KRISS Korea Research Institute of Standards and Science

Progress Report of KRISS Mass-Related Quantities Metrology

(18th meeting of the CCM, May 2021)

This report gives a brief summary of the main activities in the area of Mass-Related Quantities at KRISS since the last CCM meeting (May 2021).

1. Mass Metrology

Contact: Dr. Kwang-Cheol Lee (kclee@kriss.re.kr)

Since the last meeting, the discrepancy in the results between weighing and moving mode experiments has been resolved through improved alignment. KRISS acquired 1st measurement data with respect to one Pt-Ir prototype and one stainless steel (E1) artefact in the beginning of 2020 using Kibble Balance (KB-1). As a result, KRISS joined 1st key comparison of kilogram realization (CCM.M-K8.2019) after mass redefinition with the uncertainty of 1.2×10^{-7}.

But we still have problem related to commercial weighing cell, reacting with respect to the parasitic force and torque. Even if compensating its effect and solving additional several minor problems, our KB-1's ultimate uncertainty is expected to be around 5×10^{-8}. Apart from improving the KB-1's performance, at the same time, we decided to develop the 2nd version Kibble balance (KB-2) to achieve our target goal of 1×10^{-8} level uncertainty. Regarding weighing cell in KB-2, monolithic flexure beam balance will be fabricated to minimize the effect of parasitic force and torque. Regarding permanent magnet system, to make uniform magnetic field (targeting less than 4×10^{-4} in the air gap) Sm_2Co_{17} and Ni-Fe alloy which has high permeability will be used for magnet and yoke, each. For optical system in KB-2, we decided to introduce optical heterodyne interferometer for precise measurement of velocity of coil. And also frequency-doubled, frequency stabilized 532nm laser will replace frequency stabilized He-Ne laser. In electrical measurement system, we have bought new standard resistor that has better long term stability than our old standard resistor. We have plan to compare the performance of two standard resistors in our system. We are developing low noise programmable current source that will be used for KB-2.

2. Force and Torque Standards

2.1 Deadweight Force Machines

Contact: Dr. Minseok Kim (minsk@kriss.re.kr)

KRISS conducted a supplementary comparison (coded APMP.M.F-S2.1, pilot: KRISS, participating institutes: VMI and SASO-NMCC) in the range of 50 kN and 100 kN in 2019 and submitted the Draft B report to the APMP TCM chair in 2020. The CMC of the smallest deadweight force machine with 20 N capacity has been improved from 100 ppm to 50 ppm by removing the balance mechanism that was used to tare a loading frame. The load frame was newly designed and fabricated to have about 50 g in mass, which is corresponding to 0.5 N in force. The modified 20 N machine was compared with the 200 N force machine at 5 N, 10 N and 20 N, and the results showed all En values are less than 1. KRISS joined the small force comparison in the range of 200 N and 500 N, which is coded as CCM.F-K23, using the 200 N and 2 kN force machines in 2020. The measurements were finished and data were reported to the pilot laboratory (METAS).

2.2 Hydraulic/Build-up Force Machines

Contact: Dr. Jong-Ho Kim (jhk@kriss.re.kr)

The development of a hydraulic force standard machine is in progress. Its capacity is 5.5 MN and its target uncertainty is 0.01%. The deadweight force is 22 kN and thus the amplification system formed is of 250:1 ratio. The piston and cylinder for generating hydraulic force were completed, and the system of hydraulic force standard machine was installed. The operation of machine is being checked currently. Two new build-up systems with a capacity of 16.5 MN and 50 MN, respectively, were also recently installed in the laboratory. The build-up system (16.5 MN) has been operated since 2022 because of modification of control hardware. In case of 50 MN build-up force machine, more investigations to improve uncertainty are under way.

2.3 Small Force Metrology

Contact: Dr. Jae-Hyuk Choi (jhchoi@kriss.re.kr)

KRISS is developing a photon-pressure-based small force standard, which is applicable to general sized force sensors with general surface material. With a single optic fiber geometry, the local reflectivity of a silicon-nitride cantilever at a force-acting point has been measured to agree with theoretical expectation, and its measurement precision is being improved.

2.4 Deadweight Torque Machines

Contact: Dr. Minseok Kim (minsk@kriss.re.kr)

KRISS is developing a deadweight torque machine with 22 kN·m capacity and target relative uncertainty of 5×10^{-5}. The characterization and improvement will continue in the year of 2021.

2.5 Planck constant-based Torque Machine

Contact: Dr. MyeongHyeon Kim (mhkim@kriss.re.kr)

KRISS has initiated a project to develop torque metrology based on Planck constant according to kilogram redefinition. Planck constant can be also implemented in realization of standard force and torque, mass-related units, by adopting the Kibble balance principle. In this study, we propose and develop a new dual-mode torque standard machine, which can produce static and dynamic torque at the same system. We established the whole mechanical system. Now, we are conducting basic tests for feasibility.

3. Pressure and Vacuum Metrology

3.1 Pressure Standards

Contact: Dr. In-Mook Choi (mookin@kriss.re.kr)

A new compact and space-efficient impulse pressure generator based on a shock accelerometer is being developed and improved. The shock acceleration exciter is known to be used for an impact standard that generally consists of pneumatic exciter, air-borne hammer and anvil. An optical interferometer has been installed in order to obtain the displacement of the piston in the dynamic pressure standard. Since the 2nd derivative of the piston displacement could be very noisy, a new way based on the density change determination by using the piston displacement information is being considered, which could be traceable to SI units. From the known density change according to the volume change which is proportional to the piston displacement, the pressure inside test chamber can be estimated.

In this year, KRISS is supposed to participate in the CCM key comparison in gauge and absolute pressure up to 350 kPa, and in gauge pressure up to 7 MPa.

3.2 Vacuum Standards

Contact: Dr. Han-Wook Song (hanugi16@kriss.re.kr)

KRISS started to develop a new vacuum standard for the pressure range from 1 Pa to 100 kPa using an optical method (one of 'new realizations of the pascal') since 2018. The optical interferometer was set-up and the optical cavity was in design. Currently, the KRISS designed a Fabry–Perot (FP) cavity structure having two channels to calculate an arbitrary pressure by comparing the laser resonance frequency in a vacuum state, which served as a reference pressure, and that in an arbitrary pressure state. Zerodur^{TM} was used as the material for the cavity. The cavity was designed to be a rectangular parallelepiped with a width of 50 mm and a length of 150 mm considering the wavelength (633 nm) of the He–Ne laser used as a light source, the pressure range to be implemented, and the implementation range of a single mode. We independently fabricated a single-mode (SM) He–Ne laser instead of a commercially available laser to modulate the frequency freely and to achieve a single polarization regardless of the quantum number. With the system, KRISS started the feasibility study.

4. Gravity Standards

Contact: Dr. In-Mook Choi (mookin@kriss.re.kr)

Using the established gravity calibration line, relative gravimeters used for the geoid determination in Korea are being calibrated. This work has been done with a cooperation between KRISS and NGII (National Geographic Information Institute). The relative gravity data collected for last 10 years are being evaluated. The gravity features over Korean peninsula would be characterized using the machine learning method.

In addition, the development of superconducting gravimeter using SQUID is being continued. The components for the superconducting gravimeter were fabricated and their performance tests were done. After the optimization of each component, then the whole system will be integrated as planned. In addition, the atomic gravimeter, being developed in time and frequency group, is fully operational now and started to measure the Earth tide successfully.

5. Hardness Standards

Contact: Contact: Mr. Nae-Hyung Tak (nhtak@kriss.re.kr)

The measuring system for the Rockwell and Vickres hardness indenter will be set up by LTF SpA Italy in June. In addition, KRISS measurement of the APMP.M.H-5(Brinell hardness) and APMP.M.H-6(Vickers hardness) were finished and its results were reported.

6. Fluid Flow Standards

6.1 Gas Flow Metrology

Contact: Dr. Woong Kang (woong.kang@kriss.re.kr)

In high pressure gas flow standard system in KRISS, a compressed air flow system has been used for primary standard gravimetric system with CMC in BIPM. KRISS are cooperating with KOGAS who is a governmental company for nation's import and supply of natural gas in Korea. KOGAS has the natural gas flow calibration facility related to KRISS high pressure gas flow standard system. KRISS and KOGAS are preparing the comparison (Key comparison or Bi-lateral comparison) in the high pressure natural gas flow. We have plan to claim CMC for natural gas after the comparison and peer review process in 2022.

6.2 Liquid(Water) Flow Metrology

Contact: Dr. Sejong Chun (sjchun@kriss.re.kr)

The research, which was being conducted between KRISS and NMIJ/AIST, was completed by submitting a Final Report on APMP.M.FF-S1 to the CCM-WGFF Chair (Dr. Bodo Mickan) and the APMP-TCFF Chair (Dr. Takashi Shimada) in march 2021. Only the approval procedure is left for its publication to BIPM KCDB. Another Final Report on CCM.FF-K1.2015 is expected to be completed during the year 2021. It is because the Draft B Report is being prepared by the Pilot Laboratory (PTB, Dr. Enrico Frahm) by the end of June 2021. New key comparison for large-capacity water flow measurement is expected to be held by the same Pilot Laboratory (PTB), starting in this year. As a research activity, a mini-scale gravimetric water flow measurement system is being planned to design for demonstrating the core-concept of gravimetric water flow measurement such as a variable-width flow diverter nozzle.

6.3 Liquid (Hydrocarbon) Flow Metrology

Contact: Dr. Seok Hwan Lee (seokhwan.lee@kriss.re.kr)

In the light oil flow standard system (Viscosity: 3.6 cSt @ 20°C), the KRISS and PTB oil flow standard systems were compared using a Coriolis flowmeter. The Re number was used to compensate for the density and viscosity differences in the working fluid. The calibration values of the Coriolis flowmeter in KRISS and PTB were 0.21–0.23% (U=0.08%, k=2) and 0.18–0.24% (U=0.05%, k=2), respectively, for Re number range between 35,000 and 145,000. The results from the gravimetric method at KRISS matched very well with the results from the volumetric method at PTB, within the estimated uncertainties. In heavy oil flow standard system (viscosity : 20 cSt @ 20 °C), recently a level retaining device in the oil reservoir was added and the flow control valve was replaced. Improvements to the heavy oil flow standard system reduced the measurement uncertainty from 0.11 % to 0.08 % (k=2) in the flow rate range from 2 to 22 m^3/h.

6.4 Air Speed Metrology

Contact: Dr. Woong Kang (woong.kang@kriss.re.kr)

KRISS has improved the air flow standard system to calibrate three-dimensional velocity probe with the non-nulling method for the gas flow velocity measurement in the smoke-stack. The flow velocity distributions in the smoke-stack of the domestic power plant are measured by three-dimensional probes with KRISS on-site stack gas velocity field measurement system. The greenhouse gas flowrate national test bed is constructing to simulate the smoke-stack in the industrial and power plant of Korea. KRISS and National Institute of Environmental Research of Korea will conduct collaborative research to improve the flow velocity measurement within the smoke-stack for the accurate estimation of the greenhouse gas emission with the proper uncertainty levels.

7. KC and MRA

7.1 Comparison Activities since 2019

- ✧ CCM.M-K8.2019 (Mass, 1kg) Final Report
- ✧ APMP.M.M-K5, Participation, Completed but not published yet
- ✧ GULFMET.M.M-K4, Participation, Published in Metrologia Tech. Suppl.
- ✧ CCM.F-K3.1 (Force 500 kN and 1000 kN) Draft A in progress
- ✧ APMP.M.F-S2.1 (Force 50 kN and 100 kN) Draft B in progress
- ✧ CCM.F-K23 (Force 200 N and 500 N), Measurement phase
- ✧ APMP.M.P-K4 (Vacuum 1 Pa to 10 kPa), Draft A in progress
- ✧ APMP.M.P-K9 (Absolute pressure, 110 kPa), Published in Metrologia Tech. Suppl.
- ✧ CCM.G-K2.2017 (Absolute Gravity), Published in Metrologia Tech. Suppl.
- ✧ CCM.G-K3 (Absolute Gravity), Draft B in progress
- ✧ APMP.M.G-K1 (Absolute gravity), Published in Metrologia Tech. Suppl
- ✧ APMP.M.P-k1.c2 (Gauge pressure, 0.4 MPa ~ 4 MPa), Published in Metrologia Tech. Suppl.
- ✧ CCM.P-K16, K17, K18 (Gauge pressure, 0.25 kPa ~ 350MPa, Absolute Pressure, 0.25 kPa~ 350 kPa, Gauge pressure, 0.7 MPa ~ 7 MPa), Measurement in progress
- ✧ APMP.M.H-S5 (Brinell Hardnbess), Draft A in progress
- ✧ APMP.M.H-S6 (Vickers Hardnbess), Draft A in progress
- ✧ APMP.M.FF-K6.2018 (Low-Pressure Gas Flow 10 to 100 m3/h), Measurement phase
- ✧ CCM.FF-K6.2017 (Low-Pressure Gas Flow 2 to 10 mL/min), Draft B in progress
- ✧ APMP.M.FF-S1 (Water Flow between 300 m3/h and 1200 m3/h)/, Draft B Completed
- ✧ CCM.FF-K2.2011 (Hydrocarbon between 5 kg/min and 60 kg/min)/, Draft B in progress
- ✧ CCM.FF-K1.2015 (Water between 30 m3/h and 300 m3/h)/ Draft B in progress
- ✧ APMP.M.FF-K3 (Air speed 2 m/s to 20 m/s), Measurement phase
- ✧ APMP.M.FF-K2 (Hydrocarbon between 60 m3/h and 150 m3/h), Measurement phase

7.2 MRA Activities in 2021

N/A

8. List of publications

[1] Dongmin Kim *et al.*, Realization of the kilogram using the KRISS Kibble balance, Metrologia, Volume 57, pp. 055006(16), 2020

[2] Minseok Kim *et al.*, Determination of temperature and humidity sensitivity coefficients

of torque transducers and estimation of their uncertainties based on a Monte Carlo method, Metrologia, Volume 57, pp. 025011, 2020

[3] W. Kang *et al*. Uncertainty analysis of stack gas flow measurements with an S-type Pitot tube for estimating greenhouse gas emissions using a continuous emission monitoring system, Metrologia, Volume 57(6), 065031, 2020

[4] S.H. Lee *et al*. Heat transfer characteristics of kerosene phase change based on fuel flow rates in the regenerative cooling heat exchanger of scramjet engines, Journal of Mechanical Science and Technology, In press.

[5] MyeongHyeon Kim, Design of a New Dual-Mode Torque Standard Machine Using the Principle of the Kibble Balance, IEEE T INSTRUM MEAS, 70, 2021

[6] H. W. Song *et al*. Development of a refractive index measurement system for vacuum pressure measurement, J. Kor. Phys. Soc., Volume 78, No. 2, 124-129, 2021

[7] H. W. Song *et al*. Characterization of a Newly Designed Vacuum Valve Having a Variable Conductance Function, MAPAN, Volume 35, No. 3, 309-315, 2020

[8] In-Mook Choi *et al*., "Investigation of 1 GPa Controlled Clearance Piston Gauge Using Finite Element Analysis", MAPAN, 35, 105-110, 2020.

(Written and Edited by Dr. Min-Seok Kim, May 7, 2021)