Report on the Activities in Electricity and Magnetism within National Institute of Metrology (NIM), China
CCEM 2017

RESEARCH PROGRESS

DC&LF

1. Joule Balance

The new Joule balance has been mounted by the end of 2015. This year, we are doing the research work on the following aspects: 1) The electrical measurement system, including the current sources for the electromagnet, the magnetic flux measurement system; 2) The length measurement system and position control system based on the laser locking technology; 3) The control system of the mass on, off and exchange; 4) The vacuum system; 5) The software to run the whole system. Besides, some alignment and adjustment have also been done. Recently, we are doing some test in the vacuum status to check if everything is ok in the vacuum.

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2. Programmable Josephson Voltage Standards

A differential sampling system based on the PJVS and a commercial sampling ADC was developed to measure the ac voltages provided by the Fluke 5720A calibrator. After averaging, a relative Type A uncertainty of 1 ppm was achieved with the technique when measuring a 2.8 V rms sine wave generated by a calibrator at 200 Hz. An intrinsically accurate automated system for low-voltage measurements has been developed at NIM based on a differential programmable Josephson voltage standard. At 1microvolt level, the typical difference between the mean value of 250 measurement points and the nominal value is 0.17 nV with the standard deviation of 1.4 nV. New step we will continue the research on projects mentioned above, and develop Cryo-cooled 1 V PJVS at NIM.

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3. Calculable Capacitance

The new calculable capacitor (CC) with a movable guard electrode at the second stage had been undertaken since 2014. Using the new calculable capacitor, NIM will participate the new key comparison of CCEM-K4 organized by BIPM which will be started from March, 2017.

1) The optimal hollow active auxiliary electrode was developed. In comparison with the mechanical compensation method such as spike, modified-cone spike and nosepice for compensating the end-effect error, the optimal hollow active auxiliary electrode (OHAAE) is developed and its performances are also investigated by the model tests at NIM's primitive scale calculable capacitor model device in 2016. The hollow active nosepiece of the OHAAE may be regarded as one capacitive sensor with sufficient sensitivity, which can measure the lateral displacement of the moving guard electrode during one measurement, and monitor the possible positon variation of the four main electrodes after long-term operation. In addition, the eccentricity coefficient *k* of OHAAE due to the movable guard electrode being

off-center is ten-times less than that of general nosepiece of NMIA, which can decrease the difficulty of the alignment installation.
2) The re-installation and re-adjustment of the new CC is finished. The new CC is disassembled except the four main electrodes and re-alignment between the mechanical axis and the optical axis has been carried out. The whole assembly is finished at the middle of 2016.
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4. Quantum Devices for Electrical Standards

Quantum Devices for electrical standards:
1) Single Quantum Hall devices
Single quantum Hall devices with high (about 10 T) and low (about 7 T) working magnetic fields were developed. The two devices were compared with the BIPM device by calibrating the same NML 1 Ω transfer standard resistor. The calibration results showed that NIM-made devices can be equipped in the QH resistance standard system.
2) Quantum Hall Array Devices
The 1 kΩ QHARS device based on the GaAs/AlxGa1-xAs heterostructures were developed. The relative difference between the calibrated resistance value and the designed value is -1.96×10-7 with the standard uncertainty of 2.07×10^{-7}.
3) Josephson junction devices for the voltage standards
We are on our way to develop the Josephson junction arrays for the 1V or higher programmable Josephson voltage standards.
4) SNS SQUID
A SQUID based on the Nb/NbxSi1-x/Nb Josephson junction are developed. The V-Phi curve was measured and the ratio of the working point is 394 μV/Φ0. The device can work at flux lock mode.
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5. Energy Measurement for Electrical Vehicles

An Energy measurement standard was developed to measure energy for electrical vehicles. The standard involved an energy meter, a voltage divider and a current transformer, which could achieve measuring voltage up to 1000 V and current up to 600 A. Energy was measured by a high-speed synchronous sampling integral system set up using FPGA which was the main part of the energy meter. The uncertainty of measuring energy from DC to 2 kHz is $(1\sim2)\times10^{-4}$.
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6. High Frequency Power Standard

A new project to establish ac power standard at frequencies up to 100 kHz, has been activated since 2014 and will been finished at 2016. Main work of this project is focus on the self-calibration of phase angle errors between voltage and current signals of ac power, including three significant parts as follow.
1) A new design of resistive voltage divider (RVD) has been proposed at voltage ranges up to 600 V and frequencies up to 100 kHz. A measurement setup has also been developed to determine the phase angle errors of this RVD with standard uncertainties less than 40 μrad.

2) A new design of current comparator has been built to compare two shunts at common ground and rated currents, and the phase angle errors have also been calibrated at current from 10 mA to 100 A at frequencies up to 100 kHz.
3) A commercially available digitizer, the National Instruments PXI-5922 two-channel high-speed digitizer is applied to measure two voltage signals at ranges from 0.5 V to 2 V at frequencies up to 100 kHz. The characteristics of this digitizer have been evaluated, including the phase angle, ac flatness, linearity errors and input impedance.
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7. High Voltage and High Current

1) Wide-band currents and full-optical-fibre current sensor

Series of optical fibre current sensors based on Faraday Effect are to be developed for super-high dc current in-situ calibration for electrolytic industry, and its wider band and lower uncertainty are targeted for long-pulse and specially dc&ac currents use in industry. 50 Hz to 1 MHz active current transformer and sensor and their calibration system are under development.

2) Impulse voltage system

A 800 kV impulse system are built, which intend to attend EURAMET comparison hosted by SP Sweden from 2017.
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8. Quantum Hall Resistance Standard

The Quantum Hall Array Resistance Standard (QHARS) device with the value of 1 kΩ and 10 kΩ based on the GaAs/$Al_xGa_{1-x}As$ heterostructures is fabricated and measured. Preliminary experiments indicate that the relative deviation between the measured and the nominal value is -1.96×10^{-7} for the 1 kΩ, and -1.64×10^{-7} for the 10 kΩ. The Single Hall device with large measuring current up to 116μA is also designed and will be measured later.
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9. New projects for 5-year plan

We just started a new project in the field of electromagnetic metrology to support the National Quality Infrastructure (NQI) which is the base for the structural transformation of the economy of the country. The project is aimed to improve the application of the electrical standards combined with information technology for the industry development. The project is divided into five aspects as follows.

1. Smart meter on-site verification based on big data analysis.
2. On-site calibration and verification for device in the grid in the working condition.
3. Portable standards for the electrical vehicle charging station calibration.
4. Ultra-low frequency voltage standard for the power battery production.
5. High performance gateway meter development

The project gets the financial support from the government with the budget totally 3,000 000 USD for the next five years.
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RF and Microwave

1. Free Space

Atom-based RF electric field metrology

RF field measurements should be directly linked to SI units with low intrusion, high sensitivity, high spatial resolution, wide dynamic range and low uncertainty. The current state-of-the art is far short of this goal.

Research of atom-based RF electric field metrology using quantum interaction of highly-excited Rydberg atoms and the RF electric field has been started since 2015. After the proof-of-concept work which was mainly carried out last year, we are focusing on precision measurements, and has validated the possibility of two-photon RF transition of Rydberg atom, sub-wavelength field imaging, and broadband measurement using different alkali atoms. A special vapour cell as small as a 3mm cubic has been fabricated in order to minimize the field disturbance. A sensitivity as low as 0.5 V/m at K-band has been achieved.

Meanwhile, since the electric field metrology is extensively linked to antenna parameters, we also developed a novel antenna finite range gain measurement method, which allows gain value be determined by measuring RF field induced splitting frequency of an electromagnetically induced transparency (EIT) window, antenna feeding power. The method can result in consistent gain value as conventional extrapolation technique, and is promising due to its advantages of simplicity, accuracy, low-cost.

Key issues of quantum sensor and measurement uncertainty evaluation will be focused in future.

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Spherical Near-field Antenna Metrology

A precise spherical near-field (SNF) scanning facility (shown as below) has been developed in the 2016, based on the hardware and RF instrument for the three antenna extrapolation range facility. The SNF facility can measure the radiation pattern of antennas from 400 MHz to 110 GHz, provided the aperture of the antenna is less than 2 m and the weight less than 250 kg. At -40 dB side-lobe, the repeatability of the radiation measurements is less than 0.2 dB, and the expanded uncertainty is less than 2.8 dB from 2.6 GHz to 110 GHz.

2. Microwave parameters

RF&MW Power

NIM finished WR-10 (75 to 110GHz) power primary standard setup this year, including microcalorimeter manufacture and uncertainty evaluation. It is used to measure effective efficiency of WR-10 commercial RF thermistor mounts, which is used as transfer standard calibrating power sensors. Some new techniques are used to reduce the measurement uncertainty by re-evaluating the correction factor by foil short measurements. NIM is proposing a Key comparison at CIPM for wr-15 power international comparison, there are 6 NMIs have positive response.

The WR-6 power standard is conducted at same time. Now the calorimeter design is finished, a WR-6 power sensor was designed and manufactured by NIM, from the measurement, the specification is fine for calibrating the power sensor in this frequency band.

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3. Modulation

VOR and ILS parameters

A Very High Frequency Omnidirectional Radio Range (VOR) signal standard is completed in 2015. It covers the 0 rad -2π rad with a sub-carrier frequency of 9.96 kHz. The expanded uncertainty is 0.35 mrad (*k*=2).

An Instrument Landing System (ILS) signal standard is also completed in 2015. It covers the frequency range of 75 MHz - 350 MHz, modulation depth of 20% -80%, and with a expanded uncertainty of 0.2% (*k*=2).

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4. Information Technology

Metrology Research on Elastography

Transient elastography equipment was successfully used to evaluate hepatic fibrosis which elastic modulus covers 2-30kPa. The elastic value of transient elastography equipment was expected to be traceable through the followed two stages: elastic quantity was traced 1) from elastography equipment to elastography mimicking phantom by elastography imaging, and 2) from phantom to length standards and mass standards by indentation test. The project has been closed in 2015, and calibration specification for elastography systems is under being formulated.

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Beamforming of Array Antennas

Array antennas would be one of the main characteristics of the next wireless communication. An 1X8 array patch antennas were developed and they could be regarded as the basic element of the massive MIMO antennas. Beamforming could be realized by phase controlled of each antenna channel. The practical beamforming test in anechoic chamber was agreed with the simulation results, no more than 2 degrees. It was helpful to develop the 3D MIMO beamforming in the near future.

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International Comparison

1. CCEM k2 DC resistance comparison
   Measurements completed and results submitted to the pilot laboratory.
2. AMPM. EM-s12 Multimeter
   Measurements completed and results submitted to the pilot laboratory.
3. APMP.EM-k5.1 AC Power
   Draft A completed and submitted for discussion.
4. CCEM k13 Harmonic power
   Preparing for the stability evaluation of the travelling standard.
5. CCEM k4 Capacitance
   Preparing for the participation.
6. Capacitance
   NIM and NPLI India proposed a bilateral comparison in four terminal pair capacitance at frequency from 10 kHz to 10 MHz. Protocol is drawn and waiting for comments.