Report from NMIJ for CCM 2021

1. Main research activities

Mass/Gravity

- Realization of the kilogram based on the Planck constant using ^{28}Si-enriched spheres
- Development of an optical interferometer for Si sphere volume measurement
- Development of a vacuum spectroscopic ellipsometer for Si sphere surface analysis
- Development of an XPS system for Si sphere surface analysis
- Mass measurement in sub-microgram region by electrostatic force balance

Force/Torque

- Design and development of new force and torque standard machines with a very low capacity based on the Kibble balance method using electromagnetic force
- Design and development of new dead-weight force standard machines from 0.1 N to 10 N
- Replacement of the counter driving system of the 20 kN·m torque standard machine
- Development of a practical tuning-fork type force transducer with long-term stability in the sensitivity

Pressure/Vacuum

- Development of optical-based pressure standards
- Development of web distribution system of atmospheric pressure
- Precise characterization of a gas pressure gauge in a high pressure region (>about 10 MPa)
- Cooperative research on precise pressure monitoring at seafloor to detect crustal movements.
- Study on the extreme small leak rates down to 10^{-15} Pa m^3/s.

Density/Viscosity/Refractive Index:

- Development of density calibration techniques based on the silicon density standard and their applications to PVT property measurements for working fluids to meet demands from industry, and density measurements for standard sea water samples
- Development of refractive index standard based on optical interferometry and its application to in-situ absolute salinity measurement in the deep-sea
- Development of measurement and calibration techniques for viscometry and rheometry
- Development of measurement techniques for other related liquid physical properties such as speed of sound and dielectric constant

Hardness

- Coordinate measurement approach for the consistent direct verification of indenter geometry
- Study on the instrumented indentation technique
- Development of indentation diameter/diagonal length measurement method

Fluid Flow

- Investigation on flow dynamics of pipe flow at very high Reynolds number.
- Development of ultrasonic in-situ flow measurement technique.
- Development of measurement and calibration techniques for liquid microflow.

2. Participation in relevant comparisons

Comparison ID	Subfield	Number of participants	Pilot	Status	Years
APMP.M.M-K5	Mass	-	NIM	Report in progress, Final draft	2013 -
CCM.G-K2.2017	Gravity	30	NIM	Approved for equivalence *Metrologia*, 2020, 57 (1A), Tech. Suppl., 07002	2017 -
Pilot Study for the realization of the kilogram	Mass	7	BIPM	Approved for equivalence, *Metrologia*, 55, T1-T7 (2018)	2015 -
CCM.M-K8.2019	Mass	7	BIPM	Approved for equivalence *Metrologia*, 2020, 57 (1A), Tech. Suppl., 07030	2019-
CCM.F-K23	Force	-	METAS	Measurement in progress	2019 -
APMP.M.F-K3.b	Force	-	NIM	Measurement in progress	2011 -
APMP.M.T-K1	Planned	8	KRISS	Planned.	2011
CCM.P-K16, 17, 18	Pressure	9	CENAM PTB	Measurement in progress	2020-
APMP.M.P-K9	Pressure	14	KRISS	Approved for equivalence *Metrologia, 2020, 57, Tech. Supp., 07017*	2009-
APMP.M.P-K15	Vacuum	7	NMIJ/AIST	DraftA	2013-
APMP.M.P-K7.3	Hydraulic gauge pressure	7	NIMT and NMIJ	Final Report Approved	2016-
APMP.M.P-K4	Pressure measurements in gas (absolute mode)	8	KRISS	Measurements completed	2018-
APMP.M-H1.2020	Hydraulic gauge pressure	2	MUSSD and NMIJ	Report under review	2020
APMP.M-H2.2020	Gas gauge pressure	2	MUSSD and NMIJ	Report under review	2020
EURAMET.M.D-K1.1	Density of silicon spheres	16 from EURAMET, 1 from APMP (NMIJ/AIST)	PTB	Approved for equivalence *Metrologia*, 2020, **57**, *Tech. Suppl.*, 07028	2008 -

CCM.D-K3	Solid density standards		NMIJ/AIST	Protocol in progress	2011-
CCM. D-K5	Density of liquids determined by using density meters	15	BEV	Preparing liquid samples to be delivered	2019-
CCM. D-K6	Refractive Index of Liquids	-	NMIJ	Planned	
APMP. M. D-K4	Hydrometers	10	KRISS	Report in progress, Draft A	2007-
CCM.V-K3	Viscosity	19	NMIJ/AIST	Approved for equivalence *Metrologia, 2018, 55, Tech. Supp., 07010*	2012-2018
CCM.V-K4	Viscosity	11	CENAM	Report in progress, Draft A	2018-
CCM.H-K3	Hardness (Rockwell C)	-	INRiM, PTB, NIST, NMIJ	Protocol Complete A)	-
APMP.M.H-S5	Brinell hardness	3	NIMT	Final Report	2018-
APMP.M.H-S6	Vickers hardness	4	NIMT	Final Report	2018-
CCM.FF-K1.2015	Water flow	11	PTB	Measurement in progress	2015
CCM.FF- K2.2011	Fluid flow of hydrocarbon and water	8	VSL	Report in progress, Draft B	2013-
CCM.FF- K2.1.2011	Fluid flow of hydrocarbon and water	9	VSL	Report in progress, Draft A	2013-
CCM.FF-K5.2016	High pressure gas flow	8	PTB	Planned	2016-
CCM.FF-K6.2017	Low pressure gas flow	10	CMS/ITRI	Report in progress, Draft B	2017
APMP.M.FF-K2.2021	Hydrocarbon flow	4	NMIJ	Planned	2021-
APMP.M.FF-K2.2019	Hydrocarbon flow	3	NMIJ	Planned	2019-
APMP.M.FF-K3.2020	Air Speed	7	CMS/ITRI	Measurement in progress	2019-
APMP.M.FF-S1.2015	Water flow	2	KRISS/ NMIJ	Report in progress, Draft B	2015-
APMP.M.FF-S2.2016	Water flow	2	RCM-LIPI	Report in progress, Draft B	2016-
APMP.M.FF-S3.2020	Water flow	7	NIMT	Measurement in progress	2020-

A) CCM.H.K3: The status in KCDB of Key comparison of Rockwell C scale hardness is planned. Frist circulation between pilots was already done in 2011. CCM WGH decided to re-start the comparison after long pause in the last WGH meeting held in NPL at Sep. 2015.

B) Pressure: New CMCs are under review.

3. List of relevant publications in 2019-2021

Mass/Gravity

1) N. Kuramoto: New definitions of the kilogram and the mole: paradigm shift to the definitions based on the physical constants, *Anal. Sci.*, 37, 177-188 (2021)

2) N. Kuramoto, S. Mizushima, L. Zhang, K. Fujita, Y. Ota, S. Okubo and H. Inaba: Realization of the new kilogram using ^{28}Si-enriched spheres and dissemination of mass standards at NMIJ, *MAPAN*, 35, 491-498 (2020)

3) N. Kuramoto, S. Mizushima, L. Zhang, K. Fujita, S. Okubo, H. Inaba, Y. Azuma, A. Kurokawa and K. Fujii: Reproducibility of the realization of the kilogram based on the Planck constant by the XRCD method at NMIJ, accepted for publication in *IEEE Trans. Instrum. Meas.*, DOI: 10.1109/TIM.2021.3061805

4) Y. Ota, S. Okubo, H. Inaba and N. Kuramoto: Volume measurement of a ^{28}Si-enriched sphere to realize the kilogram based on the Planck constant at NMIJ, accepted for publication in *IEEE Trans. Instrum. Meas.*, DOI: 10.1109/TIM.2021.3061249

5) L. Zhang, N. Kuramoto and A. Kurokawa: XPS analysis of a ^{28}Si-enriched sphere for realization of the kilogram to realize the kilogram, accepted for publication in *IEEE Trans. Instrum. Meas.*, DOI: 10.1109/TIM.2021.3066190

6) S. Mizushima, N. Kuramoto and T. Uchida: Determination of defect concentrations in ^{28}Si crystals using ERP for the realization of the kilogram, accepted for publication in *IEEE Trans. Instrum. Meas.*, DOI: 10.1109/TIM.2021.3062186

7) K. Fujita, K. Fujii, Y. Yamamoto, Y. Ota and N. Kuramoto: Verifying the reliability of a voltage balance apparatus to measure small mass and force standards at NMIJ, accepted for publication in *IEEE Trans. Instrum. Meas.*, DOI: 10.1109/TIM.2021.3052020

8) Y. Ota, M. Ueki and N. Kuramoto: Evaluation of an automated mass comparator performance for mass calibration of sub-milligram weights, *Measurement*, 172, 108841 (2021)

9) M. Stock, P. Conceição, H. Fang, F. Bielsa, A. Kiss, L. Nielsen, D. Kim, M. Kim, K.-C. Lee, S. Lee, M. Seo, B.-C. Woo, Z. Li, J. Wang, Y. Bai, J. Xu, D. Wu, Y. Lu, Z. Zhang, Q. He, D. Haddad, S. Schlamminger, D. Newell, E. Mulhern, P. Abbott, Z. Kubarych, N. Kuramoto, S. Mizushima, L. Zhang, K. Fujita, S. Davidson, R. G. Green, J. O. Liard, N. F. Murnaghan, C. A. Sanchez, B. M. Wood, H. Bettin, M. Borys, M. Mecke, A. Nicolaus, A. Peter, M. Müller, F. Scholz and A. Schofeld, Report on the CCM key comparison of kilogram realizations CCM.M-K8.2019, *Metrologia*, 57, 07030 (2020)

10) Y. Yamamoto, K. Fujita and K. Fujii: Development of a new apparatus for SI traceable small mass measurements using the voltage balance method at NMIJ, *IEEE Trans. Instrum. Meas.*, 69, 9048-9055 (2020)

Force/Torque

1) A. Nishino, K. Fujii: Calibration of a torque measuring device using an electromagnetic force torque standard machine, *Measurement*, **147** (2019), 106821.

2) J. Zhu, T. Hayashi, K. Ogushi: Evaluation of Small Capacity Force Transducers, *Proc. Asia Pacific Measurement Forum on Mechanical Quantities, 2019 (APMF 2019)*, Niigata, Japan, November 2019.

3) A. Nishino, M. Kiuchi, K. Ogushi: Development of a low nominal capacity reference torque calibration machine, *Proc. Asia Pacific Measurement Forum on Mechanical Quantities, 2019 (APMF 2019)*, Niigata, Japan, November 2019.

4) T. Hayashi, H. Maejima, J. Zhu, K. Ueda, H. Otani: Renovation of NMIJ's 20 MN Hydraulic Amplification Type and 1 MN Lever Amplification Type Force Standard Machines, *Proc. Asia Pacific*

Measurement Forum on Mechanical Quantities, 2019 (APMF 2019), Niigata, Japan, November 2019.

5) Y. Toda, T. Kurokawa, H. Teshigawara, K. Ogushi: Calibration of Torque Measuring Devices Using the Reference Type Torque Calibration Machine in JQA, *Proc. Asia Pacific Measurement Forum on Mechanical Quantities, 2019 (APMF 2019)*, Niigata, Japan, November 2019.

6) J. Zhu, T. Hayashi, A. Nishino, K. Ogushi: Development of 2 N dead-weight type force standard machine, *Measurement*, **154** (2020), 107463.

7) J. Zhu, T. Hayashi, A. Nishino, K. Ogushi: New microforce generating machine using electromagnetic force, *ACTA IMEKO*, **9** (5) (2020), 109–112.

8) M. Kiuchi, A. Nishino, K. Ogushi: Calibration procedures for torque measuring devices by using a reference type torque calibration machine at NMIJ, *ACTA IMEKO*, **9** (5) (2020), 179–183.

9) K. Ogushi: The testing evaluation of several digital torque wrenches by using a torque wrench tester, *ACTA IMEKO*, **9** (5) (2020), 189–193.

10) T. Hayashi, J. Zhu: Evaluation of newly developed 50 N dead-weight type force standard machine using tuning-fork type force transducer, *Precision Engineering*, **68** (2021), 158–165.

11) J. Zhu, T. Hayashi, K. Ogushi: Evaluation of small-capacity force transducers using a developed 2 N dead-weight type force standard machine, *SICE Journal of Control, Measurement, and System Integration*, **14** (1), 12–19.

Pressure/Vacuum

1) T. Kobata and H. Kajikawa, Development of a system for measuring head differential pressure and density of working fluid at high pressures, *Measurement* 131 (2019) 79-84.

2) H. Kajikawa, T. Kobata, Evaluation and correction for long-term drift of hydraulic pressure gauges monitoring stable and constant pressures, *Measurement* 134 (2019) 33 - 39..

3) H. Kajikawa, T. Kobata, Different long-term characteristics of hydraulic pressure gauges under constant pressure applications, *Acta IMEKO* 8 (2019) 19 - 24.

4) H. Iizumi, H. Kajikawa, T. Kobata, Calibration values uninfluenced by the kind of pressure medium and the setting posture for quartz Bourdon-type pressure transducers, *Acta IMEKO* 8 (2019) 25 - 29.

5) Y. Takei, K. Arai, H. Yoshida, Y. Bitou, S. Telada, T. Kobata, Development of an optical pressure measurement system using an external cavity diode laser with a wide tunable frequency range, *Measurement* 151 (2020) 107090.

6) I.M. Choi, S.Y. Woo, J. Man, M. Aldammad, W. Sabuga, Y. Jin, N.N. Thang, G. J. Wu, C. Sutton, M. Kojima, APMP key comparison of absolute pressure from 10 kPa to 110 kPa (APMP.M.P-K9), *Metrologia* 57 Tech. Suppl. 07017 (2020).

7) S. Suginuma, Numerical simulation of relative sensitivity factor of Bayard–Alpert gauge, *Vacuum* 179 (2020) 109525.

8) Y. Takei, S. Telada, H. Yoshida, K. Arai, Y. Bitou, T. Kobata, In-situ measurement of mirror deformation using dual Fabry–Pérot cavities for optical pressure standard, *Measurement*, 173 (2021) 108496.

9) Y. Takei, H. Yoshida, E. Komatsu, K. Arai, Uncertainty evaluation of the static expansion system and its long-term stability at NMIJ, *Vacuum* 187 (2021) 110034

Density/Viscosity/Refractive Index:

1) N. Kuramoto, L. Zhang, S. Mizushima, A. Waseda, S. Okubo, H. Inaba, A. Kurokawa and K. Fujii: Absolute measurement of the density of silicon spheres to improve the primary density standard of NMIJ, *Metrologia*, 57, 025006 (2020)

2) Y. Kano, Y. Kayukawa and Y. Fujita: Dipole moment and heat capacity in the ideal gas state derived

from relative permittivity and speed of sound measure of HFO-1123 and HCFO-1224yd(Z), *Int. J. Refrigeration*, 118, 354-364 (2020)

3) Y. Kayukawa: *pρT* property measurements for HFO-1123 by a single sinker magnetic levitation densimeter, *Int. J. Refrigeration*, 119, 349-355 (2020)

4) Y. Kano: Multi-property evaluation for a gas sample based on the acoustic and electromagnetic resonances measurement in a cylindrical cavity, *J. Chem. Thermodynamnics*, 159, 106448 (2021)

5) Y. Kano: Thermophysical properties of 1,1,1,3,3,3-hexafluoro-2-methoxypropane (HFE-356mmz) in the vapor phase measured by using an acoustic-microwave resonance Technique, *Energies*, 13, 5525 (2020)

6) T. Muramoto, H. Kajikawa, H. Iizumi, K. Ide and Y. Fujita: Design of a high-pressure viscosity-measurement system using two pressure balances, *Meas. Sci. Technol.*, 31, 115302 (2020).

Hardness

1) Y. Tanaka, Y. Seino and K. Hattori, "Measuring Brinell hardness indentation by using a convolutional neural network", *Measurement Science and Technology*, **30**, 065012(2019).

2) Y. Tanaka, Y. Seino and K. Hattori, "An application of deep learning for measurement of Brinell and Vickers hardness", *Proc. APMF2019*, Niigata, Japan, Nov. 2019.

3) K. Hattori, C.-L. Wu, N.-H. Tak, P. Yang, T. Sanponpute, R. Leung, P.T. Ha and S. Takagi, "Final report of the key comparison of Vickers hardness: APMP.M.H-K1.b and APMP.M.H-K1.c", *Metrologia*, **57**, 07010(2020).

4) S. Kato, K. Hattori, Y. Tanaka, Y. Miyazaki, G. Ishii, S. Koura and N. Negishi, "Development of monolithic titanium dioxide ceramic photocatalysts with high physical rigidity and photocatalytic activity for underwater use", *Ceramics International*, **46**, 19285(2020).

5) Y. Tanaka, Y. Seino and K. Hattori, "Automated Vickers hardness measurement using convolutional neural networks", *International Journal of Advanced Manufacturing Technology*, **109**, 1345(2020).

6) S. Takagi, et al., "On the direct verification of Knoop indenter geometry in nanoindentation range with an atomic force microscope", *J. MTRAJ*., **65** (1),18-24 (2020).

7) S. Takagi, Y. Tanaka and Y. Seino, "Errors in the Vickers diagonal length measurement caused by different designs of microscopes", *Acta IMEKO*, **9** (5), 261-264 (2020).

8) Y. Tanaka, Y. Seino and K. Hattori, "Verification of radial displacement correction effect in instrumented indentation testing", *Acta IMEKO*, **9** (5), 265-269 (2020).

Fluid Flow

1) A. Iwai, T. Funaki, N. Kurihara, Y. Terao, Y. M. Choi, New air speed calibration system at NMIJ for air speeds up to 90 m/s, Flow Measurement and Instrumentation 66, (2019), pp.132-140

2) T. Kyoden, S. Akiguchi, T. Tajiri, T. Andoh, N. Furuichi, R. Doihara, T. Hachiga, "Assessing the infinitely expanding intersection region for the development of large-scale multipoint laser Doppler velocimetry", Flow Measurement and Instrumentation, Vol 70,101660 (2019).

3) N. Furuichi, Y. Terao, Re-definition of the discharge coefficient of throat-tapped flow nozzle and investigations on the influence of geometric parameters, Flow Measurement and Instrumentation 65 (2019), pp.16–21

4. Topical issues

The kilogram is presently defined by the Planck constant. Under this new definition, in principle, any national metrology institute (NMI) has the possibility to realize the kilogram independently. To confirm the consistency among the individual realizations by NMIs, the first international comparison of the realizations based on the new definition, CCM.M-K8.2019, was organized from 2019 to 2020. Six NMIs including NMIJ and BIPM participated in the comparison and used their own realization methods. By this key comparison, the consistency of the individual realizations was confirmed, and the internationally coordinated dissemination of the kilogram has entered into a new phase on 1st February 2021.

In CCM.M-K8.2019, NMIJ realized the new kilogram by the X-ray crystal density method. Fundamental concept of this method is the counting of Si atoms in a Si sphere. The volume of the sphere was determined by an optical interferometer and the number of Si atoms in the Si sphere was determined from the sphere volume and the lattice constant of Si crystal. The mass of a Si atom is derived from the Planck constant. From the number of Si atoms, the mass of the sphere was therefore determined on the basis of the Planck constant. The relative standard uncertainty of the sphere mass determination was estimated to be 2.1×10^{-8}. This corresponds to the realization of the new kilogram with a standard uncertainty of 21 μg for 1 kg.