Publishable Summary for 17IND07 DynPT
Development of measurement and calibration techniques for dynamic pressures and temperatures

Overview

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.

Need

Improved dynamic measurements of pressure and temperature are needed for developing next generation technologies and products with improved quality, energy and material efficiency, and safety. Developments within this project will have a wide-ranging impact on competitiveness of European industry, mitigating climate change and improving the safety and welfare of European citizens.

The need for better accuracy and reliability of dynamic measurements is driven from a variety of industrial sectors. Better knowledge about the pressure and temperature inside an internal combustion engine is needed for improving engine performance, i.e. engine power and fuel consumption. In manufacturing processes, e.g. injection moulding, better process control through improved dynamic pressure measurements will result in higher product quality and more efficient use of materials and energy. Improved dynamic measurements is needed in many safety critical applications, such as crash testing of cars, ammunition safety testing, explosion protection, and dynamic mechanical testing of materials, to reduce the currently very wide safety margins and thus ensure user safety in a cost effective way.

Measurement standards for dynamic pressure were developed in an earlier joint research project (EMRP IND09 Dynamic). Further development and validation is, however, necessary to enable industry to adopt these new calibration methods. In addition, dynamic temperature needs to be considered because in many processes, e.g. inside an engine, dynamic pressure and temperature changes take place simultaneously. Current practice to calibrate pressure and temperature sensors only at static conditions significantly limits the achievable measurement accuracy, errors up to 10 % might occur. To ensure the quality of measurements, new sensor technologies that can withstand harsh condition, e.g. inside an engine, is needed in addition to a better understanding of the influence of process conditions on sensor response. To implement a shift from static to dynamic, industry needs guidelines and standards for dynamic measurements and calibrations.

Objectives

The overall objective of the project is to improve the accuracy and reliability of dynamic pressure and temperature measurements that are widely performed as part of manufacturing, product and safety testing, and research and development activities. The specific objectives of the project are:

1. **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 ICE applications.
2. **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.

3. **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 400 MPa and 3000 °C, respectively, will be covered with uncertainty levels relevant for respective application.

4. **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.**

5. **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.

Progress beyond the state of the art

This project is continuing the work started in EMRP IND09 *Dynamic* and the scope is widened to include dynamic temperature. Most importantly, going beyond IND09 the traceability up to the end users will be established and supported by a study on the influence of process conditions including documented calibration and measurement procedures.

Current practice to calibrate dynamic sensors with reference to static methods might introduce errors up to 10 %. In this project, new and improved dynamic measurement standards for pressure and temperature are developed to provide traceability in terms of dynamic tests and measurements instead of static. The new dynamic measurement standards with related validated calibration procedures will enable calibrations at conditions that better corresponds to actual use with an uncertainty level demanded by industry, i.e. 1 %. Some of the dynamic pressure primary measurement standards are now ready for service providing metrologically traceable dynamic calibrations. These measurement standards are based on the drop weight and shock tube methods. For the dynamic temperature, a method for radiance calibration of the dynamic thermometer traceable to ITS-90 devised using high-temperature blackbody furnace up to 3000 °C has been developed and successfully trialled with fibre-optic dynamic thermometer.

There are no appropriate means available to evaluate the uncertainty of dynamic measurements due to insufficient understanding of factors influencing their response. In this project, the influence of process conditions – such as pressure, temperature, signal frequency, and measurement media - on the response of dynamic sensors are to be investigated and quantified. Based on these results, appropriate calibration procedures and uncertainty estimation methods will be defined.

Current dynamic sensors show insufficient accuracy and reliability when used in harsh conditions, such as inside a combustion engine. In this project, novel sensors, e.g., based on non-contact techniques with improved reliability are developed and characterised. Design, construction and modelling of the fibre optic based dynamic thermometer with measurement range up to 3000 °C is completed. This novel ultra-fast fibre-optic based dynamic thermometer is traceably calibrated in a wide temperature range, up to 2600 °C, and tested for speed (up to 250 kHz) using the pyrotechnic facility and cross-validated. The work done so far has been presented at the EVI-GTI 2019 conference on gas turbine instrumentation in Graz, Austria in November 2019. Improvement of the novel dynamic pressure sensor designed for measuring pressures up to 30 MPa and to withstand transient pressure spikes of up to 100 MPa is completed. First test results of this sensor have been presented at the 19th International Congress of Metrology (CIM2019) in Paris, France in September 2019 and in 4th Dresden Metrologist’s Summit in Dresden, Germany in May 2019.

The performance of the new developed sensors will be demonstrated in real engines. The developed methods will be validated through these demonstrations, too. Based on the results, recommendations for suitable dynamic pressure and temperature measurement methods and sensors for use in harsh conditions will be prepared.

Results

In this project, a solid framework for dynamic pressure and temperature measurements will be developed. This will enable a shift in paradigm from static to dynamic, which will significantly improve the accuracy and reliability of dynamic measurements in industry.

Traceability for dynamic pressure and temperature

This project is establishing traceability for dynamic measurements, and thus, a solid basis for accurate and reliable dynamic measurements of pressure and temperature through development and validation of dynamic measurement standards. The pressure range from 0.1 MPa up to 400 MPa and temperatures up to 3000 °C are covered and the work towards target uncertainty levels demanded by industry, 1 % and 3 %, respectively, is ongoing. The measurement range of the dynamic pressure primary standard based on the drop-weight method is extended down to 2 MPa. Characterization and improvement of measurement uncertainty towards the target uncertainty is ongoing. Shock tube facilities have been improved. A method for radiance calibration of the dynamic thermometers traceable to ITS-90 up to 3000 °C with an uncertainty of less than 3 % is devised. New calibration services are promoted and made available to accredited calibration laboratories and end-users to enable a wide-spread use of the developed measurement capabilities. Traceable dynamic pressure calibration services are already opened by the project partners. Guidelines for dynamic calibrations and input to relevant standards will support industry in a shift to dynamic calibrations.

Effects of influencing quantities

As a result of comprehensive studies on the influence on process conditions on the sensor response, reliable data on the behaviour of dynamic sensors at “real world” measurement conditions will be obtained. Specified liquids are selected to investigate the influence of different liquid media on the pressure sensor response and tests have been performed to study the influence between gas and liquid media. A test chamber capable of handling multiphase media is designed to study the influences on pressure sensor response. This data is valuable for sensor manufacturers and end-users as it supports the interpretation of measurement results, and most importantly, enables improvements in the quality of measurements through development of better sensors and data analysis methods. To support this, models are developed and validated to establish a robust physical basis for analysing measurement data. In addition, appropriate calibration procedures will be defined, as well as procedures for estimating measurement uncertainty in dynamic measurements.

New measurement methods and sensors

In this project, novel pressure sensors (non-contact techniques and a patented piezoelectric design) and high-speed temperature sensors with improved reliability are developed and characterised in the laboratory. Design of a novel dynamic pressure sensor is further improved, and it is measuring pressures up to 30 MPa and withstands transient pressure spikes of up to 100 MPa. The metrological characterisation of this pressure sensor is ongoing. Development of a fibre optic dynamic pressure sensor is ongoing. Design, construction and modelling of the fibre optic based dynamic thermometer with a measurement range up to 3000 °C and associated models are completed. This dynamic thermometer is traceably calibrated and cross-validated.

Validation of the methods and sensors developed in this project

Tests in real engines will be performed to demonstrate and compare their performance to currently available sensors. Based on the results, recommendations for suitable dynamic pressure and temperature measurement methods and sensors for use in harsh conditions will be prepared.

Impact

Impact on industrial and other user communities

Early uptake will be among accredited laboratories, companies manufacturing dynamic pressure and temperature sensors and also industry end-users exploiting the new calibration capabilities developed in this project. In engine development, dynamically characterised pressure and temperature sensors will enhance the accuracy and reliability of measurements inside the engine and thus support development of engines with improved performance. In injection moulding, which is the principle method for plastic manufacturing, improved dynamic pressure measurements will result in better quality of the end products and enhance efficiency of the process through reduced scrap. Uptake and dissemination of project outcomes will be ensured by close interaction with industry during the course of the project through Stakeholder Committees, workshops, training courses, seminars and conferences. Almost ten conference presentations, a presentation at an external event,

a training course and a workshop on Improved measurement of dynamic pressures and temperatures have been given. The size of audience reached so far is approximately three hundred people.

Impact on the metrology and scientific communities
As an outcome of this project, calibration services for dynamic pressure and temperature will be readily available to customers at several National Metrology Institutes covering a wide pressure range 0.1 – 400 MPa and temperatures up to 3000 °C. This will be an important step in the transition from static to dynamic calibrations within the measurement community. Based on the knowledge generated in the project, a calibration guide for dynamic pressure will be developed. This guide will be the first of its kind, and as such, an important reference for industrial calibration laboratories developing calibration capabilities for dynamic pressure. Recommendations for temperature measurements under harsh conditions will also be given.

Impact on relevant standards
Guidelines for best measurement and calibration practices developed within this project will serve as input for ongoing work towards standardisation, e.g., in ISO/TC108/WG34/WT19666: Dynamic pressure calibration and EN 60079-1 on explosion protection. Consortium members are participating actively on these works. A close interaction and involvement in relevant EURAMET and BIPM consultative committees in the related fields will provide a channel for regional and international dissemination of the best practices developed within the project. Regarding the safety testing of ammunition, the WG GT 2-7 (“Qualité des traveaux”) of the C.I.P. will be informed about the progress of this project. A presentation of consortium activities has been given in the WG GT 1-1.

Longer-term economic, social and environmental impacts
Economic impact – Internal combustion engine and injection moulding are both multi-billion-dollar industries, where even a slight improvement in engine and process performance would give European companies in this line of business a competitive edge through better quality and reduced material and energy costs.

Environmental impact – The transportation and manufacturing industry together accounts for roughly 50 % of the global CO_2 emissions and thus an even slight improvement in energy and material efficiency would have a significant impact on the environment.

Social impact – European companies adopting new calibration and measurement techniques developed within this project will gain a competitive edge in the highly competitive global market of internal combustion engines and manufacturing. This, in turn, will generate economic growth, jobs and welfare for European citizens.

List of publications

Yasin, Durgut *et al* 2019. Improvement of dynamic pressure standard for calibration of dynamic pressure transducers. Proceedings of 19th International Congress of Metrology 27009. doi:10.1051/metrology/201927009

Saxholm, Sari *et al* 2018. 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). J. Phys.: Conf. Ser. 1065 162015. doi:10.1088/1742-6596/1065/16/162015

Yasin, Durgut *et al* 2018. Development of Dynamic Calibration Machine for Pressure Transducers. J. Phys.: Conf. Ser. 1065 162013. doi:10.1088/1742-6596/1065/16/162013

Project start date and duration:	1.5.2018, 36 months	
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Internal Funded Partners: 1 VTT, Finland 2 ENSAM, France 3 NPL, United Kingdom 4 PTB, Germany 5 RISE, Sweden 6 TUBITAK, Turkey 7 VSL, Netherlands	External Funded Partners: 8 DTU, Denmark 9 KTH, Sweden 10 Minerva, Netherlands 11 Wärtsilä, Finland	