Report of NIM

The research activities related to CCM in NIM are mainly in the field of mass measurement, force and torque measurement, volume and density measurement, hardness measurement, gravitational acceleration measurement, pressure measurement, flow measurement and viscosity measurement. NIM took part in key comparisons in the field of mass, force, torque, volume, density, gravimeter, pressure and flow organized by CCM or APMP in the past two years. The list of relevant publication since 2019 is shown in section 3.

1 Main research and development activities related to CCM activities

1.1 Mass measurement

1) The Joule Balance at NIM

With a series of improvements, in September of 2019, the type A relative standard uncertainty of the NIM-2 joule balance been reduced to 3×10^{-8}(k=1) and the combined relative standard uncertainty is less than 1×10^{-7}(k=1). In 2019, NIM participated in the first key comparison of realizations of the kilogram piloted by BIPM. which has contributed to the calculation of the first consensus value for the dissemination of the kilogram. Two masses of 1kg were used as the travelling standards. One is made of Pt/Ir and another is made of stainless steel. The values of them were determined by NIM-2 joule balance based on the Planck constant. The relative standard uncertainties are 5.2×10^{-8} and 6.5×10^{-8} respectively. In Oct. 2020, the final report of the CCM key comparison of kilogram realizations (CCM.M-K8.2019) was published and the uncertainty of NIM-2 joule balance is evaluated as 4.9×10^{-8} with a relative difference of 1.17×10^{-8} from the Key Comparison Reference Value (KCRV). Fig. 1 shows the final comparison result of the CCM.M-K8.2019.

Differences □mi between mass values attributed to 1 kg mass standards using the realization experiment of the participants and by the working standards of the BIPM, and associated standard uncertainty.

The objectives of this comparison are to determine the level of agreement between realizations of the kilogram based on Kibble and joule balances and the X-ray crystal density (XRCD) method and to provide input for the calculation of the first “consensus value” of the kilogram. The latter will serve as the basis for an internationally coordinated dissemination of the kilogram until sufficient agreement between realization experiments will have been achieved.

Since 2020, the successive improvements of the NIM-2 joule balance are still in progress to decrease the uncertainty contribution from the alignment and statistic.

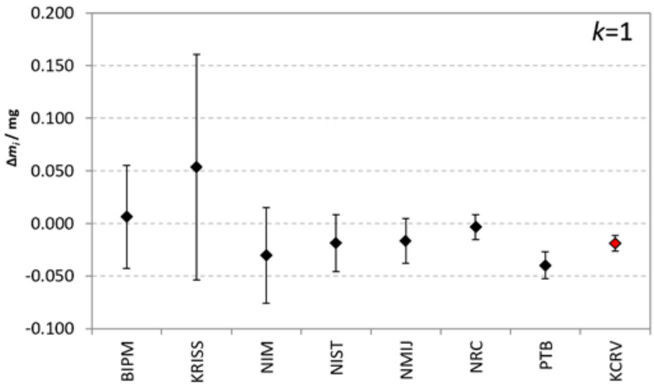

Fig. 1: the final comparison result of the CCM.M-K8.2019

2) The vacuum transfer equipment with Joule Balance

Joule balance developed by NIM is an equipment for measuring the Planck constant. After the redefinition of mass unit, it will be used to determine the mass value of primary mass standard under vacuum. During the measurement, the primary mass standard will be placed into vacuum. If the primary mass standard will be stored in air after the measurement. Due to the surface sorption effect, the true value of primary mass standard may be not stable. In order to ensure the stability of primary mass standard, the dissemination from primary mass standard to secondary mass standard may be carried out under vacuum. At the same time, the primary mass standard will be stored in vacuum, and the secondary mass standard will be stored in air.

Joule balance located at Building 23 of Changping Campus at NIM. Vacuum mass comparator located at Building 20 of Changping Campus. The distance between two buildings is about 100 m. If the primary mass standard is moved from Joule balance to vacuum mass comparator after the measurement from Planck constant to primary mass standard, vacuum transfer equipment (VTE) and vacuum vessel are necessary. They are used to move the primary mass standard in vacuum. According to the structures of Joule balance, one VTE and one vacuum vessel were developed by NIM. The equipment is shown as Fig. 2.

Fig. 2 The vacuum transfer equipment with Joule balance

1.2 Force and torque measurement

1) 100 kN•m torque standard machine at NIM

A 100 kN•m torque standard machine is newly established at National Institute of Metrology (NIM). The torque standard machine adopts the lever-deadweight type. The main knife assembly is adopted as the moment arm support to minimize the friction at the fulcrum, the moment arm system is precisely machined and adjusted to ensure parallelism between main knife edge and side knife edges, the weight suspension assembly is designed to ensure that the force generated by the weight is applied perpendicularly on the moment arm free from parasitic force, the weight loading system is designed to ensure weight loading and unloading accurately and reliably. 100 kN•m torque standard machine may realize the torque in range of 1 kN•m to 100 kN•m both in clockwise and anti-clockwise direction, the uncertainty is 1×10^{-4} (k=3).

Fig. 3 100 kN•m torque standard machine

2) The research on the micro/nanonewton force at NIM

The research topic of the force measurement in NIM has been focused on the micro/nanonewton force since 2012. The development if transfer standard along with its performance study have been continued since 2019. The calibration method of the transfer standard was studied based on the contilever on contilever measurement, as shown in Figure 3. According to the precision measurement of the cantilever stiffness based on the electromagnetic compensation, the transfer standard measurement is below 3%. The research also carried out so as to implementing imagine analysis, which can be used for the calibration without sending the sample to the authority.

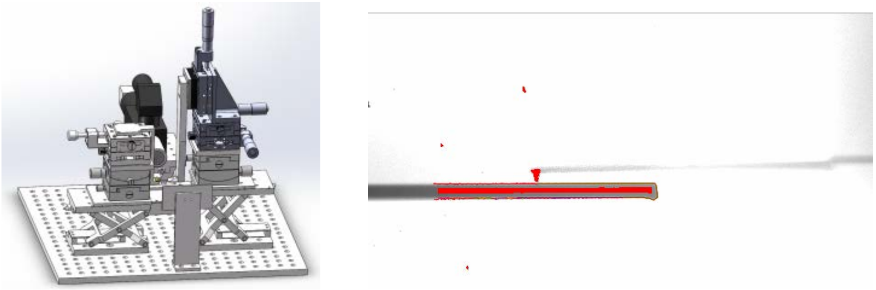

Figure 2 The research on the micro/nanonewton force

3) The 1 kN·m torque standard machine

In torque field the new 1 kN·m torque standard machine has been under development since 2016. Now the whole construction has been completed and the machine is under evaluation, as shown in Figure 4. This new torque standard machine can generate the torque in range of 5 N·m to 1200 N·m with an expected relative standard uncertainty of 1e-5.

Fig. 4 The 1 kN·m torque standard machine

1.3 Volume and density measurement

[1]2018-2020, "Preparation of high precision solid density standard and its precision measurement method research." Preparation of high precision solid density standard for quartz column and Quartz Sphere, the relative uncertainty of density is 3×10^{-6} (k=2).

[2]2019-2020, "Development of single channel and 12 channel ultra micro pipette metrological standard device." The single channel and 12 channel ultramicro pipette metrological standard devices were designed and developed, the measurement range is (1~200) μL. The measurement uncertainty of the system is 0.05 μL(k=2) at 1 μL and 5.12 μL(k=2) at 200 μL.

1.4 Hardness measurement

The main work of hardness laboratory in these two years is to study the calibration method, quantity Traceability Method and uncertainty evaluation method of Martens hardness machine, with the purpose of establishing a standard Martens hardness machine.

During 2019 and 2020, we initiated, carried out and finished a project on micro-scale Martens-hardness measurement calibration method based on a machine from Fischer company.

The structure design of Martens hardness tester is closed-loop and self-consistent. It supports "start-up, loading and unloading, calculation and display" one button automatic measurement, which allows little outside intervention. Because of this, it is difficult to calibrate the test force module and displacement measurement module in the client side, which brings great difficulties to the establishment of reference and standard Martens hardness tester. In the process of value transmission, it is necessary to calibrate the influence quantity with fast, convenient and accurate transfer standard, which also has some difficulties. Therefore, the contents of laboratory research include the establishment of non-assisted and assisted force calibration methods; the establishment of laser interferometry and standard block displacement calibration methods; the establishment of uncertainty evaluation methods of Martens hardness, instrumented indentation hardness and indentation modulus.

In addition, the design and implementation of high-precision Martens hardness machine based on piezoelectric ceramic and capacitance sensor is also studied. The hardware structure design of Martens hardness tester is shown in Fig. 5.

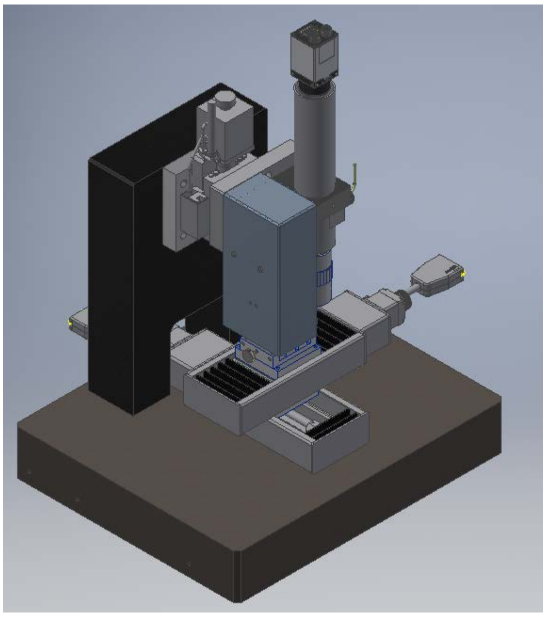

Fig.5 Hardware structure of Martens hardness tester

The mechanical part is mainly composed of four parts: loading frame, sliding table, indenter assembly and microscope.

The indenter assembly is mainly composed of frame, linear actuator, force sensor and displacement sensor. The linear actuator is the main moving part of the indenter assembly, which mainly plays the role of advancing the indenter. The linear actuator of this machine adopts the structure of flexible hinge and piezoelectric ceramic. When the piezoelectric ceramic obtains high-resolution signal, the linear actuator can output nanometer displacement, which means producing force below 1kg on the sample surface. The force sensor of this machine is directly connected to the linear actuator. Capacitance sensor technology is used to measure the indentation depth of indenter.

1.5 Gravimeter measurement

A new generation of atomic gravimeter, named NIM-AGRb-2, has ben developed in progress rencently, which aims at mesuring gravity outside laboratory. The physical package was designed with a diameter of 50 cm and height of 120 cm, which is reduced about 50% relative to the first generation of NIM-AGRb-1. Compact Raman laser system has been completed with a dimension of 50 cm×50 cm×10 cm, which is also much smaller than that of NIM-AGRb-1. The laser was stabilied to Rb atomic line by the modulation transfer spectrocopy technique, reaching a fractional frequency stability of 10^{-11} level. An active vibration isolation system was constrcted with a passive isolator, a seismometer and servo electronics. The active servo loop has been completed with a time constant up to 10s.

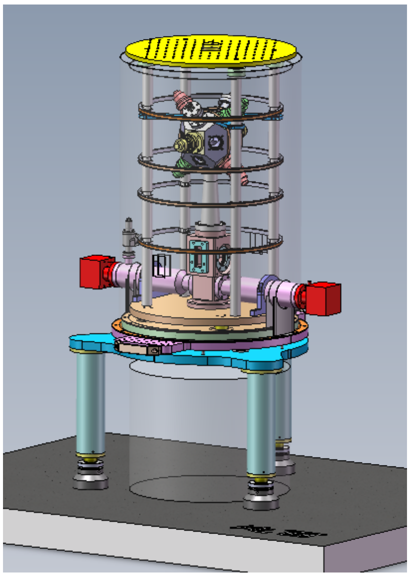

Fig.6 The physical package of NIM-AGRb-2.

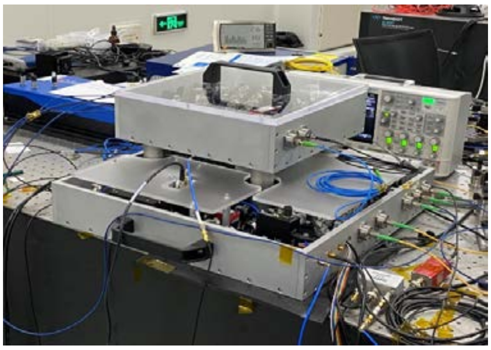

Fig.7 Raman laser system of NIM-AGRb-2.

As the International Key Comparsion of Absolute Gravimeters Site and Primary Standard of gravity acceleration in China, we have applied two CMCs and passed the CMC international peer review in the frame of APMP. We provided the service to Major National Science and technology infrastructure projects (HuaZhong University of Science and Technology, Precise gravity acceleration measurement project) and geodesy community in China. We signed a Cooperation Agreement with the China Earthquake Administration to contribute to China gravity network by providing the standard instruments and calibrating service in future. NIM sent a staff to South Pole for half a year and established a gravity acceleration calibration site.

1.6 Pressure measurement

NIM has developed an optical pressure standard for the pressure measurement from 100 Pa to 100 kPa. The standard is aimed to realize the pressure unit Pascal based on fundamental constant and gas properties, which are the refractivity of helium, nitrogen or argon measured by optical refractometry. Continued research is under way to lower the uncertainty till it's better than the primary piston gauge which is the primary pressure standard of NIM nowadays.

1.7 Flow measurement

1) The peer review was conducted in the fluid flow field in NIM in November, 2017, the new CMC was released in the website of KCDB in May, 2020. The new CMCs in the field of high pressure gas flow, air speed were approved;

2) The first gas flow close loop facility was built in NIM, which was approved to provide the service in public in January, 2020. For the close loop facility, there are 4 turbine meters of DN100 as the master meter, which are traceable to the sonic nozzle facility in NIM. The pressure range is within (190~2500) kPa, while the flow range is within in (40~1400) m^3/h. The best uncertainty of the meter under test (MUT) can be 0.20% (k=2).

1.8 Viscosity measurement

1）Peer review

In August 2019, NIM viscosity laboratory passed the peer review by expert group including Dr. Yoshitaka Fujita of NMIJ and expert of CNAS (China National Accreditation Service for Conformity Assessment).

2）CMCs

Based on the results of peer review in 2019, NIM submitted an application for new CMCs. 15 Newtonian fluid viscosity reference materials capabilities are claimed on the basis of the existed 15 viscosity measurement capabilities. New CMCs have be published on kCDB website in December 2020.

2 Participation in relevant comparisons

2.1 Comparison of mass

NIM has participated in the key comparison of CCM.M-K8.2019 at 1 kg organized by BIPM at 2019. This results is published at Metrologia, 2020, 57, Tech. Suppl., 07030.

2.2 Comparison of force

1) NIM, as the pilot laboratory, organized APMP.M.F-K3 0-500 kN-1000 kN force comparison, the comparison tests had been finished by the end of 2020, the comparison report is being prepared.

2) In 2020 NIM participated in the force comparison of CCM.F-K23 (200 N and 500 N, piloted by Metas). Now the comparison will be continued once the transfer standard arrives in China after the measurement carried out by the pilot laboratory.

2.3 Comparison of volume

Participated the EURAMET.M.D-K4.2020 “Comparison of the calibrations of high resolution hydrometers for liquid density determinations.”

2.4 Comparison of hardness

Nothing.

2.5 Comparison of gravimetry

We have hosted and participated in the CCM.G-K2.2017. According to the Draft A of the result, we have got the good agreement with other KC instruments.

2.6 Comparison of pressure

NIM participated in the comparison APMP.M.P-K4 piloted by KRISS for the pressure range from 1 Pa to 10 kPa. Measurements were completed in 2019. NIM is waiting for the report.

2.7 Comparison of flow

1) APMP.M.FF-k6, the comparison of low pressure gas flow

2) APMP.M.FF-K3, the comparison of air speed

2.8 Comparison of viscosity

Nothing.

3 List of relevant publications

3.1 Mass measurement

[1] Zhengkun Li, Yang Bai, Jinxin Xu, et al. The improvements of the NIM-2 joule balance. IEEE Transactions on Instrumentation and Measurement, 2019, 68(6): 2208-2214.

[2] Yang Bai, Yunfeng Lu, Zhengkun Li, et al. Misalignment recognition of mass pan in joule balance. Tenth International Symposium on Precision Engineering Measurements and Instrumentation. International Society for Optics and Photonics, 2019, 11053: 1105310.

[3] Zhengkun Li, Yang Bai, Jinxin Xu, et al. The upgrade of NIM-2 joule balance since 2017. Metrologia, 2020, 57(5): 055007.

[4] Zhengkun Li, Jinxin Xu, Yang Bai, et al. The Recent Progress of the NIM-2 Joule Balance. 2020 Conference on Precision Electromagnetic Measurements (CPEM). IEEE, 2020: 1-2.

[5] Lushuai Qian, Jinxin Xu, Zhengkun Li, et al. The interaction between the magnetized coil-suspension system and the compensation coil in the joule balance. Metrologia, 2020, 57(4): 045010.

[6] Jinxin Xu, Lushuai Qian, Zhengkun Li. The Magnetization Effect in the Joule Balance with Compensation Coil. 2020 Conference on Precision Electromagnetic Measurements (CPEM). IEEE, 2020: 1-2.

[7] Cheng Peng, Jian Wang, Di Wu. Impacts of Air Density Fluctuations Toward the Mass Measurements of a 1 kg Silicon Sphere.2020(8):140840-140847.

[8] Jian Wang. Research on Vacuum Transfer Equipment in NIM.IEEE Access.2019,7,114014-114020.

[9] Manhong Hu, Jian Wang, Changqing Cai. Experimental study on the mass determination of silicon sphere from vacuum to air based on Monte Carlo method. Asia Pacific Measurement Forum on Mechanical Quantities(APMF),2019.

[10] M. Hu, J. Wang, C. Cai. Experimental research on mass determination of non-metal weights.IMEKO ACTA.2020,9(4):23-26.

[11] Jian Wang, Changqing Cai, Manhong Hu. Vacuum Transfer Equipment for the Dissemination of Mass Unit. Asia Pacific Measurement Forum on Mechanical Quantities(APMF),2019.

[12] Ruilin Zhong, Jian Wang and Sungjun Lee.Research on the Device of Measuring the Centre of a Weight. ICMEM2020.2020,N205.

3.2 Force and torque measurement

[1] Zhang Zhimin，Hu Gang,Zhang Yue and etc. Design of 100 kN • m Deadweight Torque Standard Machine, Asia Pacific Measurement Forum on Mechanical Quantities, 2019, 17th - 21st November, 2019, Toki Messe, Niigata, JAPAN.

[2] Gang Hu, Jile Jiang, Zhimin Zhang and etc. Investigation of the deadweight force standard machine with a 1 mN -10 N range, ACTA IMEKO, September 2019, Volume 8, Number 3, 3-9.

[3] Gang Hu, Jile Jiang,Kun Wu and etc. Performance investigation and comparison of 10 N and 200 N deadweight force standard machines in NIM, Asia Pacific Measurement Forum on Mechanical Quantities, 2019, 17th - 21st November, 2019, Toki Messe, Niigata, JAPAN.

[4] Jile Jiang, Huiyan Zhou, Kun Wu, et al. The stiffness measurement of various cantilever with the small force standard based on electromagnetic compensation. Asia Pacific Measurement Forum on Mechanical Quantities, 2019, 17th - 21st November, 2019, Toki Messe, Niigata, JAPAN

[5] Jile Jiang, Bin Guo, Kun Wu, et al. The design and the development of 1 kN·m torque standard machine in National Institute of Metrology, China, Asia Pacific Measurement Forum on Mechanical Quantities, 2019, 17th - 21st November, 2019,

Toki Messe, Niigata, JAPAN

[6] Yelong Zheng, Meirong Zhao, Jile Jiang, et al. Dynamic Force Transducer Calibration Based on Electrostatic Force, IEEE Access, Volume 7, 2019, 48998 - 49003

[7] Jile Jiang， Huiyan Zhou，Ye Zhang et al. PERFORMANCE TEST OF CANTILEVER TRANSFER STANDARD USED FOR AFM TIP CALIBRATION BASED ON ELECTROMAGNETIC COMPENSATION, ACTA IMEKO, December 2020, Volume 9, Number 5, 129 – 132

[8] Meng feng, Zhang zhi min, Zhang yue, A Multifunctional Torque Standard Device for Calibrating Torque Sensors and Torque Multipliers, 2019 Asia-Pacific Symposium on Measurement of Mass Force and Torque, November 17- November 21, 2019, Niigata, Japan.

[9] Zhang Wei, Li Nan and etc., The verification and calibration of force measuring devices, China Metrology, 2020,9, pp: 122-124.

3.3 Volume and density 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.

3.4 Hardness measurement

[1] Cui Yuanyuan, Ye Ming, Zhang Feng, Liu Jiping.A method of measuring the arc radius of Rockwell diamond indenter, 2nd International Conference on Mechanical Manufacturing and Industrial Engineering, 2019,012011,1-6.

[2] Liu Jiping, Wang Jingtao, Cui Yuanyuan ,Zeng Limin. Development of the primary standard machine of the ball indentation hardness, ACTA Metrologica SINICA, 2020, 41, (7), 823-829. (In Chinese)

3.5 Gravimeter measurement

[1] Shuqing Wu, Jinyang Feng, Chunjian Li et al. The results of CCM.G-K2.2017 key comparison. Metrologia, 2020, 57(1A): 07002-07002.

[2] Jinxin Xu, Jinyang Feng, Qiyu Wang et al. The determination of gravitational acceleration in the joule balance at NIM. Metrologia, 2020, 57 045013

[3]Yang Zhao, Shaokai Wang, Wei Zhuang, Tianchu Li. Raman-Laser System for Absolute Gravimeter Based On 87Rb Atom Interferometer. Photonics, 2020, 7(2):32.

3.4 Pressure measurement

[1] Y. Yang, R.G. Driver, J.S. Quintavalle, J. Scherschligt, K. Schlatter, J.E. Ricker, G.F. Strouse, D.A. Olson, J.H. Hendricks, An integrated and automated calibration system for pneumatic piston gauges, Measurement, 134 (2019) 1-5.

3.5 Flow measurement

[1] C.H. Li, Bodo Mickan and Shan Gao, The bilateral comparison between NIM and PTB for small gas flow, Flomeko, Lisbon, 2019.

[2] C.H. Li, Bodo Mickan and Lishui Cui, The high pressure sonic nozzle gas flow standard facility in NIM, Flomeko, Lisbon, 2019.

[3] C. Wang, C.H. Li, Ming Xu and Wencan Yan, The high pressure close loop gas flow standard facility in NIM (Corresponding author), Flomeko, Lisbon, 2019.

3.6 Viscosity measurement

[1] Zhang Y., Song X., Kan Y., Zhang Z.D. et al. Effects of stick–slip transition on polymer melt apparent shear viscosity measurement[J]. Journal of Applied Polymer Science, 2019:48230.