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Framework for development of an instrument thermal controller

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Abstract

As a national measurement institute, NPL aims to deliver high accuracy calibration of reference standards to science and industry. A new engineering project has emerged to develop a secondary standard calibration system for 1-dimensional artefacts, called the "1D-machine". This instrument is specified to be an all-in-one calibration device, able to provide a traceable link to the primary realisation of the metre, for the lengths of artefacts of various types. These are gauge blocks, length bars, step gauges, and internal & external diameter standards. The ability to measure multiple types of artefacts presents several advantages, including small form factor, process automation, adaptability to customer demands; this new concept also promises a step change in measurement uncertainty.

This new instrument relies on laser interferometry measurement through air at temperature controlled at or close to 20 °C, along a distance varying from a few millimetres to 2 metres. This interferometric measurement is influenced by the refractive index of air, which for instance would be locally affected by heat from various thermal sources, such as motion system actuators, measurement artefacts introduced at different temperatures, convective air flow within the enclosure, thermal radiation… To overcome these issues, thermoregulation of the optical transit path through enclosed air has been proposed, relying on using multiple air diffusers (with independent thermal control) to ensure the uniformity and stabilisation of enclosed air volume temperature, over the full measurement displacement range. The concept is being studied as part of a prototyping or breadboarding phase of instrument development.

In 2021, the research team began the development of a thermal breadboard (as a smaller scale analogue of the full system), consisting of a rectangular enclosure with two diffusers located internally along the top longitudinal edges. The diffusers introduce air at a controlled temperature from external heat exchangers, built around aluminium heatsinks connected to thermoelectric coolers. Temperature is measured at multiple locations within the enclosure (and the air delivery system) by means of PT-100 resistance thermometers, serving as feedback sensors for a MIMO controller in development. The temperature controller targets a temporal and spatial uniformity of ±0.01 °C (at 20 °C) over a 400 mm distance, with a setpoint temperature from 18 to 22 °C.

While the experimental system has long thermal time constants, controller development has been accelerated through the deployment of a model-based design approach (MATLAB/Simulink), combined with low-cost control hardware. Concept, early development, and implementation will be presented during the conference.

Control, Measuring instrument, Prototyping, Temperature