Publishable Summary for 14IND06 pres2vac
Industrial standards in the intermediate pressure-to-vacuum range

Overview

The purpose of this JRP is to enable the SI traceable measurement of absolute, positive and negative gauge pressures in the intermediate range from approximately 1 to 10^4 Pa with an accuracy level of $3\times10^{-5}\ p + 0.005$ Pa in order to increase the efficiency of industrial productions and processes. These objectives include providing primary and transfer standards for dissemination of the pressure scale and developing appropriate calibration methods for high-accuracy state-of-the-art pressure devices in order to establish a calibration service in this pressure range.

Need

The overall objective of this project is to enable the SI traceable measurement of absolute, positive and negative gauge pressure in the intermediate range from approximately 1 to 10^4 Pa. This will be done for relevant industries such as power plants, cleanroom technologies, petrochemical and pharmaceutical production, storage of nuclear and toxic wastes, in order to support innovation and efficiency in industrial production and processes.

Reliable, accurate, traceable pressure measurements are needed for such industries as they are subject to strict international requirements with respect to safety, precision, sterility and performance. Therefore, to ensure traceability of measurements with sufficient accuracy for the demands of industry, high-accuracy primary standards for disseminating the pressure scale in the intermediate range need to be developed.

Low absolute, differential, positive and negative gauge pressure measurements play a vital role in numerous industrial processes that demand high accuracy of positive and negative gauge pressure measurements at all stages of the traceability chain. Conventional calibration procedures (applied to instruments for low differential pressures) are also extremely dependent on weather conditions, especially the stability of atmospheric pressure; and often the target uncertainty level cannot be achieved. Therefore, there is a need for alternative calibration approaches and techniques to ensure a constant low level of uncertainty, independent of ambient conditions, and for a high-accuracy calibration service.

The EU mercury strategy includes a comprehensive plan addressing mercury pollution both in the EU and globally. In addition, an amendment by the Commission Regulation restricts the use of mercury in barometers and sphygmomanometers for industrial and professional use from 10 April 2014. Therefore, a support is required for the replacement of primary mercury manometers which are still in use in many research institutions and reference laboratories.

Objectives

The specific objectives of the project are:

- **To develop and characterise primary and transfer pressure standards -** for realisation and dissemination of the pressure scale in the intermediate range 1 to 10^4 Pa. This will enable comparisons with both primary high pressure standards, e.g. dead-weight pressure balances and liquid column manometers, and primary vacuum standards, usually static and continuous expansion systems.
- **To develop calibration methods for positive and negative gauge pressure standards in the range from approximately -10^5 to 10^4 Pa** - in order to reduce the uncertainty of the pressure calibration down to $3\times10^{-5}\ p + 1$ Pa independent of variable ambient conditions, and in industrial conditions to better than $2\times10^{-4}\ p + 3$ Pa. This will enable accurate calibrations with a high level of accuracy that is independent of variable ambient conditions.
- **To meet the EU restrictions of mercury use in measuring devices (barometers)** - replacement of primary mercury manometers with alternative pressure standards.

- **To establish a calibration service in the range of approximately -10^5 to 10^4 Pa of gauge pressure and approximately 1 to 10^4 Pa of absolute pressure** – with an accuracy level sufficient for accredited calibrating laboratories and industrial companies. This will be achieved by the development of state-of-the-art pressure measurement instrumentation such as force-controlled piston gauges with a resolution of 1 mPa.
- **To engage with industries that utilise pressure in the intermediate range 1 to 10^4 Pa** - facilitating the uptake of the technology and the measurement infrastructure developed by the project.

Achieving these objectives will support the uptake and development of new innovative industrial products, e.g. by instrumentation manufacturers, and hence the competitiveness of EU industry.

Progress beyond the state of the art

Primary and transfer pressure standards for a consistent dissemination of the pressure scale in the intermediate range 1 to 10^4 Pa

Primary pressure standards - dead-weight pressure balances and liquid column manometers - allow traceability of the pressure unit to the SI basis units kilogram, meter and second. The operating range of the dead-weight pressure balance is limited by approximately 5 kPa. The lowest pressure accurately measured with mercury manometers is approximately 1 kPa. Oil is an advantageous alternative to mercury due to its low density, low vapour pressure and much better stability of the free surface, but is not widely used because of a relatively large variation of the oil density with pressure. The project will go beyond this by the *in situ* measurement of oil density in a novel oil micromanometer.

New force-balanced piston gauges (FPGs) allow gauge and absolute pressures to be accurately measured from 15 kPa downwards to zero, but have been used only as secondary standards so far. This project will go beyond this by developing appropriate 3D flow models taking into account molecular properties of gas. Combined with dimensional measurements carried out on piston-cylinders, for the first time their effective area will be determined as a function of variable pressure conditions. In this way the FPGs will be characterised as primary pressure standards.

Calibration methods for positive and negative gauge pressure standards in the range from approximately -10^5 to 10^4 Pa

To solve the problem of inaccurate pressure calibrations due to unstable ambient conditions, new procedures and techniques will be developed for low differential pressures calibrations. This will reduce the calibration uncertainty down to $3 \cdot 10^{-5} \times p$ + 1 Pa independent of variable ambient conditions and will be beneficial for accredited and industrial calibration laboratories.

EU strategy on restrictions of mercury use in measuring devices (barometers, sphygmomanometers)

Mercury manometers are operated by very few European NMIs, but are still used by numerous calibration, industrial and research laboratories. Commission Regulations restrict the use of mercury in barometers and sphygmomanometers for industrial and professional use. The project will enable users of mercury-containing pressure devices to meet the restrictions for the use of mercury in pressure measurements. Within the project, two strategies will be followed: first, investigation of alternative standards based on refractometry techniques, and second: comparisons between mercury-containing and existing mercury-free pressure standards. The comparisons will be used to specify conditions and methods with which the alternative pressure standards have comparable or even better measurement capabilities than those of mercury manometers.

Calibration service in the range of approximately -10^5 to 10^4 Pa of gauge pressure and approximately 1 to 10^4 Pa of absolute pressure

Advanced FPGs, which accurately measure pressure in the range 15 kPa downwards to zero, can only be calibrated against dead-weight pressure balances or mercury manometers at pressures above few kilopascals. Below these pressures, there are no alternative pressure standards. By developing new reference pressure standards and calibration methods an adequate calibration service in Europe will be provided.

Currently, the traceability for industrial calibration services in the range of approximately -10^5 to 10^4 Pa of gauge pressure and approximately 1 to 10^4 Pa of absolute pressure is insufficient. The project will develop a calibration service better than $2 \cdot 10^{-4} \times p$ + 3 Pa under industrial conditions.

Results

New primary and transfer pressure standards for realisation and dissemination of the pressure scale in the intermediate range 1 to 10^4 Pa will be developed and characterised. New calibration methods for positive and negative gauge pressure standards in the range from approximately -10^5 to 10^4 Pa with reduced uncertainty, independent of variable ambient conditions and applicable in industrial conditions will be developed. To meet the EU restrictions of mercury use in pressure measuring devices, conditions for replacement of mercury-containing manometers with alternative pressure standards will be created. A calibration service in the range of approximately -10^5 to 10^4 Pa of gauge pressure and approximately 1 to 10^4 Pa of absolute pressure, with an accuracy level sufficient for accredited calibrating laboratories and industrial companies, will be established. Engagement with industries that utilise pressure in the intermediate range 1 to 10^4 Pa will facilitate the uptake of the technology and the measurement infrastructure developed by the project.

The results of this project will also provide input to international guidelines and standards for calibration and pressure measurements in the intermediate pressure range. In addition, the project will organise workshops and present the project's results at conferences and in scientific journals. Knowledge will also be disseminated to end users through training courses. Furthermore, an advisory group consisting of industrial stakeholders will regularly meet to exchange information with the consortium and ensure that the project is delivering relevant information for end users.

Impact

The project will impact many industries. The reliability and accuracy of low gauge, differential and absolute pressure measurements will be improved at NMIs, accredited commercial laboratories, in industry and with end users. It will also have a direct and indirect positive influence on the European economy, environment and society.

Impact on relevant standards

The project will have an impact on the Commission Regulation (EU) No 847/2012 of 19.9.2012 which restricts the use of mercury in barometers and sphygmomanometers for industrial and professional use. The execution of the Directive will be facilitated by providing equivalent alternative pressure standards. It will also support the reduction in the number of mercury-containing pressure-measuring devices in Europe.

In addition, the consortium will promote the results of the project within the standardisation community and will provide input into the standardisation process (ISO, CEN, and EA). For ISO, the standards relevant to the project that are in preparation/revision will be identified, and the work on these standards will be suggested to the appropriate working groups or committees.

The project partners who are members of corresponding technical committees will inform them about the results of this project and will endeavour to ensure they are incorporated in any updates to the standards or guidelines. Representatives on the corresponding committee or working group from the project partners will jointly ask the chairperson to include a point in the agenda to briefly present the outputs of the project related to the working group activities and ask for comments to the other committee/working group members. Where appropriate a written report will be submitted for consideration by the committee or working group.

Impact on industrial and other user communities

The project will establish a new primary standard and support dissemination of the pressure scale in the intermediate pressure range 1 to 10^4 Pa. This will improve the reliability and accuracy of low gauge, differential and absolute pressure measurements at many levels from NMIs, to accredited commercial laboratories, to the end users. This traceability is the basis for more accurate pressure measurement (e.g. for the cleanroom technologies and processes) and will allow realisation of tighter tolerances of non-equilibrium conditions and, as a consequence, reduce energy expense and costs without the loss of safety, sterility and precision. The costs of operation with toxic and nuclear materials as well as of the storage of environmentally dangerous toxic and nuclear wastes should also be reduced and the safety of these processes increased.

The project will establish improved calibration service that will give access to end-users to calibrations in the range 0 to 15 kPa absolute pressure with uncertainties on the level $3 \cdot 10^{-5} \times p$ + 5 mPa. Such conditions will be beneficial for more efficient and safe use of airspace by aircraft.

Dissemination of traceability amongst NMIs will provide access to improved capabilities for national and accredited laboratories in Europe and support consistency in measurement capabilities. Additionally, it will benefit the industrial companies that rely on such calibration services. Information on the calibration services will be disseminated via accredited bodies (for pressure) in Europe, calibration laboratories and their committees of experts for pressure. Transportable middle vacuum range calibration equipment will be created to provide a calibration service at an end user site.

The project outcome will be disseminated to industrial stakeholders such as manufacturers of pressure measuring devices in the corresponding pressure range as well as end users and calibration laboratories. The participation of industrial partners in the project will also help to align the project with industrial needs.

Finally, the project will create preconditions for the replacement of mercury-containing pressure-measuring instruments mercury-free alternatives. The results will be provided to policy makers and stakeholders in the European industry including the CCM Pressure Working Group, IMEKO TC 16, JRP Stakeholder Committee and Pressure subcommittees of the RMOs, forecast services and airlines.

At least one international and one national workshop aimed at collaborators and stakeholders will be organised for the measurement and traceability issues in the gauge and absolute pressure ranges below 15 kPa, improvement of pressure measurement accuracy at variable ambient atmospheric conditions and industrial environment.

Impact on the metrological and scientific communities
Based on the project results, a recommended *mise en pratique* for assuring traceability in the range 1 Pa – 15 kPa using FPGs in both absolute and gauge mode will be derived. This will create a large impact on calibration laboratories. The recommendation is to be presented to the accreditation authorities in Europe as well as to end users and manufacturers of FPGs.

In the area of FPGs, knowledge transfer from experienced NMIs to those less experienced on how to use this new type instruments will be very beneficial. On a broader scope, the project will strengthen the collaboration of European NMIs and will increase their competitiveness with NMIs outside Europe. Secondary accredited commercial laboratories will also gain a better calibration service from the European NMIs which will avoid high costs for calibration of their standards abroad and will increase their calibration capabilities. A draft calibration guide for using FPGs in both absolute and gauge mode will be produced and submitted to EURAMET for publishing as a EURAMET calibration guide.

Improved calibration methods for positive and negative gauge pressure standards in the range from approximately -100 kPa to 15 kPa will be developed. A EURAMET calibration guide for positive and negative gauge pressure standards will be drafted that will describe different calibration systems, conditions under which they are to be operated, procedures to be followed, uncertainties aimed at and the best working practices. The draft guide will be submitted to EURAMET and made available to end users.

Project start date and duration:		01 June 2015, 36 months
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