

Report to the CCM from the National Physical Laboratory, UK
Updates covering the period since the 18th CCM (May 2021)

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1. Main research and development activities related to CCM activities

1.1 Mass

NPL continues to maintain the UK's national standard of mass, copy No. 18 of the IPK, with traceability to the consensus value. Two of NPL's primary kilogram standards, one of platinum-iridium and one of tungsten, continue to be stored in specially-constructed vessels for long-term storage in pure nitrogen. The pressure in the vessels is continuously monitored and maintained at 10 % above atmospheric pressure to ensure the integrity of the storage medium. Contamination is monitored in real-time using a quartz crystal microbalance and the storage vessel also contains surface samples which can be characterised by surface analysis before and after the storage period. A new Sartorius 10 kg mass comparator has replaced the Mettler AX10005.

NPL has provided traceability for particulate monitoring applications using a custom-designed environmental monitoring chamber attached to the NPLone vacuum balance. Micro-particle filters were exposed to controlled levels of contamination, monitored using a particle counter, and the uptake of the filters was measured gravimetrically.

NPL has recently established a measurement service to determine the centre of gravity of a range of components using a range of devices based on the "weighbridge" apparatus described in the 1994 Metrologia publication by Richard Davis. Recent measurements have been made on satellite and aerospace components up to masses of about 20 kg.

1.2 Kibble balance

NPL continues to develop its next-generation Kibble balance, collaborating with RISE, Sweden and NMISA, South Africa who will receive copies of the balance. The mechanical design for the prototype Kibble balance system has been completed and the mechanical components manufactured. Two forms of mechanical design will be evaluated, one using flexure strips and one using parallel guidance linkages (watt linkages) to guide the movement of the inner frame of the balance. The watt linkages have been assembled and initial tests have shown levels of stiffness and linearity compatible with the performance requirements of the balances. The tare and weighing magnets have been assembled, using tooling specifically developed to control the alignment of the magnet and pole pieces. The temperature control system developed for the magnets has been installed and initial tests in an uncontrolled laboratory environment show temperature stability being maintained to better than 10 mK. This is expected to improve significantly when transferred into vacuum and to deliver magnetic field stability of better than one part in 10^8 .

NPL commissioned four copies of the Demonstration Kibble balance system, a portable demonstrator which comprises all the components of a working Kibble balance such as a magnet, a coil, a tare mechanism, a guidance mechanism, a current source, voltage measurement, velocity measurement, a real-time computer, balance control software, and a mass lift. The real-time balance control software was developed to run in both weighing and moving modes, combining the

measurements to determine mass. Balances were supplied to both NMISA and RISE to assist with the ongoing collaborations and to allow development of measurement and analysis processes.

The control and electronics modules developed for the Demonstration balance were used together with a single magnet/coil system and a 3D-printed, low-mass pivoted flexure structure, to construct a simplified balance to demonstrate the feasibility of making gram-level measurements.

NPL, in collaboration with INMETRO, Brazil, has developed a prototype radiation force balance based on Kibble balance technology and measurement techniques. Such a device has the potential to provide direct traceability to the SI for the calibration of ultrasound sensors and to improve on the state of the art in terms of uncertainty.

1.3 Force

With regard to the maintenance of standards, NPL has been upgrading the control systems for its deadweight machines. Work has been completed on the 1.2 MN and 2.5 kN machines, and the 120 kN and 20 kN machines are currently being addressed – the plan is to have similar modern hardware and software on all four for ease of use and long-term maintainability. At higher forces, work has started on modelling piston-cylinder assemblies in preparation for the design of a replacement for the 5 MN hydraulic amplification machine.

NPL has also been heavily involved in the EMPIR ComTraForce project, with most input into the workpackage looking at improving traceability for continuous force measurement in materials testing. Work to characterise novel graphene-based strain gauges has also been performed.

1.4 Torque

NPL designed, built and commissioned a rig for the measurement of dynamic torque and power transfer. This is being used by a commercial company for the validation of the measurements made in the field of indoor cycle trainers and similar equipment but has also been used to assess efficiency and wear improvements for chain/sprocket drives. In future the knowledge and technology developed will be applied to Net-Zero metrology areas such as electric vehicles and wind turbines.

1.5 Pressure

NPL is in the process of upgrading its capability for the calibration of gas-operated pressure balances (3.5 kPa to 21 MPa), replacing the control systems and updating the control and analysis software. A new service for the calibration of high-accuracy pressure sensors has been developed in collaboration with Druck. NPL has also undertaken research in collaboration with companies in the health area to provide traceable measurements to characterise the performance of interfacial pressure monitoring devices. Uncertainty budgets for NPL's gas and oil pressure balances have been reviewed and an improvement in CMCs has been agreed with UKAS.

1.6 Density

NPL has produced helium pycnometry standards based on the density of pure silicon to give traceability to assess the porosity of materials as part of projects to evaluate the quality of additively manufactured components and to characterise samples in the pharmaceutical and biotechnology areas.

2. Comparisons

2.1 Density

CCM.D-K5 Comparison on density determination of liquid samples using oscillation-type density meters

2.2 Force

CCM.F-K2.a.2 Force Key Comparison (5 kN to 200 kN)

EURAMET.M.F-S5 Force Key Comparison (10 kN to 500 kN)

3. Publications

1. Ultrasonic power measurement by Kibble balance R.C. Mayworm, E. Webster, S. Davidson, A.V. Alvarenga, R.P.B. Costa-Felix, *Measurement*, Volume 203, 15 November 2022, 111788, <https://doi.org/10.1016/j.measurement.2022.111788>
2. Final report on the CCM key comparison of kilogram realizations CCM.M-K8.2021, M. Stock, S. Davidson et al, *Metrologia*, Volume 60, Number 1A, <https://iopscience.iop.org/article/10.1088/0026-1394/60/1A/0700>
3. DISSEMINATION OF THE KILOGRAM FOLLOWING ITS REDEFINITION, M. Stock , S. Davidson, H. Fang, IMEKO 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference 11 – 13 October 2022, Cavtat-Dubrovnik, Croatia, www.doi.org/10.21014/tc3-2022.011
4. EFFECTS OF FORCE APPLICATION RATE ON TRANSDUCER PERFORMANCE, A. J. Knott, R. S. Oliveira, IMEKO 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference 11 – 13 October 2022, Cavtat-Dubrovnik, Croatia, www.doi.org/10.21014/tc3-2022.020
5. DISSEMINATING FROM THE KIBBLE BALANCE TO INDUSTRY, P. Potgieter, S. Davidson, I. Robinson, J. Berry, IMEKO 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference 11 – 13 October 2022, Cavtat-Dubrovnik, Croatia, www.doi.org/10.21014/tc3-2022.086
6. THE ARCHITECTURE OF THE NPL NEXT GENERATION KIBBLE BALANCE, I. A. Robinson, IMEKO 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference 11 – 13 October 2022, Cavtat-Dubrovnik, Croatia, www.doi.org/10.21014/tc3-2022.088
7. KIBBLE BALANCE FOR GRAM-LEVEL MASS MEASUREMENTS, E. Webster, I. A. Robinson, H. Chong, S. Davidson, IMEKO 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference 11 – 13 October 2022, Cavtat-Dubrovnik, Croatia, www.doi.org/10.21014/tc3-2022.092
8. DEVELOPING A KIBBLE BALANCE FOR MEASURING ULTRASONIC RADIATION FORCE AT 1 MEGAHERTZ, R. C. Mayworm , E. Webster , S. Davidson , A. V. Alvarenga , R. P. B. Costa-Felix, IMEKO 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference 11 – 13 October 2022, Cavtat-Dubrovnik, Croatia, www.doi.org/10.21014/tc3-2022.100
9. VIBRATIONAL ANALYSIS FOR THE NEXT GENERATION NPL KIBBLE BALANCE, J. Berry, P. Lovelock, I. A. Robinson, J. Urquhart, IMEKO 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference 11 – 13 October 2022, Cavtat-Dubrovnik, Croatia, www.doi.org/10.21014/tc22-2022.077
10. Mass Loss of Platinum-Rhodium Thermocouple Wires at 1324 °C, Sivahami Uthayakumaar, Stuart Davidson, Jonathan Pearce, *Johnson Matthey Technol. Rev.*, 2021, 65, (4), 568–573
11. EURAMET key comparison 1031 (EURAMET.M.D-K1.1)—solid density comparison, S Davidson et al, *Metrologia*, Volume 57, Number 1A 2021
12. Beginning of a new phase of the dissemination of the kilogram, S Davidson and M Stock, *Metrologia* 58, 2021
13. Developing definitions of conventional hardness tests for use by National Metrology Institutes, S. Low, A. Germak, A. Knott, R. Machado, J. Song, IMEKO 2021, TC3 Measurement of Force, Mass and Torque, August 30 - September 3, 2021