Report from the National Institute of Metrology (NIM), China

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1 Main research and development activities related to CCM activities

1.1 Mass measurement

NIM has improved the NIM-2 Joule Balance on its alignment method and mechnical, electrical system since 2020. A new alignment method which can automatically minimize the parasitic horizontal forces and torques of the suspended coil was proposed. By using several flexure hinges, this alignment process was performed in vacuum and the parasitic horizontal forces and torques were significantly reduced. In order to restrain the hysteresis and nonlinearity during the posture adjustment of the suspended coil, a controlling method based on fuzzy modeling (Fuzzy Model Predictive Control, FMPC) has been proposed for a predictive control. This method can decompose the original complex system into multiple subsystems according to the system characteristics, and establish discrete state space control models for the subsystems based on MPC. With these improvements, the measurement uncertainty from the misalignment was reduced from 4.5×10^{-8} to 1.7×10^{-8} in comparison with the previous alignment results.

The improvements of mechnical system included the renew of translation stage, the replacement of the aluminium alloy supporting adapter inserted between the magnet and the magnet lifting system with a new one made of ceramic, etc. To improve the accuracy of voltage measurement, the periodical calibration of Digital Voltmeters (DVMs) used in the Joule Balance with the Programable Josephone Voltage Standard (PJVS) was realized and embedded into the control system of Joule Balance. The current source was also improved to enhance the stability during weighing mode. In addition, the ground loops have been carefully checked.

With all these efforts, the Type A uncertainty of NIM-2 Joule Balance for calibration of a 1 kg weight was reduced from 3.8×10^{-8} to 1.4×10^{-8}, and the combined standard uncertainty was reduced from 6.5×10^{-8} to 3.7×10^{-8}.

1.2 Force and torque measurement

The subsystems of NIM's new Electrostatic Force Balance (EFB) are being optimized with an aim to decrease the relative standard uncertainty for micro-force measurement down to 1.0×10^{-4}. A subsystem supporting the high-level alignment of capacitor cylinder was fabricated and tested this year. Based on the capacitance characteristics of capacitor cylinder, the designed subsystem can make an in-situ measurement of the original position of inner capacitor cylinder and then adjust the relative distance between the outer and inner capacitor cylinders through PZT. The relative standard uncertainty resulted in by the alignment of capacitor cylinders is anticipated to reduce

from 2.0×10^{-5} to approximately 8.0×10^{-6}. Since we found 4 broken flexure hinges in the EFB during the latest inspection, all double-end flexure hinges in the balance mechanism are going to be replaced by single-end flexure hinges to reduce mechanical assembling costs. A position-limit mechanism has been built into the balance frame so that the unexpected damage to the balance mechanism will be avoided. The balance stiffness is hoped to be minimized to approximately 10^{-2} N/m this year.

Research on parallel calibration technology and devices for large force up to 120 MN is being carried out. NIM has built a 30 MN transfer standard based on three 10 MN force transducers and a 60 MN transfer standard based on three 20 MN force transducers for calibrating large force standard machines. A 120 MN transfer standard based on six 20 MN force transducers will be finished in 2023 to calibrate large force testing machines.

A set of 100 N·m reference torque standard machine is under development for calibration of reference torque wrenches, with the measurement range from 1 N·m to 100 N·m, and the expected uncertainty of 0.05% (k=2). The machine will be completed by 2024.

1.3 Density and Viscosity measurement

A new liquid density measuring device based on static weighing method was built for purpose of developing high-precision liquid density reference materials. Five kinds of liquid density reference materials ranging from 690 kg/m^3 to 1900 kg/m^3 were measured, and the uncertainty of these liquid density reference materials was analyzed to be 4×10^{-5} (k=2).

NIM has further extended the temperature range for its Newtonian fluid viscosity metrology, with the abilities to assign quantity values to viscosity CRMs in the temperature range from -40 °C to 120 °C. The non-Newtonian fluid viscosity CRMs, including oil-based and water-based kinds (all pseudoplastic) have also been developed. In order to meet the demands in polymer industries, a series of plastic apparent shear viscosity CRMs have been developed with value-assignment temperature around 200 °C.

1.4 Hardness measurement

A Knoop hardness standard machine is under development. The machine is designed to have measurement capability of eight scales (10 g, 25 g, 50 g, 100 g, 200 g, 300 g, 500 g and 1 kg). The dead-weight method was adopted for loading/unloading part of the machine. A motor drives the cam to rotate to realize speed control during the loading/unloading process, and an anti-torsion spring is used to realize the spindle guidance and reverse force application. For indentation measurement system, the optical microscope plus grating method was adopted, while the optical microscope plus digital CCD method was tested. The machine can realize semi-automatic measurement with the host electrical control mode and the computer software control mode operated in cooperation.

1.5 Gravimeter measurement

A new generation of transportable atomic gravimeter, named NIM-AGRb-2, which

aims at measuring gravity outside laboratory, has been developed recently. The physical package was designed with a diameter of 50 cm and height of 120 cm. Compact Raman laser system has been completed with a dimension of 50 cm×50 cm×10 cm. System effects including laser wavelength, Coriolis effect, two-photon line shifts effect etc., have been evaluated. The superconducting gravimeter and absolute gravimeter were used to continuously observe the key comparison sites of ICAG2017 (International Comparison of Absolut Gravimeters) and the gravity change was monitored. In order to improve the instrument performance of NIM-3A free-fall laser absolute gravimeter, the standard device for key comparison of NIM, the error evaluation and optimization on the falling body rotation using a monitoring device based on optical lever method was carried out.

1.6 Pressure measurement

NIM has developed an optical method-based pressure standard (OPS) for the new realization of Pascal in the range of 1 Pa to 100 kPa. The OPS has been characterized in detail, and its metrological performance was scrutinized by comparison to a piston gauge, which is the primary pressure standard at NIM. With working gas of nitrogen, we claimed an uncertainty of ~23 ppm. At present, the OPS works as a secondary standard because the traceability of its deformation coefficient was based on the piston gauge used. We are continuing the work to further reduce the uncertainty and make it to be a primary standard.

1.7 Flow measurement

The 19th International Flow Measurement Conference, Flomeko 2022 was held online in November 2022. It was co-hosted by NIM and the Chinese Society for Measurement (CSM). There were 162 full papers submitted from 21 affiliations.

2 Participation in relevant comparisons

2.1 Comparison of mass

NIM-2 Joule Balance participated in the second key comparison for kilogram realizations (CCM.M-K8.2021) piloted by BIPM during September 2021 to March 2022. According to the final report published by BIPM, the relative standard uncertainty of NIM's Joule Balance is 3.99×10^{-8}.

2.2 Comparison of force

NIM piloted the APMP.M.F-K3 force comparison, which is organized in two groups: APMP.M.F-K3.a (force steps of 0 kN, 500 kN, 1000 kN) and APMP.M.F-K3.b (force steps of 0 kN, 500 kN). The comparison tests have been finished, and the comparison report is being drafted. In 2020, NIM participated in the force comparison of CCM.F-K23 (200 N and 500 N, piloted by Metas). The Draft B of comparison report has distributed to participating lab.

2.3 Comparison of density and viscosity

In 2023, NIM participated in the key comparison of CCM.D-K1.2023 Density

Measurements of a Silicon Sphere (1 kg) by Hydrostatic Weighing. In 2022, NIM participated in the ASTM viscosity comparison. The comparison temperature includes 20 °C, 25 °C, 40 °C and 100 °C, and the viscosity covers range from 4 mm^2/s to 21500 mm^2/s.

2.4 Comparison of pressure

NIM participated in the comparison of APMP.M.P-K4 for absolute pressure in the range from 1 Pa to 10 kPa, piloted by KRISS. Draft A is in preparation.

2.5 Comparison of flow

NIM piloted the comparisons of APMP.M.FF-K4.2022 and APMP.M.FF-K4.2.2021 for Liquid Volume. NIM participated in the comparisons of CCM.FF-K5.2021 for High-Pressure Gas Flow, and APMP.M.FF-K6.2018 for Low Pressure Gas Flow.

3 List of relevant publications

3.1 Mass measurement

[1] Jian Wang, Zhi Han, Cheng Peng* and Di Wu. Preliminary Study of Parameter Optimizations toward a Lab-designed Acoustic-based Volume Measuring System for Weights.Measurement.2022,197,111244

3.2 Force and torque measurement

[1] Z. M. Zhang, G. Hu, Y. Zhang, etc. Development of 100 kN·m deadweight torque standard machine at NIM，IMEKO 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference. 11-13 October 2022, Cavtat-Dubrovnik, Croatia.
[2] Jiang Jile, Wukun, Guobin, etc. The New 1 kN·m Torque Standard Machine in National Institute of Metrology, China, 2021 5th International Conference.

3.3 Density and viscosity measurement

[1] Liu X , Wang J , Huang L , et al. Direct observation of the impact of water droplets on oil replenishment in EHD lubricated contacts. Friction, 2021.

[2] Liu X , Wang J , Zhang JY , et al. Analysis of International Standard ISO17034: General Requirements of Producer Capacity of Reference Materials. China metrology, 2022.

3.4 Hardness measurement

[1] Cui Yuanyuan, Zhang Feng, Ye Ming. A monochromatic-light-interference system for measurement of diamond-indenter's angle parameter, 2021 4TH World Conference on Mechanical Engineering and Intelligent Manufacturing, 2021, 54-57.

3.5 Gravimeter measurement

[1] Y Yu，X Hu，W Shi，Z Ye，F Bao，R Wang，J Feng,“Measuring and adjusting the distance between the center of mass and opticalcenter of a free-falling body in an

absolute gravimeter”，Metrologia 59 (2022) 045001（9pp）

[2] Ruo Hu, Jinyang Feng, Zonglei Mou, Xunlong Yin, Zhenfei Li, Hongrong Ma, “Incipient fault diagnosis for the cam-driven absolute gravimeter”，Review of Scientific Instruments 93,054501,(2022)

3.6 Pressure measurement

[1] Yuanchao Yang, Tom Rubin, Jianping Sun, Characterization of a vacuum pressure standard based on optical refractometry using nitrogen developed at NIM, Vacuum, 2021, 194: 110598.

[2] Yuanchao Yang, Kun Ma, Tom Rubin, Xiaojuan Feng, Bowen Wang, Analysis of the outgassing in an optical pressure standard, IMEKO 24th TC3, 14th TC5, 6th TC16 and 5th TC22 International Conference, 11-13 October 2022, Cavtat-Dubrovnik, Croatia.

3.7 Flow measurement

[1] Chunhui Li, Bodo Mickan, Mengna Li, Jia Ren, Yan Wu, Ming Xu, The comparison of the gas flow primary standard facilities at high pressure, Flomeko, Chongqing, China, 2022

[2] Chunhui Li, Rundong Qi, Xiaoyi Zhu, Peng Cao, The upstream flow condition effect on the premature unchoking phenomena of the sonic nozzles, Flomeko, Chongqing, China, 2022