.

These activities align directly with the identified needs of the end-user, who requires specific guidance on how to apply the outputs of JRP IND09: to their own measurements of dynamic effects in engines, and to their selection of suitable sensors so as to establish confidence in their measurement results; to be able to show that they comply with best practice in uncertainty evaluation in accordance with the GUM; and to understand how the deconvolution and correction algorithms needed for this purpose can be embodied in validated software.

The project will also create impact by enabling efficient application of the methods developed in JRP IND09 by disseminating software that demonstrates the methods in action on industrially relevant example data, to industry end users and through the public websites of NPL and PTB.

In the longer term, the outputs of the project will assist high-value manufacturing in the optimization of products and processes where dynamic measurements are necessary. To quote Rolls-Royce itself, "As companies strive to reduce margins even further to optimize performance, costs and reliability, it becomes more important to quantify the uncertainties involved rigorously and to be able to demonstrate metrological traceability of the resulting data".

Figure 1 shows the effect of ignoring dynamic effects. It shows how the use of a statically calibrated sensor produces erroneous results, which becomes evident when compared with the results obtained by a dynamically calibrated sensor. The project will ensure that end users are able to correct measurements for dynamic effects and thus produce good estimates of the underlying dynamic signal.

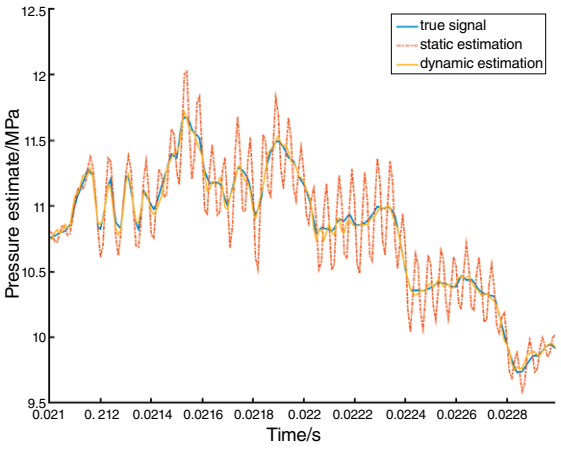

Figure 1:
Estimating the value of a dynamic signal: effect of ignoring the dynamic properties of a measuring system compared with taking dynamic effects into account.