Report from NMIJ for CCM 2023

1. Main research activities

Mass/Gravity

- Realization of the kilogram based on the Planck constant using ^{28}Si-enriched spheres.
- Mass measurement in sub-microgram region by electrostatic force balance.

Force/Torque

- Development of a new dynamic torque standard machine based on the Kibble balance method.
- Development of a new force and torque standard machines with a very low capacity based on the Kibble balance method.
- Development of the remote calibration technique for force calibration machines.

Pressure/Vacuum

- Development of optical-based pressure standards.
- Dynamic pressure measurement (atmospheric pressure) for infrasound observations.
- Cooperative research on precise pressure monitoring at seafloor to detect crustal movements.

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 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	19	NIM	Approved, *Metrologia*, 2023, 60 (1A) 07002	2013 -
CCM.M-K8.2021	Mass	9	BIPM	Approved, *Metrologia*, 60 (1A), 07003, 2023	2021-

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Comparison ID	Subfield	Number of participants	Pilot	Status	Years
CCM.F-K1.a.2022	Force	20	UME	Planned	2022 -
CCM.F-K23	Force	-	METAS	Draft B	2019 -
APMP.M.F-K3.b	Force	-	NIM	Measurements completed.	2011 -
CCM.T-K1	Torque	-	-	Planned	2024
CCM.T-K2.1	Torque	2	NMIJ	Measurements completed.	2021 -
CCM.T-K3	Torque	10	PTB	Planned.	2023 -
APMP.M.T-K1	Torque	8	KRISS	Planned.	2011
CCM.P-K16, 17, 18	Pressure	9	CENAM PTB	Measurement in progress	2020-
APMP.M.P-K15	Vacuum	7	NMIJ/AIST	DraftA	2013-
APMP.M.P-K7.3	Hydraulic gauge pressure	7	NIMT and NMIJ	Approved, *Metrologia* 2022 **59**, 07015	2016-
APMP.M.P-K4	Pressure measurements in gas (absolute mode)	8	KRISS	Measurements completed	2018-
CCM.D-K1.2023	Density of a silicon sphere	11	PTB	Measurement in progress	2022 -
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	Measurement in progress	2019-
CCM. D-K6	Refractive Index of Liquids	10	NMIJ	Planned	
APMP. M. D-K4	Hydrometers	10	KRISS	Approved, *Metrologia,* 2023, **60**, 07007	2007
CCM.V-K4	Viscosity	11	CENAM	Report in progress, Draft B	2018-
CCM.H-K3	Hardness (Rockwell C)	-	INRiM, PTB, NIST,	Protocol Complete A)	-
APMP.M.H-S5	Brinell hardness	3	NIMT	Approved, *Metrologia* 2022 **59**, 07019	2018-
APMP.M.H-S6	Vickers hardness	4	NIMT	Approved, *Metrologia* 2022 **59**, 07020	2018-
CCM.FF-K1.2015	Water flow	11	PTB	Approved, *Metrologia, 2022, 59, 07013*	2015

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Comparison ID	Subfield	Number of participants	Pilot	Status	Years
CCM.FF-K1.2022	Water flow	6	METAS	Planned	2022
CCM.FF- K2.2011	Fluid flow of hydrocarbon and water	8	VSL	Report in progress, Draft B	2013-
CCM.FF-K5.2021	High pressure gas flow	8	PTB	Measurement in progress	2021-
CCM.FF-K6.2017	Low pressure gas flow	10	CMS/ITRI	Approved, *Metrologia, 2022, 59, 07012*	2017
APMP.M.FF-K2.2021	Hydrocarbon flow	4	NMIJ	Measurement in progress	2021-
APMP.M.FF-K3.2020	Air Speed	8	CMS/ITRI	Report in progress, draft A	2019-
APMP.M.FF-S1.2015	Water flow	2	KRISS/ NMIJ	Approved, *Metrologia, 2022, 59, 07004*	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	Report in progress, draft A	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.

3. List of relevant publications in 2021-2022

Mass/Gravity

1) N. Kuramoto: The new kilogram for new technology, *Nat. Phys.*, **18**, 720 (2022).

2) 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).

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, *IEEE Trans. Instrum. Meas.*, **70**, 1005609 (2021).

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, *IEEE Trans. Instrum. Meas.*, **70**, 1005506 (2021).

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, *IEEE Trans. Instrum. Meas.*, **70**, 1006305 (2021).

6) S. Mizushima, N. Kuramoto and T. Uchida: Determination of defect concentrations in ^{28}Si crystals using ERP for the realization of the kilogram, *IEEE Trans. Instrum. Meas.*, **70**, 1005706 (2021).

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, *IEEE Trans. Instrum. Meas.*, **70**, 1004205 (2021).

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) Y. Ota, M. Ueki and N. Kuramoto: Evaluation of automatic sub-multiple mass calibration for sub-

milligram weights at NMIJ, *Measurement*, **198**, 111320 (2022).

10) K. Fujita, K. Fujii, L. Zhang, Y. Azuma, S. Mizushima and N. Kuramoto: Investigating stability of Si sphere surface layer in ambient-vacuum cycling measurements using ellipsometry, *IEEE Trans. Instrum. Meas.*, **71**, 1001409 (2022).

11) S. Mizushima and T. Umeda: Electron paramagnetic resonance study of silicon-28 single crystal for realization of the kilogram, *Metrologia*, **59**, 025005 (2022).

12) M. Stock, , K. Fujita, H. Inaba, K. Kano, N. Kuramoto, S. Mizushima, S. Okubo, Y. Ota, L. Zhang et al. : Final report on the CCM key comparison of kilogram realizations CCM.M-K8.2021, *Metrologia*, **60**, 07003 (2023).

Force/Torque

1) J. Zhu, T. Hayashi, A. Nishino, K. Ogushi: Development of a novel microforce-generating machine based on a force generation method using electromagnetic force, *Meas. Sci. Technol.,* **33**, 015010 (2022).

2) A. Nishino, M. Kinoshita: Development of a nano-torque generating machine using electromagnetic force based on the principle of the Kibble balance, *Measurement,* **194**, 111081 (2022).

3) M. Hamaji, A. Nishino, K. Ogushi: Development of a novel dynamic torque generation machine based on the principle of a Kibble balance, *Meas. Sci. Technol.,* **33**, 115901 (2022).

Pressure/Vacuum

1) H. Iizumi, H. Kajikawa, T. Kobata: Estimation of Calibration Values of Quartz Bourdon-Type Pressure Transducers Using Various Gases, *MAPAN,* **36**, 435-441 (2021).

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

3) Y. Takei, S. Telada, H. Yoshida, Y. Bitou, and T. Kobata: Challenges of an optical pressure standard in medium vacuum measurements, *Measurement: Sensors,* **22**, 100371 (2022).

4) M. Kojima, T. Kobata: Simultaneous measurements of atmospheric pressure at multiple locations and their distribution via website, *Meas. Sci. Technol.,* **33**, 125005 (2022).

Density/Viscosity/Refractive Index:

1) 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).

Hardness

1) Y. Tanaka, K. Hattori, Y. Harada: Micro-cantilever testing of microstructural effects on plastic behavior of Ti-6Al-4V alloy, *Mater. Sci. Eng. A*, **823**, 141747 (2021).

2) Y. Tanaka, K. Hattori, Y. Harada: Evaluating local strain rate sensitivity of titanium alloy using dynamic nanoindentation testing, *Measurement: Sensors*, **18**, 100094 (2021).

3) Y. Tanaka, K. Hattori, Y. Harada: Nanoindentation and micro-cantilever testing for understanding cold-dwell sensitivity of heat-resistant titanium alloys, *Materials Characterization*, **190**, 112055 (2022).

4) Y. Tanaka, K. Hattori, Y. Harada: A study of the high-temperature strength of titanium alloys using nanoindentation and micro-cantilever bending tests, *Metall. Mater. Trans.*, **53A**, 3827-3832 (2022).

5) M. Pakkratoke, N. Sasom, K. Hattori, N-H Tak: APMP.M.H-S5 final report of the supplementary comparison of Brinell hardness, *Metrologia*, **59(1A)**, 07019 (2022).

6) M. Pakkratoke, N. Sasom, K. Hattori, N-H Tak, C.-L Wu, S. Jarbua, M. Al Ayden and A. Al Anazi: APMP.M.H-S6 final report of the supplementary comparison of Vickers hardness, *Metrologia*, **59(1A)**, 07020 (2022).

Fluid Flow

1) Yoshida,T., Wada, S., Furuichi, N.: A calibration methodology of ultrasonic transducers: Evaluation of spatial propagation characteristics of pulse-echo, *Measurement*, **214**, 112783 (2023).

2) Yoshida, T., Furuichi N.: Development of controllable volumetric prover for evaluating responsiveness of flowmeter under controlled-transient flows, *Measurement*, **208**, 112456 (2023).

3) Cheong, KH., Doihara, R., Furuichi, N., Nakagawa, M., Karasawa, R., Kato, Y., Kageyama, K., Akasaka, T., Onuma, Y., Kato, T.: Optimum Pressurization Mechanism for a Non-Electrical Piston-Driven Infusion Pump, *Applied Science*, **12**, 8421 (2022).

4) Wada, S., Furuichi, N.: Applicability evaluation of the ultrasonic pulse-train Doppler method on the disturbed flow in a pipe, *Flow Measurement and Instrumentation*, **87**, 102225 (2022).

5) Furuichi, N., Arias, R., Yang, C.T., Chun, S., Meng, T., Shinder, I., Frahm, E., Büker, O., Mills, C., Akselli, B., Smits, F.M.: Final report "Key comparison CCM.FF-K1.2015 - water flow: 30 m3/h ... 200 m^3/h," *Metologia*, **59**, 1A (2022).

6) Ono, M., Furuichi, N., Wada, Y., Kurihara, N., Tsuji, Y.: Reynolds number dependence of inner peak turbulence intensity in pipe flow, *Physics of Fluids*, **34**, 045103 (2022).

7) Chun, S., Furuichi N, Final report of the APMP water flow supplementary comparison (APMP.M.FF-S1), *Metrologia*, **59**, 1A (2022).

8) Wada Y., Furuichi, M., Tsuji Y.: Correction method of measurement volume effects on time-averaged statistics for laser Doppler velocimetry, *European J. of Mechanics B/Fluids*, **91**, p.233-243 (2022).

9) Takegawa, N., Ishibashi, M., Iwai, A., Furuichi, N., Morioka, T.: Verification of flow velocity measurements using micrometer-order thermometers, *Scientific report*, **11**(1), 23778 (2021).

10) Furuichi N., Cheong, KH., Yoshida, T.: Experimental study to establish an evaluating method for the responsiveness of liquid flowmeters to transient flow rates, *Flow Measurement and Instrumentation*, **82**, 102067 (2021).

11) Cheong, KH, Doihara, R., Furuichi, N., Kamazawa, S., Kasai, S., Hosobuchi, N.: A comparison between a Coriolis meter and a combination method of a volumetric positive-displacement flowmeter and a densitometer in measuring liquid fuel mass flow at low flow rates, *Measurement: Sensors*, **18**, 100321 (2021).

12) Doihara, R., Shimada, T., Cheong, KH., Furuichi, N.: Weighing system with low evaporation error for liquid microflow down to 1 mg/min, *Flow Measurement and Instrumentation*, **81**, 1012030 (2021).

13) Cheong KH, Doihara, R., Furuichi, N., Terao, Y., Shimada, T.: Primary standard for traceability in low liquid hydrocarbon fuel flow rates, *Metrologia*, **58**, 065003 (2021).

14) Furuichi, N., Ono, M.: Static pressure measurement error for wall taps with high Reynolds number turbulent pipe flow, *Flow Measurement and Instrumentation*, **79**, 101962 (2021).

15) Wada, S., Furuichi, N.: Improving accuracy of pipe flow rate measurement with ultrasonic time-domain correlation method under small number density of reflectors, *Measurement*, **179**, 109439 (2021).

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 second international comparison of the realizations based on the new definition, CCM.M-K8.2021, was organized from 2021 to 2023. Eight 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 consensus value of the kilogram was updated on 1st March 2023. In CCM.M-K8.2021, NMIJ realized the new kilogram by the X-ray crystal density method using a ^{28}Si-enriched sphere. The relative standard uncertainty of the realization was estimated to be 2.3×10^{-8}. This corresponds to the realization of the new kilogram with a standard uncertainty of 23 μg for 1 kg.