Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

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Report from PTB for CCM 2023

1. Main research activities in Mass, Force/Torque, Pressure/Vacuum, Density, Viscosity, Hardness and Fluid Flow

Mass

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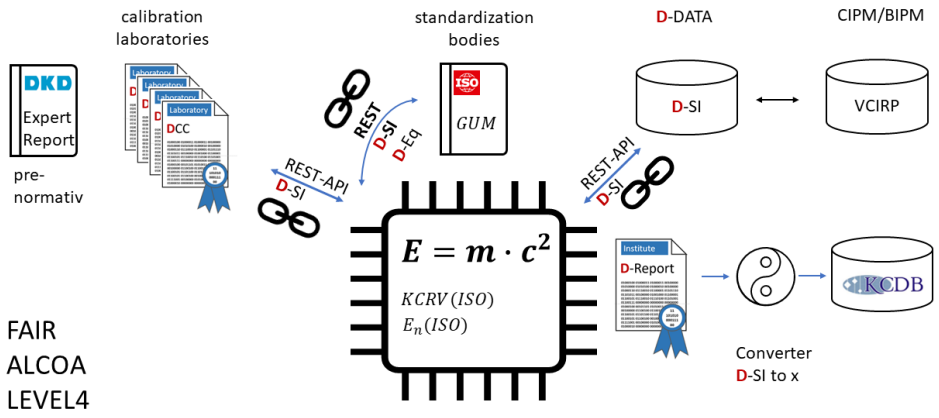
Adaption of the general machine-actionable **D**CC-scheme to the specific needs and demands of mass metrology together with accredited calibration laboratories and industry from Germany, Austria and Switzerland. Publication of a first guide on the set-up and use of digital calibration certificates in mass (DKD expert report). This makes use of the current activities in the digital representation of units in the **D**-SI scheme. A respective project regarding **D**CCs for non-automatic weighing instruments is on its way in strong cooperation with industrial partners.
- Developments and cooperation with leading industry started in order to establish a digital product passport (**D**PP) for measuring instruments. Based on an asset administration shell and taking into account the information elements contained in a **D**CC, initial concepts were developed. A first demonstrator will be expected by mid of 2023.
- First International Summer School on the **D**CC was held on 13. – 24. June 2022. More than 70 participants from 40 countries, representing NMIs, DIs, calibration service providers and industry stakeholders from numerous metrology domains received a fundamental introduction into the main aspects of the **D**CC. It was complemented by hands-on exercises and discussions on implementation aspects.
- PTB established a **D**CC-Focus group where interested developers can meet weekly in order to participate in the developments of the **D**CCs or receiving support for their own developments.
- First demonstrator for automatable generation of a **D**CC report from any laboratory control software
- In order to advance the digital infrastructure for calibration service providers, PTB has developed a pilot application for machine-interpretable and fully automatic key comparisons. In addition to the machine-interpretable calibration certificate for mass, it includes access to a machine-interpretable database in which the SI units are stored. A central evaluation module generates the result report. The study shows one way of implementing the FAIR (Findable, Accessible, Interoperable, and Reusable) principles, Persistent Identifiers (PIDs) and Level 4 (IDIS Whitepaper “SCENARIOS FOR DIGITIZING STANDARDIZATION AND STANDARDS” 2021) specifications. Important components are the **D**-SI metadata format and the digital calibration certificate based on it. The structure of the digital calibration certificate is based on the specifications of the DKD (German Calibration Service) expert report (DKD-E7.2; Instructions on how to use the **D**CC schema to create a digital calibration certificate for weights; https://www.ptb.de/cms/metrologische-dienstleistungen/dkd/publikationen.html). This was developed in cooperation with calibration service providers and industry. PTB is taking on the role of coordinator. Interested parties worldwide are invited to help shape the developments and to use them themselves.



The illustration shows the interaction of a digital metrological twin (**D**-TM), shown here as a processor. This communicates via a digital interface (REST API) with data sources and machine-interpretable standards. A result report is output. The implementation also took into account developments that were decided at the last CGPM meeting and at the CIPM meeting.

- In 2021, 2022 and 2023 three workshops were held in order to establish machine actionable **D**CCs on a global harmonized marked. More than 1000 participant of much more than 70 countries participated at the workshops.
- Integration of activities in the area of digital transformation in metrology with work carried out by other bodies of the German quality infrastructure. The corresponding initiative "QI-Digital" aims to develop a set of digital tools and solutions to later form the fundamental basis for a digitally interoperable quality infrastructure. This initiative is a national implementation of the ideas behind the "Joint Statement of Intent" signed by several bodies of the international quality infrastructure in 2022.
- First realization of a comprehensive and agile demonstrator for FAIR principles in the quality infrastructure and level 4 digital maturity of certificates, guidelines and standards was developed and will be transferred to calibration services and industry. First industry ready applications bring together automated key comparison handling, access to machine-readable standards and automated creation of a machine-actionable report. The implementation of a digital metrological twin (**D**-MT) acts as an autonomous AI system. An important element of this setup is the provision of constants in a machine-comprehensible way. To this end, a web-based service is being developed that will later also be accessible for other purposes than the demonstrator.
- Organization of the first international conference on metrology and digital transformation - the IMEKO TC6 M4Dconf. The conference took place September 2022 as a fully hybrid event. Contributions included digital certificates, digital representation of units of measurement and digital infrastructures for metrology.
- Further development of the Planck-Balance - test of new facility and subassemblies, implementation of an AC quantum voltmeter in an automated measurement procedure. First usability example of a digital metrological twin ("virtual Planck-Balance") for the uncertainty estimation.
- Development of novel transfer artefacts made of silicon. Young Excellent Paper Award at IMEKO World Congress 2021 by K. Lehrmann
- Online-Workshop “Round & established^2 2022” with partners of the Si-Trust regarding the long-term experience in handling, storage and use of silicon spheres made of natural silicon was held at 2022/08/23

and 24. Participants of 10 countries reported about their experience of using silicon spheres as mass standards.

- International exchange with NIST, NIM and CENAM
- Final improvements to the setup of the absolute lattice parameter measurement of Si-28 are underway to control all relevant systematic effects. The following measures were found to be necessary: re-etching of the splitter-/mirror-crystal, introduction of a temperature shield, as well as the implementation of an interferometric 6DoF-Sensor to measure the 3D trajectory while scanning.
- A second x-ray interferometer from a different Si-28 crystal will be manufactured and used for the absolute lattice parameter measurement.
- The setup of a lattice comparator for relative measurements is underway. It is planned to investigate the homogeneity of the lattice parameter from different locations inside one crystal as well as between different crystals of Si-28 with a relative uncertainty in the range of a few parts per billion.
- Participation in the second CCM key comparison of realisations of the kilogram (CCM.M-K8.2021). ^{28}Si spheres were used as primary mass standards with relative standard uncertainties (k = 1) of 1.6×10^{-8} and 1.5×10^{-8}, respectively. One platinum-iridium prototype and one ^{nat}Si sphere were used as travelling standards.
- Relative correction of PTB mass scale by -5×10^{-9} in accordance with the introduction of the Consensus Value 2023 (“Dissemination from the Consensus Value for the kilogram”, CCM February 2023), implementation of changes in QM system and information of customers
- Investigation of mathematical models for a treatment of artefact instability effects in interlaboratory comparisons
- Repeated gravimetric measurements of cleaned silicon spheres confirmed a repeatability of the applied cleaning method for silicon spheres in the order of two micrograms (standard uncertainty)
- Peer Review of the Department 1.1 Mass, Working Group 1.11 Mass Standards: Verification of the requirements of the CIPM MRA within the EURAMET project 1083 based on the international standard ISO/IEC 17025:2017 and the CIPM document MRA-G-12.
- Automatization of mass determinations in the mass range between 1 mg and 10 g by means of a robotic system

Force/Torque

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Adaption of the general machine-actionable DCC scheme to the specific needs and demands of force and torque metrology together with accredited calibration laboratories and industry from Germany, Austria and Slovenia. Work on the harmonisation of the XML element attributes and their names. This makes use of the current activities in the digital representation of units in the D-SI scheme. Extensive work on tools for the automated generation of an XML DCC within the GEMIMEG framework and also for a direct data path from spreadsheets to XML
- Traceability of probing forces for AFM, stylus instruments, CMM and nanoindenters.
- Development und investigation of methods for traceability of force measurement for continuous and dynamic applications (https://www.ptb.de/empir2018/comtraforce/home/).

- Development of methods for traceable mechanical and electrical power measurement for efficiency determination of wind turbines (https://www.ptb.de/empir2020/windefcy/home/).
- Development of a torque standard machine with a capacity of 5 MN·m with the possibility of an extension to 20 MN·m in the new competence center for wind energy
- Development of standards and methods for the multi-component calibration of force and torque transducers
- Development and investigation of low force standards for the range from 1 N down to 1 nN
- Development and investigation of low torque standards for the range from 1 N·m down to 1 mN·m

Pressure/Vacuum

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Automatized generation of a digital calibration certificate for vacuum gauges and corresponding digital infrastructure
- Development of digital calibration certificates for calibration of barometers and pressure transducers.
- Pressure realization by fundamental measurement of refractivity
- Evaluation and standardization of a new type of ionization vacuum gauge suitable as transfer standard
- Validation of a new high and medium vacuum standard made of aluminum (static expansion system)
- Development of an oil-based interferometric micromanometer with an integrated oil density measurement facility as a primary pressure standard for 2 kPa range of absolute and gauge pressure.
- Characterisation of force-balanced piston gauges as primary pressure standards in the range of 15 kPa based on state-of-the-art dimensional metrology and methods of the rarefied gas dynamics.
- Development of methods and standards for reliable calibration of low gauge pressures and particularly negative gauge pressure based on pressure balance and liquid column manometry.
- Research on piston-cylinder assemblies of pressure balances: Study of piston rotation rate effect. Stability of the effective area based on dimensional measurements. 2D flow modelling of piston-cylinders' effective area.

Density

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The discussions on DCCs for mass and weights were accompanied by input from solid density to ensure compatibility during future developments for DCCs in density.
- Development of a high-precision hydrostatic system to compare 1 kg spheres manufactured from natural and isotopically enriched silicon
- Development and validation of a liquid density measurement facility for elevated pressures up to 700 bar

- Development and investigation of traceable liquid density measurements under wide conditions (EMPIR 17RPT02 rhoLiq, Establishing traceability for liquid density measurements)

Hardness

- Development of fast measurement techniques for nanomechanical characterization of nanowires used in energy harvesting nanodevices (EMPIR 19ENG05 NanoWires "High throughput metrology for nanowire energy harvesting devices", https://www.ptb.de/empir2020/nanowires/project/)
- Automation of Rockwell measurement systems based on measurements at the preload phase (TransMet Project)

Fluid Flow

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The topic of a DCC was discussed in the DKD Technical Committee "Flow Measurands" and there is interest in developing DCC here as well.
A first draft for a DCC for piston-stroke pipettes was discussed in the DKD technical subcommittee "Volume".
- Development of a virtual ultrasonic flowmeter
- Development of a new wind primary Lidar standard for 3D wind vector measurements and measurement heights between 10 m and 300 m with high spatial and time resolution.
- Development of test infrastructure for calibration and testing as well for conformity assessments (type approvals) with gaseous fuels containing hydrogen up to 100 %.
- Establishment of traceable test infrastructure for gaseous fuels containing hydrogen up to 100 % and for CO2 on site of industrial partners.
- Scientific based establishment of transferability of calibration results obtained with conventional gases for application with hydrogen
- Durability tests for domestic gas meters for renewable gaseous fuels and fuels containing hydrogen up to 100 %.
- Development of infrastructure and test regimes for the characterization of flow meters closer to operating conditions including dynamic calibrations
- Research in the use of cavitation nozzles in liquid flow metrology
- Development of transfer setups for onsite calibrations and intercomparisons of flow meters
- Development of time-resolved laser optical temperature measurements in water with Filtered Brillouin Scattering combined with Laser Doppler velocimetry

2. Participation in relevant comparisons after/until 2021

Comparison ID	Subfield	Number of Participants	Pilot	Status	Years
EURAMET EMPIR 17RPT02 rohLiq	Density of liquids	12	IPQ	In progress	2018-
CCM.D-K1.2023	Density standards	11	PTB	Measurements in progress	2022-
CCM.D-K5 and EURAMET comparison No. 1440	Density of liquids	15	BEV	In progress	2019-
CCM.D-K5 and EURAMET comparison No. 1440	Density of liquids	15	BEV	In progress	2019-
EURAMET.M.H-S2.a.b	Hardness	3	INRIM	Measurements completed	2018-2019
CCM.H-K3	Hardness	5	INRIM	Protocol complete	2020-
EURAMET.M.D-K4.2020	Hydrometers	9	INRIM	Completed, final report: Metrologia 59 (2022) 07005	2020-2022
CCM.M-K8.2021	Mass standards	9	BIPM	Completed, Final report: Metrologia 60 (2023) 07003	2021-2022
EURAMET.M.M-K7	Mass standards	20	UME	Measurements in progress	2020-
CCM.P-K4.2012.1	Pressure	2	NIST	In progress	2019-
EURAMET.M.P-K4.2020	Pressure	5	PTB	In progress	2019-2023
CCM.P-K16	Pressure	9	CENAM	In progress	2020-2023
CCM.P-K17	Pressure	9	CENAM	In progress	2020-2023
CCM.P-K18	Pressure	9	CENAM	In progress	2020-2023
CCM.V-K3	Viscosity	19	NMIJ	Report in progress, Draft A	2012-xxx
SIM.M.FF-S9	Water flow	6	PTB/CENAM	Report in progress, Draft A	2015-2019
EURAMET Project No. E 1507	Water flow	13	CMI	Report in progress, Draft A	2020-2021
EURAMET Project E. 1506 – Pilot study	Water flow	8	CETIAT	Draft B	2020-2021
CCM.FF-K5.2021	Gas Flow	5	PTB	In progress	2021-2024
CCM.FF-K6.2017	Gas Flow	10	CMS/ITRI	Published *Metrologia* 2022 **59** *Tech. Suppl.* 07012	2022
EURAMET Project F 1515	Air speed	9	UME	Published	2022
Euramet Pilot study no. F1565	Air speed	11	CMI	In progress	2022-2024
CCM.F-K23	Force	11	METAS	Report in progress, Draft A	2019-2022

Comparison ID	Subfield	Number of Participants	Pilot	Status	Years
CCM.F-K1	Force	21	TUBITAK UME	In progress	2021-2022
CCM.T-K3	Torque	7	PTB	In progress	2022-

3. List of relevant publications since 2021

Mass

Beyer, E.: Oberflächenquantifizierung von Siliziumkugeln für die Neudefinition and Realisierung des Kilogramm mit röntgenspektroskopischen Methoden, PTB-Bericht MA, 103 (2021)

Foyer, G.; Schulz, K.: Overview study of the use of several weighing instruments for static determination of vehicle mass in Germany, Measurement: Sensors 18 (2021), 100114

Members of the Technical Committee Mass and Weighing Instruments of the DKD: Instructions on how to use the DCC schema to create a digital calibration certificate for weights: Expert Report DKD-E 7-2, https://doi.org/10.7795/550.20220419B

Wu, Yu-Hsin; Tsao, Lin; Chiu, Jeng-Yu; Chen, Sheng-Jui; Fliegauf, Rolf; Müller, Matthias; Beyer, Edyta; Kolbe, Michael: Quantification via X-ray fluorescence analysis of oxygen in the surface layer of a Si-sphere used as a new mass standard. X-Ray Spectrom. 2021, 1 – 7

Lehrmann, K.; Härtig, F.; Tutsch, R.: Numerical simulation for the determination of the measurement uncertainty for the calibration of mass standards by transfer artefact. Measurement: Sensors, 24 (2022), 100414

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Marschall, M.; Wübbeler, G.; Borys, M.; Elster, C.: On modeling of artifact instability in interlaboratory comparisons. Metrologia 2023 (submitted)

Poroskun, I, Rothleitner, Ch., Heißelmann, D.: Structure of digital metrological twins as software for uncertainty estimation, Journal of Sensors and Systems: 11 (2022), 1, 75-82

Poroskun, I., D. Heißelmann, and C. Rothleitner: Building Blocks for an Adaptive Software-based Uncertainty Estimation. SMSI 2021-System of Units and Metreological Infrastructure (2021): 327-328.

Poroskun I., Rothleitner Ch., Heißelmann D.: Systematische Realisierung von Software zur Messunsicherheitsbestimmung am Beispiel der virtuellen Planck-Waage. VDI-Berichte. (2021). VDI Verlag, Düsseldorf. S.159–168. doi.org/10.51202/9783181023907

Vasilyan, S., Rogge, N., Rothleitner, C., Lin, S., Poroskun, I., Knopf, D., Härtig, F., Fröhlich, T.: The progress in development of the Planck-Balance 2 (PB2): A tabletop Kibble balance for the mass calibration of E2 class weights. tm-Technisches Messen. (2021). 88(12), 731-756.

Ch. Rothleitner, J. Kloß, J. Konrad: Measuring the induced AC voltage in the Planck-Balance with an AC quantum voltmeter, TC3 Conference 2022, Cavtat-Dubrovnik, CROATIA, 11 October 2022 - 13 October 2022, (2022), DOI: 10.21014/tc3-2022.071

Ch. Rothleitner, S. Svitlov, I. Poroskun, J. Kloss, and J. Konrad. Determination and correction of the force factor in the Planck-Balance. Conference on precision electromagnetic measurements (CPEM) 2022. 12-16 December 2022. Wellington, New Zealand. (2022).

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Rothleitner, C & Li, Z.: Gravitationsfeldeigenschaftsmessgerät und Verfahren zum Messen einer Gravitationsfeldgradientenänderung. Patent 2022, Aktenzeichen: 10 103 398.8 (eingereicht)

Force/Torque

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Th. Bruns, J. Nordholz, D. Röske, Th. Schrader: A demonstrator for measurement workflows using digital calibration certificates (DCCs); Measurement: Sensors, Volume 18, 2021, 100208, ISSN 2665-9174, DOI: 10.1016/j.measen.2021.100208.

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A. Dubowik, E. Mohns, C. Mester, M. Heller, M. Zweiffel, J. Quintanilla Crespo, J. Hällström, P. Weidinger; Report on the technical requirements for the electrical power measurements and definition of the measurands for nacelle test benches; Zenodo [online only], DOI: 10.5281/zenodo.4726089

J. Frühauf, E. Gärtner, Z. Li, L. Doering, J. Spichtinger, and G. Ehret, 'Silicon Cantilever for Micro/Nanoforce and Stiffness Calibration', Sensors, vol. 22, no. 16, 2022, doi: 10.3390/s22166253. [Online]. Available: https://www.mdpi.com/1424-8220/22/16/6253

K. Geva, H. Kahmann, C. Schlegel, R. Kumme: Experimental results of measurement hinge flexure stiffness determination; 24th Conference on the Measurement of Force, Mass and Torque 2022, DOI: 10.21014/tc3-2022.096

C. L. Giusca, S. Goel, I. Llavori, R. Kumme, O. Baer, A. Prato, A. Germak; Digital representation of a load cell; 24th Conference on the Measurement of Force, Mass and Torque 2022, DOI: 10.21014/tc3-2022.026

B. Gloger, L. Doering, S. Hackel, J. Jagieniak, G. Söylev-Öktem; Input management for the DCC; IMEKO TC6 M4Dconf 2022, DOI: 10.21014/tc6-2022.034.

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C. Schlegel; On the behaviour of setting-type torque screwdrivers; 24th Conference on the Measurement of Force, Mass and Torque 2022, DOI: 10.21014/tc3-2022.031

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