Capacity Building & Knowledge Transfer

Mass and Related Quantities - guidelines for comparisons and CMCs

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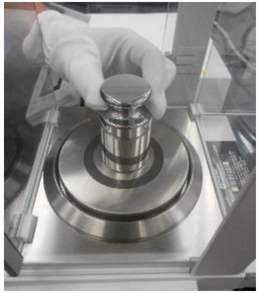
Outline

- Introduction to the range of quantities
- Organisational structure of CCM
- Guidance on CMCs and Key Comparisons
- Specific recommendations for Key Comparisons
- Examples of CMC submissions/publications
- EURAMET TC-M
  - Structure
  - Guides

Bureau International des Poids et Mesures

Mass and Related Quantities



A wide range of derived quantities need to be traceable to the SI unit of mass

- Mass
- Force
- Torque
- Hardness
- Pressure
    - High pressure
    - Barometry
    - Vacuum
- Density
    - Solid
    - Liquid
    - Hydrometry
- Viscosity
- Flow
- Gravimetry

Importance of Mass and Related quantities for economy

- Mass
  - Traceability
  - Trade
  - Pharmaceutical
- Force
  - Construction
  - Transport
  - Off-shore
  - Materials testing
- Torque
  - Power
  - Transport
- Pressure
  - Environment monitoring
  - Aerospace
  - Process control
  - Medical
- Density and Viscosity
  - Materials
  - Food
  - Fuels
- Flow
  - Process control
  - Water
  - Oil
  - Trade and Fiscal

Consultative Committee for Mass and Related Quantities

Key Comparisons and Calibration and Measurement Capabilities by technical area (2014):

- Density and Viscosity (KCs: 6 *completed* / 6 *in progress*, CMCs: 593)
- Force and Torque (KCs: 8 *completed* / 6 *in progress*, CMCs: 248)
- Fluid Flow (KCs: 10 *completed* / 5 *in progress*, CMCs: 582)
- Gravimetry (KCs: 1 *completed* / 1 *in progress*, CMCs: 4)
- Hardness (KCs: 3 *completed* / 2 *in progress*, CMCs: 125)
- Pressure (high and low) (KCs: 11 *completed* / 5 *in progress*, CMCs: 482)
- Mass standards (KCs: 5 *completed* / 3 *in progress*, CMCs: 751)

Consultative Committee for Mass and Related Quantities

Strategy for Calibration and Measurement Capability data:

- Simplify and standardise CMC submissions
  - Reduce number of entries
  - Rationalise service areas (mass/volume flow solid density/volume
  - Improve consistency of reported data
- Streamline and standardise review process
- Timely completion and publication of KCs to provide supporting evidence
- Structure expansion to include new quantities ultra high pressure, nano-force, micro-hardness, micro-mass, vacuum leak rate, ...
- Strategic approach to inclusion of dynamic measurement capability

Consultative Committee for Mass and Related Quantities

Strategy for Key and Supplementary Comparisons:

- Simplify, standardise and accelerate all steps of KCs (from the protocol to the publication of results),
- Use common resource for KCs and streamlining (protocols, data analysis, reporting) at least within each WGs,
- Share validated calculation tools,
- Encourage common views across the CCs to analyse KC data and aim at an improved coordination work across the CCs,
- Review or create directives for the technical work.

Guidance documents on comparisons and CMCs

- Statement of the CCM WG LP on CMC entries in the field of vacuum pressures (April 2008) Karl.Jousten@ptb.de http://www.bipm.org/wg/AllowedDocuments.jsp
- Review Protocol for Fluid Flow Calibration and Measurement Capabilities (CMCs) john.wright@nist.gov
- Consultative Committee on Mass Key Comparison Report Template (in draft) john.wright@nist.gov
- EURAMET (TC-M) Review Protocol for Calibration and Measurement Capabilities (in development) stuart.Davidson@npl.co.uk

CC key comparisons

A demonstration of capability (in support of CMC submissions)

- The mean time for completion of a CCM KC is > 5 years.
- For the pilot laboratory,
  - the labour is >100 man-days
  - equipment and transport costs are > € 25,000.
- This cost demonstrably decreases when KCs are repeated, especially as we learn which transfer standards offer the best performance.
- Further efficiency can be gained by;
  - Developing validated data reduction spreadsheets and protocol and report templates,
  - Increasing the periodicity between KCs,
  - Reducing the total duration of KCs and by covering more CMCs with less KCs. (see “how far does the light shine”)

Pilot (study) comparisons

- Evaluation of a new device (e.g. vacuum gauge)
- Extension to the range of measurement (sub-milligram mass, ultra high pressure)
- Examination of new measurement areas (gas density, vacuum leak rate)
- Evaluation of a new measurement technique
  - Kibble (watt) balance, X-ray crystal density
  - Dynamic force and pressure calibrations

Aims

- Validation of device (as transfer standard)
- Proof of (equivalence of) new measurement technique(s)
- Production and evaluation of protocol for future Key Comparisons

Policy on repeating of comparisons

- As a rule of thumb the repeat frequency for a (CCM) KC is 10 years, however…
- The last CCM strategy document made the following recommendations;

Density and viscosity

- A period of 10 to 15 years is considered to be adequate for density.
- As the gas density measurements will be of importance for energy savings and energy transportations, such a CMC may be covered by a new KC on the $p\rho T$ properties of fluids.
- As the food industry and agriculture need a traceable standard of the refractive index of liquids for sugar content measurements, supplying the refractive index standard liquids are necessary.
- The current situation in viscosity is to perform one key comparison every 6 years, alternating between broad viscosity range at moderate temperatures and moderate viscosities in a broad temperature range.

Force and Torque

- In general, for dead-weight force and torque facilities, no frequent KCs are necessary, a period of 15 years is considered to be adequate.
- KCs are especially necessary in the ranges not yet covered by comparisons, e.g. below 100 Nm or above 20 kN.m, and comparison of dynamic forces,
- A comparison up to 200 kN.m is foreseen
- At the moment, there are no results available as a basis for estimating an appropriate repeat frequency of comparisons with non-dead weight machines being involved

Fluid Flow

- The second round of 8 fluid flow comparisons will be finished before 2020 and a third round will be planned for start in 2021.
- The third round may include KCs in cryogenic flow or micro-flows, depending on progress at NMIs in these measurands.
- So far, a 10 year cycle is not a serious burden for the flow community. Lengthening the period could probably be tolerated, but is not recommended.
- If KCs were not organized by the WGFF, comparisons would continue (informally organized between NMIs as they were before the WGFF was formed in 2000), but they would be poorly organized, selectively documented, etc. (as they were before 2000).

Hardness

- Vickers (every 10 years changing partially the scales) (2015)
- Brinell (every 10 years changing partially the scales) (2014)
- Rockwell C (every 10 years) (2021)
- Rockwell (other scales) (every 10 years) (2015)
- Shore (10 years) (2013)
- Leeb (10 years) (2013).

Gravimetry

- Periodicity of about four years. The CCM WGG will consider to increase this periodicity according to the new CCM -IAG Strategy for Gravimetry.

Pressure

- The suggested repetition period for Key Comparisons is 12 years for Low Pressure and 15 years for High Pressure.

Mass standards (realization and dissemination)

- On going Key Comparisons of realisations of the new definition of the kilogram (the first immediately after redefinition, the second after approx. 5 years, further comparisons approx. every 10 years if the results of the previous comparisons are acceptable considering the CCM recommendation G1 (2010)
- Traditional comparisons of mass standards should continue regularly
- Comparisons below 100 mg (at least once) should be considered.

Specifics of technical protocol

- Consultative Committee on Mass Key Comparison Report Template (in draft) john.wright@nist.gov
- Based on a flow comparison (CCM.FF-K6.2011: CIPM Key Comparison of Low-Pressure Gas Flow, 2 m^3/h to 1000 m^3/h)
- Reviewed by all WG chairs and annotated to give additional guidance
- In general technical protocols are generally be based on extant protocols on the respective technical areas (at the appropriate nominal values if relevant)

Types of traveling standards

- In general mechanical transfer standards tend to be pretty robust and Stable. But……
- The transfer standards should be characterised and their stability monitored prior to the start of the comparison
- The comparison scheme must reflect the likelihood of drift in the transfer standards based on;
  - stability monitoring and
  - past performance of similar standards/devices
- Technical area specific guidance on travelling standards…..

Types of traveling standards

Density and viscosity

- In general a reference sample of liquid is characterised, its homogeneity checked and sub-samples distributed to participants.
- Care with decanting and selection of suitable containers (use monitoring of control samples)
- Issue with crystallisation of liquids due to exposure to low temperatures have been experienced.
- Solid density/volume standards tend to be robust. Stability can effectively be checked by mass determination
- HYDROMETER ARE NOT GOOD TRANSFER STANDARDS

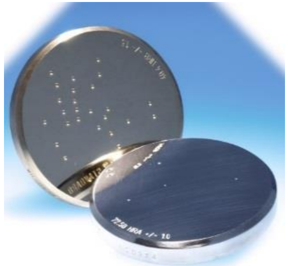
Force and Torque

- The largest source of uncertainty in the comparison (e.g. of deadweight force machines) is the repeatability/stability of the transfer standard
- Star (ABACADA….) comparison scheme should be used
- Care with transport (avoid shock, high/low temperature high humidity.)

Types of traveling standards

Fluid Flow

- The largest source of uncertainty in the comparison (e.g. gravimetric flow) is the repeatability/stability of the transfer standard
- Care with transportation



Hardness

- Main source of uncertainty is the measurement of the indentation
- Indenter and hardness block are transfer standards
- Work to improve characterisation of indentation should improve reproducibility

Gravimetry

- Direct comparison of gravimeters at a given site
- A potential issue is that the majority of gravimeters are from the same manufacturer

Types of traveling standards

Pressure

- Pressure balance are generally robust transfer standards but are bulky to transport.
- A comparison scheme with the pilot laboratory checking the stability at the beginning and end is often sufficient.
- Pressure balances also used for barometric range comparisons

Vacuum

- Solid state and spinning rotor gauges are the most robust.
- The comparison scheme should reflect the stability of the transfer standard.

Mass standards

- Transfer standards are in general very stable.
- Use two transfer standards (at each nominal value) for more challenging comparisons.

Comparison reports

- Consultative Committee on Mass Key Comparison Report Template (in draft) john.wright@nist.gov
- Draft A and Draft B reports reviewed and participants (as per Key Comparison process)
- Final report approved by WG-Chair (as appropriate) and CCM president
- Any unresolved issues with discrepant results etc. may be discussed by the appropriate technical WG and the WG-Strategy

Review of CMCs

Review parameters

- Participation by the institute in reviewed and approved scientific comparisons;
- Operation by the institute of an appropriate and approved quality management system;
- International peer-review (regional and inter-regional) of claimed calibration and measurement capabilities.

Review of CMCs – EURAMET RMO

- CMC prepared/reviewed by NMI
- (EURAMET) submissions reviewed by;
  - TC-M chair (Mass/Flow),
  - Convenor of the relevant Sub-Committee,
  - WG-Strategy
- Circulated for general comment by Contact Persons and SC members
- Submitted for inter-RMO review
- Feedback from inter-RMO review

What does a potential pilot laboratory need to know to be successful in piloting a comparison?

- For the pilot laboratory, the labour is >100 man-days
- Equipment and transport costs are > euro 25,000
- This cost decreases when KCs are repeated because
  - We learn which transfer standards offer the best performance
  - Optimum procedures are identified and protocols are produced
- Co-piloting of KCs allows sharing of resources and expertise (reducing the load on key NMIs)
- Similarly the establishment of an Advisory Group helps with planning and particularly with data analysis, linking and uncertainty calculation
- THERE NEEDS TO BE A STRATEGY IN PLANNING (RMO) COMPARISONS TO OPTIMISE THE EFFECIENCY OF THE (KC) DISSEMINATION PROCESS

Key Comparison Reference Values

- In the CIPM_MRA-D-05 it is stated that:
- *"In calculating the key comparison reference value, the pilot institute will use the method considered most appropriate for the particular comparison, subject to confirmation by the participants and, in due course, the key comparison working group and the Consultative Committee."*
- M.G. Cox. The evaluation of key comparison data (*Metrologia* **39**:2002) recommends two approached to the determination of the Key Comparison Reference Value (KCRV)
  - Mean value based on Least squares adjustment (recommended where data is consistent)
  - Median value (where data is inconsistent)

Key Comparison Reference Values (an example)

- CCM.M-K4 (http://www.bipm.org/utils/common/pdf/final_reports/M/M-K4/CCM.M-K4.pdf)
- A comparison of stainless steel kilogram mass standards
- The proposed methods to estimate the KCRV were the following:

A) the weighted mean (WM),

B) the Ordinary Least Squares estimation (OLS),

C) the Generalized Linear Least-Squares estimation (GLS),

D) the Least Squares Adjustment (LSA).

Key Comparison Reference Values

- M.G. Cox. The evaluation of key comparison data (*Metrologia* **39**:2002)
- C.M. Sutton. Analysis and linking of international measurement comparisons (*Metrologia*, **41**:2004)
- M.G. Cox. The evaluation of key comparison data: determining the largest consistent subset (*Metrologia* **44**:2007)
- R.N. Kacker, A.B. Forbes, R. Kessel and K.-D. Sommer. Classical and Bayesian interpretation of the Birge test of consistency and its generalized version for correlated results from inter-laboratory evaluations (*Metrologia* **45**:2008)
- R.N. Kacker, A.B. Forbes, R. Kessel and K.-D. Sommer. Bayesian posterior predictive *p*-value of statistical consistency in inter-laboratory evaluations (*Metrologia* **45**:2008)
- M.G. Cox and P.M. Harris. The evaluation of key comparison data using key comparison reference curves (*Metrologia* **49**:2012)

Has there been an issue of "dark uncertainty"?

(Dispersion of results greater than expected from lab uncertainties)

- No.
- Measurement procedures (and their associated uncertainties) are well understood
- Potential sources of discrepancy have generally been investigated (e.g. hardness indentation measurement)
- Transfer standards are widely used and their performance limits well understood (e.g. Magnetic properties of mass standard)
- The repeatability and stability of individual transfer standards is well characterised by the pilot laboratory
- The (generally large) number of participants assists with the calculation of a robust KCRV

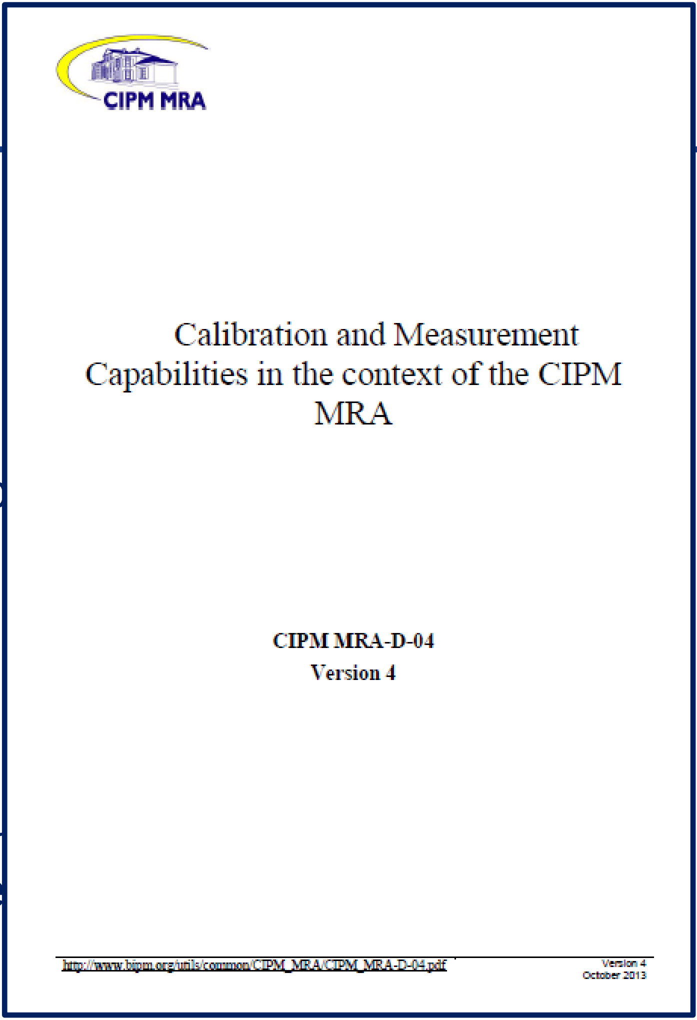
How does your area determine "how far the light shines"?

- Often the RMOs accept only CMC in exactly the range of mass, force, pressure etc. in which the KC was performed.
- This potentially increases the work for the KCs and prevents the use of the CMCs for our "customers" (e.g. calibrations laboratories).
- Generally accepted practice;
  - Comparison at one nominal value per decade is enough
  - Interpolation of capability between KC Values acceptable
  - Extrapolation of capability only in exceptional circumstances (e.g. mg mass)
  - Only the calibration of highest level device (by a given measurement method) is necessary (exception e.g. mass)

Specific requirements for CMCs

Aims

- Simplify and standardise CMC submissions
  - Reduce number of entries
  - Rationalise service areas (mass/volume flo density/volume)
  - Improve consistency of reported data
- Streamline and standardise review process
- Structure expansion to include new quantities nano-force, micro-hardness, micro-mass, vacu
- Strategic approach to inclusion of dynamic me


CIPM MRA

Calibration and Measurement Capabilities in the context of the CIPM MRA

CIPM MRA-D-04

Version 4

http://www.bipm.org/utils/common/CIPM_MRA/CIPM_MRA-D-04.pdf

Version 4
October 2013

Example CMCs - Mass

Calibration and Measurement Capabilities

Mass and Related Quantities, United Kingdom

KCDB

NPL (National Physical Laboratory), TUVNEL, NMRO (National Measurement and Regulation Office)

Calibration or Measurement Service			Measurand Level or Range			Measurement Conditions/Independent Variable		Expanded Uncertainty							
Class	Instrument or Artifact	Instrument Type or Method	Minimum value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Level of Confidence	Is the expanded uncertainty a relative one?	Comments	NMI	NMI Service Identifier
Mass	Mass standards	Comparison in air	1	100	mg			0.4 to 0.8	µg	2	95%	No	Uncertainty scales with measurand level. The volume of the mass standards is known.	NPL	
Mass	Mass standards	Comparison in air	0.1	1	g			0.8 to 0.9	µg	2	95%	No	Uncertainty scales with measurand level. The volume of the mass standards is known.	NPL	
Mass	Mass standards	Comparison in air	1	10	g			0.9 to 1.5	µg	2	95%	No	Uncertainty scales with measurand level. The volume of the mass standards is known.	NPL	
Mass	Mass standards	Comparison in air	10	100	g			1.5 to 4.6	µg	2	95%	No	Uncertainty scales with measurand level. The volume of the mass standards is known.	NPL	
Mass	Mass standards	Comparison in air	0.1	1	kg			4.6 to 30	µg	2	95%	No	Uncertainty scales with measurand level. The volume of the mass standards is known.	NPL	

Uncertainties scale with nominal value

MCs - Mass

Mass and R

Not all nominal values need to be declared

Temp and humidity values do not directly affect mass value

Uncertainty values are incoherent

Calib						Variable								
Class	Instrument or Artifact	Instrument Type or Method	Minimum value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Level of Confidence	Is the expanded uncertainty a relative one?	NMI internal identifier	Comments
Mass	Mass standard	Subdivision method	1	1	mg	Temperature	((20 to 22) ± 0.3) °C	0.00024	mg	2	95%	No	22020C	
						Humidity	((45 to 50) ± 5) %							
Mass	Mass standard	Subdivision method	2	2	mg	Temperature	((20 to 22) ± 0.3) °C	0.00018	mg	2				
						Humidity	((45 to 50) ± 5) %							
Mass	Mass standard	Subdivision method	3	3	mg	Temperature	((20 to 22) ± 0.3) °C	0.00021	mg	2				
						Humidity	((45 to 50) ± 5) %							
Mass	Mass standard	Subdivision method	5	5	mg	Temperature	((20 to 22) ± 0.3) °C	0.0002	mg	2				
						Humidity	((45 to 50) ± 5) %							
Mass	Mass standard	Subdivision method	10	10	mg	Temperature	((20 to 22) ± 0.3) °C	0.00024	mg	2				
						Humidity	((45 to 50) ± 5) %							
Mass	Mass standard	Subdivision method	20	20	mg	Temperature	((20 to 22) ± 0.3) °C	0.00018	mg	2				
						Humidity	((45 to 50) ± 5) %							
Mass	Mass standard	Subdivision method	30	30	mg	Temperature	((20 to 22) ± 0.3) °C	0.00021	mg	2				
						Humidity	((45 to 50) ± 5) %							
Mass	Mass standard	Subdivision method	50	50	mg	Temperature	((20 to 22) ± 0.3) °C	0.0002	mg	2				
						Humidity	((45 to 50) ± 5) %							
Mass	Mass standard	Subdivision method	100	100	mg	Temperature	((20 to 22) ± 0.3) °C	0.00026	mg	2				
						Humidity	((45 to 50) ± 5) %							
Mass	Mass standard	Subdivision method	200	200	mg	Temperature	((20 to 22) ± 0.3) °C	0.0003	mg	2	95%	No	22020C	
						Humidity	((45 to 50) ± 5) %							
Mass	Mass standard	Subdivision method	300	300	mg	Temperature	((20 to 22) ± 0.3) °C	0.00041	mg	2	95%	No	22020C	
						Humidity	((45 to 50) ± 5) %							
Mass	Mass standard	Subdivision method	500	500	mg	Temperature	((20 to 22) ± 0.3) °C	0.00062	mg	2	95%	No	22020C	
						Humidity	((45 to 50) ± 5) %							
Mass	Mass standard	Subdivision method	1	1	g	Temperature	((20 to 22) ± 0.3) °C	0.0012	mg	2	95%	No	22020C	

- GROUP NOMINAL VALUES OVER (DECADE) RANGES WHERE APPROPRIATE
- ROUND UNCERTIANTIES TO GIVE COHERENT VALUES
- SCALE UNCERTIANTIES WITH NOMINAL VALUES WHERE APPROPRIATE
- CMCs SHOULD BE FOR THE BENEFIT OF END USERS

Example CMCs – Solid Volume (density)

Mass and Related Quantities, Germany, PTB (Physikalisch-Technische Bundesanstalt)

KCDB

Calibration or Measurement Service			Measurand Level or Range			Measurement Conditions/Independent Variable		Expanded Uncertainty							
Quantity	Instrument or Artifact	Instrument Type or Method	Minimum value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Level of Confidence	Is the expanded uncertainty a relative one?	Comments	NMI Service Identifier	Approval Date
Volume of solid	Solid density standard	Hydrostatic weighing	50	440	cm^3	Reference temperature	20 °C	$(0.15 + 0.0015V)$, V volume in cm^3	mm^3	2	95%	No			Approved on 03 January 2007
						Mass	less than 1030 g								
Volume of solid	Mass standard: 20 kg to 50 kg	Hydrostatic weighing	[illegible]	[illegible]	[illegible]	Reference [illegible]	[illegible]	600 to 1600	mm^3	2	95%	No			Approved on 03 January 2007
Volume of solid	Mass standard: 2 kg to 10 kg	Hydrostatic weighing	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10 to 50	mm^3	[illegible]	[illegible]	[illegible]	[illegible]		Approved on 03 January 2007
Volume of solid	Mass standard 1 kg	Hydrostatic weighing	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.5	mm^3	[illegible]	[illegible]	[illegible]	[illegible]		Approved on 03 January 2007
Volume of solid	Mass standard: 0.05 kg to 0.5 kg	Hydrostatic weighing	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.7 to 1.0	mm^3	[illegible]	[illegible]	[illegible]	[illegible]		Approved on 03 January 2007
Volume of solid	Mass standard: 2 g to 20 g	Hydrostatic weighing	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.3 to 0.6	mm^3	[illegible]	[illegible]	[illegible]	[illegible]		Approved on 03 January 2007
Volume of solid	Mass standard 1 g	Hydrostatic weighing	0.12	0.13	cm^3	Reference temperature	20 °C	0.2	mm^3	[illegible]	[illegible]	[illegible]	[illegible]		Approved on 03 January 2007

Temperature directly affects the volume of the measurand. (Mass range should go in comments box).

Uncertainties scale with volume. For solid density standard uncertainty is given as an equation.

Example CMCs – Pressure (vacuum)

Mass and Related Quantities, Germany, PTB (Physikalisch-Technische Bundesanstalt)

KCDB

Calibration or Measurement Service			Measurand Level or Range			Measurement Conditions/Independent Variable		Expanded Uncertainty							
Quantity	Instrument or Artifact	Instrument Type or Method	Minimum value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Level of Confidence	Is the expanded uncertainty a relative one?	Comments	NMI Service Identifier	Approval Date
Absolute pressure	Vacuum gauge	Capacitance diaphragm gauge	1.0E+04	1.0E+05	Pa	Temperature	20 °C to 25 °C	4.2E-04p; p pressure in Pa	Pa	2	95%	No	Uncertainty values range from 4.2 Pa to 42 Pa	7.5-1.4	Approved on 03 July 2009
						Gas species	non condensable								
						Gas purity	99.9 or better								

Ranges and (especially) uncertainties will depend on measurement device

Test gas needs to be specified. (Temp no so critical)

Comment used to give clarification/additional information on uncertainty values

Example CMCs – Pressure (vacuum)

Mass and Rela… …tute of Standards and Technology)

KCDB

Wide range of devices (UUT) specified

Uncertainties will depend on the characteristics of the unit under test

Calibratio…			Range			Measure…								
Class	Instrument or Artifact	Instrument Type or Method	Minimum value	Maximum value	Units	Paran…					…e	Is the expanded uncertainty a relative one?	NMI internal identifier	Comments
Absolute pressure gas medium	Vacuum gauge	Spinning rotor gauge	1.00E-04	1	Pa	Temperature	23 °C	0.003		2	95%	Yes	30029C, 30030C	Uncertainty includes unit under test. Approved on 09 September 2008
						Gas species	nitrogen							
						Gas purity	99.9 or better							
Absolute pressure gas medium	Vacuum gauge	Spinning rotor gauge	1	30	Pa	Temperature	23 °C	[(0.003) + (6.00E-05)/p], p pressure in Pa		2	95%	Yes	30032S	Uncertainty includes unit under test. Approved on 09 September 2008
						Gas species	nitrogen							
						Gas purity	99.9 or better							
Absolute pressure gas medium	Vacuum gauge	Ionization gauge	1.00E-07	3.00E-06	Pa	Temperature	23 °C	[(0.012) + (5.00E-10)/p], p pressure in Pa		2	95%	Yes	30036C	Uncertainty increased to include unit under test. Approved on 09 September 2008
						Gas species	nitrogen							
						Gas purity	99.9 or better							
Absolute pressure gas medium	Vacuum gauge	Ionization gauge	3.00E-06	9.00E-05	Pa	Temperature	23 °C	[(0.0048) + (2.00E-08)/p], p pressure in Pa		2	95%	Yes	30036C	Uncertainty increased to include unit under test. Approved on 09 September 2008
						Gas species	nitrogen							
						Gas purity	99.9 or better							
Absolute pressure gas medium	Vacuum gauge	Ionization gauge	9.00E-05	3.00E-03	Pa	Temperature	23 °C	[(0.0042) + (7.00E-08)/p], p pressure in Pa		2	95%	Yes	30035C, 30036C	Uncertainty increased to include unit under test. Approved on 09 September 2008
						Gas species	nitrogen							
						Gas purity	99.9 or better							
Absolute pressure gas medium	Vacuum gauge	Ionization gauge	3.00E-03	0.1	Pa	Temperature	23 °C	0.0042		2	95%	Yes	30034C	Uncertainty increased to include unit under test. Approved on 09 September 2008
						Gas species	nitrogen							
						Gas purity	99.9 or better							
Absolute pressure gas medium	Vacuum gauge	Capacitance diaphragm gauge	0.1	3	Pa	Temperature	23 °C	$[(8E-04)^2 + (1E-03p)^2]^{1/2}$, p pressure in Pa	Pa	2	95%	No	30010C, 30011C	Uncertainty increased to include unit under test. Approved on 09 September 2008
						Gas species	nitrogen							
						Gas purity	99.9 or better							

www

Example CMCs – (high) Pressure

Different measurement conditions and devices

Uncertainties often given as a function of the pressure range

Comments used to clarify uncertainty statements

, Germany, PTB (Physikalisch-Technische Bundesanstalt)

KCDB

		ervice	Measurand Level or Range			Measurement Conditions/Indepen… Variable				certainty					
		trument ype or ethod	Minimum value	Maximum value	Units	Parameter	Specifi…			overage Factor	Level of Confidence	… un… relative one?		Identifier	Approval Date
Gauge pressure	Pressure balance, pressure gauge	Oil medium	1.0E+07	4.0E+08	Pa			(2E-05p + 1E-13p^2), p pressure in Pa	Pa	2	95%	No	Uncertainty values range from 210 Pa to 2.4E+04 Pa	ptb-m-p-012	Approved on 03 July 2009
Gauge pressure	Pressure multiplier, pressure gauge	Oil medium	4.0E+08	1.0E+09	Pa			(2.6E-05p + 1E-13p^2), p pressure in Pa	Pa	2	95%	No	Uncertainty values range from 2.6E+04 Pa to 1.3E+05 Pa	ptb-m-p-013	Approved on 03 July 2009
Gauge pressure	Pressure gauge	Oil medium	1.0E+09	1.4E+09	Pa			4E+06	Pa	2	95%	No		ptb-m-p-014	Approved on 03 July 2009
Differential pressure	Pressure gauge	Gas medium	0	1E+04	Pa	Line pressure, p_{line} and differential pressure, p	1E+05 Pa < p_{line} < 1.4E+07 Pa	(0.6 + 3E-08p_{line} + 3E-04p), p_{line} and p in Pa	Pa	2	95%	No		ptb-m-p-015	Approved on 03 July 2009
Differential pressure	Pressure gauge	Gas medium	0	2E+07	Pa	Line pressure, p_{line} and differential pressure, p	5E+05 Pa < p_{line} + p < 2E+07 Pa	(10 + 4E-06p_{line} + 2.2E-05p), p_{line} and p in Pa	Pa	2	95%	No		ptb-m-p-016	Approved on 03 July 2009

Example CMCs – Force and Torque

Mass and Related Quanti... KCDB

This is not strictly correct as it gives details of the calibration instruments rather than the UUT

Uncertainties apply to the machines used and not the UUTs

Calibration or Measureme...							...nt									
Quantity	Instrument or Artifact	...ethod...					...tions					...ce	Is the expanded uncertainty a relative one?	Comments	NMI Service Identifier	Approval Date
Force: tension and compression	Force measuring device	Deadweight	50	2000	kN				0.002	%	2	95%	Yes			Approved on 03 January ...7
Force: tension and compression	Force measuring device	Hydraulic amplification	0.1	5	MN				0.01	%	2	95...				...ed on ...uary ...7
Force: tension and compression	Force measuring device	Hydraulic amplification	0.1	16.5	MN				0.01	%	2	95...				...ed on ...uary ...7
Bending stiffness	Force or normal bending stiffness standard	Force-displacement measurement with compensation balance	0.01	50000	N/m	Temperature	(20 ± 5) °C		4.0	%	2	95...				...ed on ...ember ...4
						Humidity	30 % to 80 %									
Torque	Torque measuring devices	Lever deadweight system	0.01	1	Nm	Mode	clockwise, anticlockwise		2.0E-04		2	95...				...ed on ...uary ...7
Torque	Torque measuring devices	Lever deadweight system	1	20 000	Nm	Mode	clockwise, anticlockwise		2.0E-05		2	95%	Yes			...ed on 03 January 2007
Torque	Reference torque wrench	Reference method	0.1	5 000	Nm	Mode	clockwise, anticlockwise		2.0E-04		2	95%	Yes			Approved on 03 January 2007
Torque	Torque tools calibration equipment	Reference method	0.01	1 000	Nm	Mode	clockwise, anticlockwise		2.0E-03		2	95%	Yes			Approved on 03 January 2007
														The uncertainty of the...		

- CMCs SHOULD BE FOR THE BENEFIT OF THE END USER
- TYPICAL INSTRUMENTS SUBMITTED BY CUSTOMERS SHOULD BE DETIALED

Example CMCs - Force

Mass and Related Quantities, United States, NIST (National Institute of Standards and Technology)

KCDB

Too many ranges are given. These CMCs could be covered by one entry

Calibration or Measurement Service								Expanded Uncertainty						
Class	Instrument or Artifact	Instrument or Me...							Units	Coverage Factor	Level of Confidence	Is the expanded uncertainty a relative one?	NMI internal identifier	Comments
Force: tension and compression	Force measuring device	Direct comparison	2.5	5	kN	Temperature	23 °C ± 0.5 °C	0.00001		2	95%	Yes	NIST SP 250 tests 23010C-23250C	
Force: tension and compression	Force measuring device	Direct comparison	5	10	kN	Temperature	23 °C ± 0.5 °C	0.00001		2	95%	Yes	NIST SP 250 tests 23010C-23250C	
Force: tension and compression	Force measuring device	Direct comparison	10	20	kN	Temperature	23 °C ± 0.5 °C	0.00001		2	95%			
Force: tension and compression	Force measuring device	Direct comparison	20	50	kN	Temperature	23 °C ± 0.5 °C	0.00001		2	95%			
Force: tension and compression	Force measuring device	Direct comparison	50	110	kN	Temperature	23 °C ± 0.5 °C	0.00001		2	95%			
Force: tension and compression	Force measuring device	Direct comparison	110	150	kN	Temperature	23 °C ± 0.5 °C	0.00001		2	95%			
Force: tension and compression	Force measuring device	Direct comparison	150	200	kN	Temperature	23 °C ± 0.5 °C	0.00001		2	95%			
Force: tension and compression	Force measuring device	Direct comparison	200	500	kN	Temperature	23 °C ± 0.5 °C	0.00001		2	95%			
Force: tension and compression	Force measuring device	Direct comparison	500	1000	kN	Temperature	23 °C ± 0.5 °C	0.00001		2	95%			
Force: tension and compression	Force measuring device	Direct comparison	1000	1500	kN	Temperature	23 °C ± 0.5 °C	0.00001		2	95%		23250C	
Force: tension and compression	Force measuring device	Direct comparison	1500	2000	kN	Temperature	23 °C ± 0.5 °C	0.00001		2	95%	Yes	NIST SP 250 tests 23010C-23250C	
Force: tension and compression	Force measuring device	Direct comparison	2000	4448	kN	Temperature	23 °C ± 0.5 °C	0.00001		2	95%	Yes	NIST SP 250 tests 23010C-23250C	

- **CMCs SHOULD BE FOR THE BENEFIT OF THE END USER**
- **(UNNECESSARY) MULTIPLE ENTRIES MAKE THE DATABASE MORE CUMBERSOME**
- **THE KCDB IS NOT A COMPETION TO SEE WHO HAS THE MOST ENTRIES**

Example CMCs - Hardness

Mass and Related Quantities, United States, NIST (National Institute of Standards and Technology)

KCDB

Hardness has a wide range of scales and measurement procedures

And units

Calibration or Measurement Service								Expanded Uncertainty						
Class	Instrument or Artifact	Instrument Type or Method	Minimum value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Level of Confidence	Is the expanded uncertainty a relative one?	NMI internal identifier	Comments
Hardness	Hardness block	Knoop according to ISO 4547	112	130	HK	Test force	0.245 N, 0.490 N, 0.981 N	6.12	HK	2	95%	No		NIST SRM 1893 (SRM: Standard Reference Material)
Hardness	Hardness block	Vickers according to ISO 6507	112	130	HV	Test force	0.245 N, 0.490 N, 0.981 N	6.12	HV	2				
Hardness	Hardness block	Knoop according to ISO 4547	575	625	HK	Test force	0.245 N, 0.490 N, 0.981 N	30.6	HK	2				
Hardness	Hardness block	Vickers according to ISO 6507	575	625	HV	Test force	0.245 N, 0.490 N, 0.981 N	30.6	HV	2				
Hardness	Hardness block	Knoop according to ISO 4547	575	625	HK	Test force	2.94 N	30.6	HK	2				
Hardness	Hardness block	Knoop according to ISO 4547	575	625	HK	Test force	4.91 N	30.6	HK	2				
Hardness	Hardness block	Knoop according to ISO 4547	575	625	HK	Test force	9.81 N	30.6	HK	2				
Hardness	Hardness block	Vickers according to ISO 6507	575	625	HV	Test force	4.91 N	30.6	HV	2				
Hardness	Hardness block	Knoop HK2 according to ISO 4547	10	20	GPa	Test force	19.61 N	0.12	GPa	2				Standard Reference Material)
Hardness	Hardness block	Rockwell HRC according to ASTM E 18 and ISO 6508	23	27	HRC	Preliminary / total test forces	98.07 N / 1471 N	0.17	HRC	2	95%	No		NIST SRM 2810 (SRM: Standard Reference Material)

- HARDNESS MEASUREMENT IS THE CHARACTERISATION OF A MATERIAL PROPERTY
- THE CHOICE OF SCALE DEPENDS ON THE MATERIAL AND ITS APPLICATION

Example CMCs - Flow

A wide range of instruments are used but often they can cover several orders of magnitude

Measurements are often specific to certain types of gases/liquids

Calibration or Measurement Service			Measurand Level or Range					Expanded Uncertainty							
Quantity	Instrument or Artifact	Instrument Type or Method	Minimum value	Maximum value	Units	Parameter	Specifications	Value	Units	Coverage Factor	Level of Confidence	Is the expanded uncertainty a relative one?	Comments	NMI Service Identifier	Approval Date
Flowrate mass (high pressure gas)	Gasmeters	Turbine, ultrasonic, vortex and coriolis meters, differential pressure device	23	350000	kg/h	Gas	high pressure natural gas, pigsar	0.163 to 0.282, depending on Q [m^3/h]						E38	Approved on 16 November 2012
						Temperature	15° to 25°								
						Pressure	15 bar to 56 bar								
						Pipe size	DN80 to DN400, ANSI 600								
Flowrate volume (pressurized air)	Flowmeters, gasmeters	LFE, wet gas meters, critical nozzles	40	4000	L/h	Gas	air (inert gases)	0.045	%	2	95%	Yes		DE42	Approved on 16 November 2012
						Temperature	ambient								
						Pressure	1 bar to 8 bar								
						Pipe size	DN 6 to DN50								

Uncertainties are often largely dependant on the specification of the UUT. Choose the best UUT available when calculating uncertainties for CMCs

EURAMET Technical Committee for Mass and Related Quantities

TC CHAIR

Isabel Spohr, IPQ (Portugal)

SUBCOMMITTEES AND CONVENORS

Density and Viscosity	Horst Bettin, PTB (Germany)
Force	Rolf Kumme, PTB (Germany)
Pressure	Wladimir Sabuga, PTB (Germany)
Mass	Stuart Davidson, NPL (United Kingdom)

TC-M WORKING GROUP ON STRATEGY

The role of the TC-M is to ensure that the infrastructure for mass and related quantities in Europe, within the NMIs and DIs, is fit-for-purpose and internationally competitive for the benefit of Europe's multi-sector user community. The Strategy Working Group has been established to advis work of the Technical Committee to put in place the n at fostering collaboration, research and perfor AMET TC-M continually meets its objective in a timely

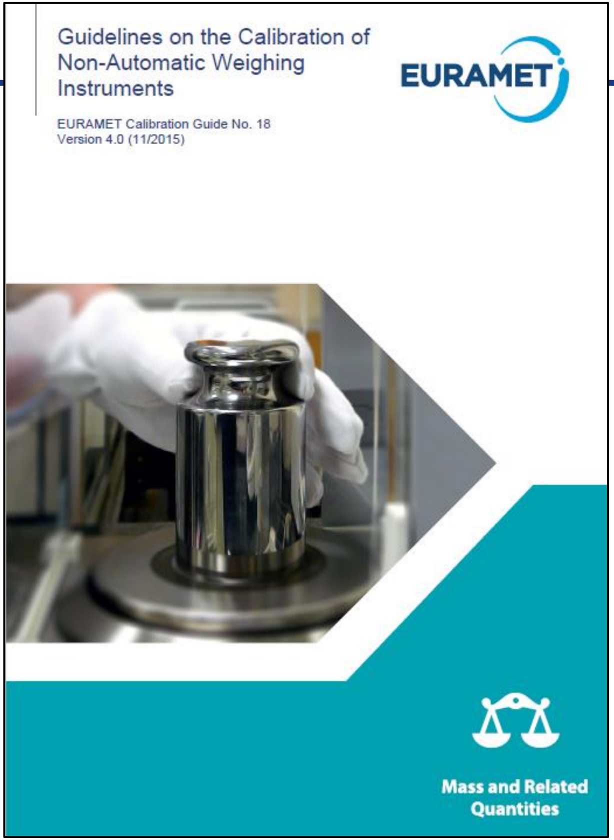
Members

Stuart Davidson (C	NPL, UK
Isabel Spohr (TC-M	IPQ, Portugal
Fredrik Arrhén	SE, Sweden
Alessandro Germa	INRIM, Italy
Matej Grum	MIRS, Slovenia
Nieves Medina Martin	CEM, Spain
Wladimir Sabuga	PTB, Germany

Including CMC review and KC planning

EURAMET TC-M Guides

- Cg 3 Calibration of Pressure Balances Version, 1.0, 03/2011
- Cg 4 Uncertainty of Force Measurements, Version 2.0, 03/2011
- Cg 14 Guidelines on the Calibration of Static Torque Measuring Devices, Version 2.0, 03/2011
- Cg 16 Guidelines on the Estimation of Uncertainty in Hardness Measurements, Version 2.0, 03/2011
- Cg 17 Guidelines on the Calibration of Electromechanical Manometers, Version 2.0, 03/2011
- Cg 18 Guidelines on the Calibration of Non-Automatic Weighing Instruments, Version 4.0, 11/2015



Capacity Building & Knowledge Transfer

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Bureau International des Poids et Mesures