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Development of measurement and calibration techniques for dynamic pressures and temperatures (DynPT): background and objectives of the 17IND07 DynPT project in the European Metrology Programme for Innovation and Research (EMPIR)

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Abstract. This project has five specific objectives: To provide traceability for dynamic pressure and temperature through development of measurement standards and validated calibration procedures; To quantify the effects of influencing quantities on the response of dynamic pressure and temperature sensors, in order to determine the appropriate calibration procedures and measurement uncertainties for industrial measurements; To develop new measurement methods and sensors for measuring dynamic pressure and temperature in demanding industrial applications, and to demonstrate the improved accuracy and reliability obtained with those; To validate all of the methods and sensors developed in this project through demonstrations in selected industrial applications; and To ensure by close engagement with industry, that the developed calibration and measurement techniques and technology are adopted by them. The challenge is that in many industrial applications pressure and temperature measurements are performed under dynamically changing conditions. The aim of this project is to improve the accuracy and reliability of pressure and temperature measurements in these challenging conditions. A European joint research project named Development of measurement and calibration techniques for dynamic pressures and temperatures (shortname DynPT) started in the summer 2018.

1. Introduction

The European joint research project named Development of measurement and calibration techniques for dynamic pressures and temperatures (shortname DynPT) started in May 2018. The project is part of the European Metrology Programme for Innovation and Research (EMPIR).
The overall objective of this project is to improve the accuracy and reliability of pressure and temperature measurements in dynamically changing conditions. Dynamic measurements are a key requirement for process control in several demanding applications, such as automotive, marine and turbine engines, manufacturing processes, and ammunition and product safety. Establishing SI traceability for these measurements through development of dynamic measurement standards and methods, and characterised sensor technologies including means of estimating measurement uncertainties in real process conditions, will significantly improve the quality of measurements and thus support the innovation potential and competitiveness of European industry.

The project will continue on the work started in EMRP IND09 Dynamic [1-9], but with widened scope including dynamic temperature.

2. Background to the Metrological Challenges

At the moment, most of the dynamic pressure sensors are calibrated using static pressure measurement standards. However, as the dynamic and static pressure characteristics of sensors may differ significantly, this calibration procedure can result in errors. To improve accuracy and reliability of results, the sensors need to be calibrated at conditions which better correspond to their actual use. Additionally, traceability for the primary measurement standards needs to be established through comparison measurements.

In many cases, industrial applications where dynamic pressures are measured, dynamic temperature changes take place at the same time [10-11]. The temperature changes are quick and difficult to measure reliably. In order to improve pressure sensor characteristics, fast and reliable temperature measurements are needed to compensate temperature effects on the sensing pressure element. At the same time, dynamic temperature measurements by itself are vital for many industrial applications (e.g., internal combustion engines, response time of safety temperature systems in nuclear power plants, etc.). Hence, there is a pressing need for the development and evaluation of methods and devices, which enable measurements of quick dynamic temperature changes. Temperature probes used in several different applications are currently calibrated at steady state conditions, despite the fact that dynamic uncertainty can be much larger compared to steady-state [12].

The effect of influencing quantities such as, pressure, temperature, signal frequency (e.g. from seconds down to nanoseconds) and measuring media (fluids vs. gases) on the response of dynamic pressure and temperature sensors are not well known. Preliminary results from a pilot study [13] on dynamic pressure suggest that these effects can be significant and certainly larger than the static pressure calibration uncertainties. The effects need to be investigated and quantified in order to evaluate, if the calibration is still valid in real application conditions. The realistic achievable level of uncertainty also needs to be estimated.

3. Objectives

The project focusses on traceable measurement and calibration methods for dynamic pressure and temperature, and aims to improve their accuracy and reliability. In order to achieve the goal, the project has set five specific objectives:

- To provide traceability for dynamic pressure and temperature through development of measurement standards and validated calibration procedures. Pressure and temperature ranges up to 400 MPa and 3000 °C, respectively, will be covered with uncertainties relevant for industries and applications involved, e.g., 1 % for internal combustion engine applications.
- To quantify the effects of influencing quantities – such as pressure, temperature, signal frequency, and measurement media – on the response of dynamic pressure and temperature sensors, in order to determine the appropriate calibration procedures and measurement uncertainties for industrial measurements. Novel simulation models will be developed for analysing the effect of transient conditions on measurement results.
- To develop new measurement methods and sensors for measuring dynamic pressure and temperature in demanding industrial applications. Improved accuracy and reliability obtained
with the new methods and sensors will be demonstrated, including for the durability of dynamic pressure sensors. The pressure and temperature ranges up to 400 MPa and 3000 °C, respectively, will be covered with uncertainty levels relevant for respective application.

- To validate all of the methods and sensors developed in this project (i.e. non-contact temperature measurement methods and novel pressure sensors) through demonstrations in selected industrial applications.
- To ensure by close engagement with industry, that the developed calibration and measurement techniques and technology are adopted by industry. Workshops and guidelines for the best measurement and calibration practices including uncertainty estimation of dynamic pressure and temperature will be prepared to facilitate efficient uptake by industry and serve as input to the preparation of international standards.

4. Work packages

The project is composed of three technical work packages (WP 1-3) and one work package devoted to impact:

4.1. WP1: Improved measurement standards and calibration methods

In this work package new measurement standards and calibration methods for dynamic pressure and temperature will be developed. Also, existing measurement standards and calibration methods will be improved to provide traceability in the pressure range 0.1 MPa up to 400 MPa and temperatures up to 3000 °C.

At the moment, the measurement ranges of primary dynamic pressure standards (shock tubes and drop weight systems) are not overlapping. The gap between these will be closed; Shock tubes will be further developed to extend the measurement range up to 40 MPa and drop weight systems will be further developed and improved to extend the pressure range down to 2 MPa. At the same time, measurement uncertainties of both methods will be reduced to better meet the industry demand of 1 %. These developments will make it possible to study the realization of the dynamic pressure unit through an interlaboratory comparison of methods, and thus establish a solid metrological basis for traceability of dynamic pressure for the first time.

Dynamic temperature calibration methods will be further developed and metrologically validated to enable traceable dynamic calibrations. Two new approaches for calibrating dynamic temperature sensors will be investigated: a modified shock tube, and a procedure based on radiance calibration of dynamic thermometers to provide traceability to the ITS-90 temperature scale via high-temperature black body facilities.

4.2. WP2: Influence of process conditions

Influence of process conditions on dynamic pressure and temperature sensors will be studied and quantified in this work package. Based on the results, appropriate measurement and calibration procedures will be defined, and improved uncertainty estimations for dynamic measurements performed under real process conditions will be developed.

The effect of different process parameters on dynamic pressure sensors performance will be studied. Similarly, the effects process parameters, such as the pressure and composition of the measurement media and temperature signal frequency, on the response of dynamic temperature sensors will be studied. Based on the results of the above mentioned studies, recommendations to industrial stakeholders on appropriate calibration and measurement procedures will be made, as well as uncertainty estimates for dynamic pressure and temperature measurements under real process conditions. Realistic uncertainty estimations are crucial for establishing traceability of measurements in industrial applications.

4.3. WP3: New measurement methods and sensors for industrial applications
The aim of this work package is to develop measurement methods and in-development sensors that are suitable for measuring dynamic pressure and temperature in harsh conditions, with particular emphasis on their application in internal combustion engines and ammunition testing. Currently, the reliability of in-cylinder pressure and temperature measurement is limited by the short lifetime of pressure sensors and the limited response times of temperature sensors. Therefore, novel sensor technologies with improved reliability will be developed, validated and tested in real process environment.

The newly developed methods and sensors will be tested and metrologically characterized in the respective facilities. Their performance, in terms of accuracy and durability, will be compared to currently available sensors. After a thorough validation in the lab, the applicability of the newly developed methods and sensors will be demonstrated in a maritime internal combustion engine. In addition, the benefit of having dynamically calibrated pressure sensors instead of statically calibrated sensors will be demonstrated in the relevant tests. Finally, the possible degradation of performance of the tested sensors will be verified in order to establish recommendations on the most suitable methods for measurement under harsh conditions.

4.4. WP4: Creating impact
It is going to be ensured, that the knowledge created in this project is effectively disseminated to industrial level. A close dialog with end-users and other stakeholders throughout the project will ensure that the project is at all times aligned with the needs of industry. This work package will also ensure that the project outcomes are available for exploitation by a wide range of stakeholders in industry, metrology, and the scientific community and societal institutes and bodies.

5. Conclusion
The project will focus on developing traceable measurement and calibration methods and improved sensors for dynamic pressure and temperature. The aim is to improve the accuracy and reliability of dynamic pressure and temperature measurements in industrial applications. Traceable dynamic calibrations will be made available for industry as well as documented procedures for performing dynamic measurements and evaluating uncertainties. The project started in May 2018 and will last for three years.

6. Acknowledgements
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