Technical Protocol of the CIPM Key Comparison

CCAUV.V-K5

2017-03-06

revised 2018-02-13 (changed schedule)

Task and Purpose of the Comparison

According to the rules set up by the CIPM MRA the consultative committees of the CIPM have the responsibility to establish “degrees of equivalence” (DoE) between the different measurement standards operated by the national NMIs. This is done by conducting key comparisons (KC) on different levels of the international metrological infrastructure. The previous top level KC in the field of Vibration metrology, CCAUV.V-K2 was finished in the year 2014 under difficult conditions and its results have since been then the foundation of many established DoE in the field.

Due to the fact, that the conditions of measurement comparability were sub-optimal during CCAUV.V-K2 the meeting of CCAUV in November 2015 took the decision to start to prepare the next KC with a scope covering that of CCAUV.V-K2 and more.

The results of this KC will, after approval for equivalence, form the new basis for DoE derived in subsequent RMO key comparisons, and therefore be the foundation for the registration of “calibration and measurement capabilities” (CMC) in the framework of the CIPM MRA.

The specific task of the KC is to measure the complex charge sensitivity of three different accelerometers at specified frequencies with primary means *I.e.* according to ISO 16063-11 “Methods for the calibration of vibration and shock transducers -- Part 11: Primary vibration calibration by laser interferometry”.

The reported sensitivities and associated uncertainties are then supposed to be used for the calculation of the DoE between the participating NMI and the key comparison reference value.

Pilot Laboratory

Pilot laboratory for this Key Comparison is

Physikalisch-Technische Bundesanstalt (PTB)
Working Group 1.71 “Acceleration”
Bundesallee 100
38116 Braunschweig
Germany

This is the delivery address for the set of artefacts and the written and signed reports. Contact Persons are

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Terms of participation

According to the recently published “Recommendations from the Working Group on the Implementation and Operation of the CIPM MRA” [1] the number of participant in a KC like this “*should typically be limited to the minimum number of institutes necessary to provide effective linkage in each region, (typically no more than three institutes per RMO)*.”

This is a recommendation to keep the consumed time for the KC from start of measurement to final publication within reasonable limits.

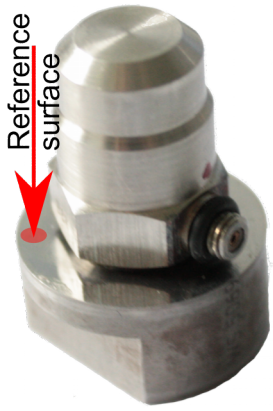
Following this recommendation, this technical protocol is distributed to the chairman of the technical committees of Acoustics, Ultra sound and Vibration (AUV) of all regional metrology organizations with the request to nominate up to three participating institutes of the respective RMO.

Beyond the obvious necessity to cover the scope of the KC (see below) with a sufficiently low measurement uncertainty, the willingness to coordinate a subsequent RMO-comparison is required from the nominated participants.

Devices under Test and Measurement Conditions

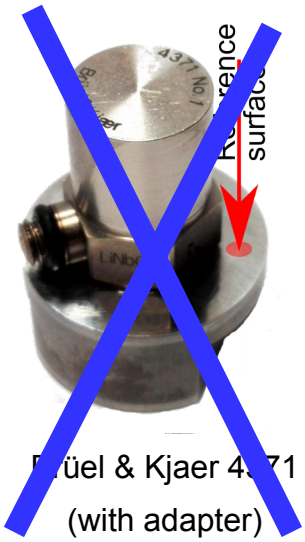
For the calibration task of this KC a set of ~~three~~ two piezoelectric accelerometers will be circulated among the participating laboratories. The individual transducers being

- a Brüel & Kjær 8305-001 (SN: 1610153) “single ended” (SE) type
- a Brüel & Kjær 8305 S (SN: ...) “back to back” (BB) type.
- ~~a Brüel & Kjaer 4371 (SN: 1) “single ended” (SE) type~~



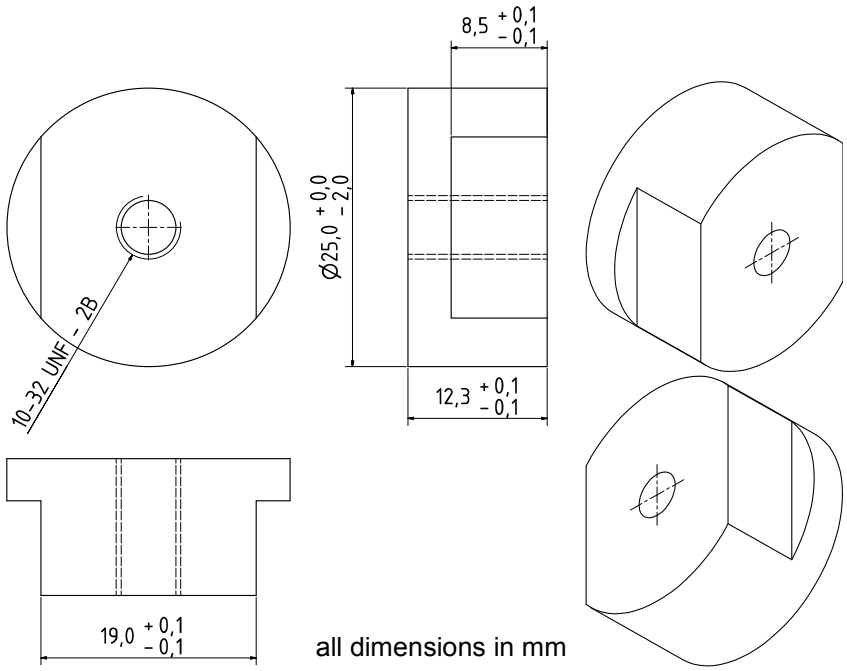
Brüel & Kjær 8305-001
(with adapter)

Brüel & Kjær 8305 S



Brüel & Kjaer 4371
(with adapter)

The ~~two~~ SE type accelerometer~~s are each~~ is mounted on a mechanical adapter, which was designed and manufactured according to the drawing below:



The adapter is made of stainless steel 1.4404 (AISI 316L) and has a weight (calculated) of 41 g. Its top surface is polished in order to provide mirror-like reflectivity for the Laser.

The accelerometers are to be calibrated for magnitude and phase of their complex charge sensitivity according to those procedures and conditions implemented by the NMI in conformance with ISO 16063-11 which provide magnitude and phase information of the artefact. The sensitivities reported shall be for the accelerometers alone, excluding any effects from the charge amplifier.

The frequency range of the measurements was agreed to be from 10 Hz to 20 kHz. Specifically the laboratories are supposed to measure at the following frequencies (all values in Hz).

10, 12.5, 16, 20, 25, 31.5, 40, 63, 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1 000, 1 250, 1 500, 1 600, 2 000, 2 500, 3 000, 3 150, 3 500, 4 000, 4 500, 5 000, 5 500, 6 000, 6 300, 6 500, 7 000, 7 500, 8 000, 8 500, 9 000, 9 500, 10 000, 10 500 11 000, 11 500, 12 000, 12 500, 13 000. 13 500, 14 000, 14 500, 15 000, 15 500, 16 000, 16 500, 17 000, 17 500, 18 000, 18 500, 19 000, 19 500, 20 000.

Note: *this set does deviate from the standard frequencies of ISO 266.*

The participating laboratories should be able to provide magnitude results over the whole frequency range with their systems and to provide phase results at least for the range from 10 Hz to 10 kHz.

The charge amplifier (CA) used for the calibration is not provided within the set of the artefacts, it must therefore be provided by the individual participant. By this measure, the capability of the participating laboratory to calibrate charge amplifiers is implicitly verified.

The measurement condition should be kept according to the laboratory's standard conditions for calibration of customer accelerometers for claiming their best measurement capability or CMC where applicable. This presumes that these conditions comply with those defined by the applicable ISO documentary standards [2,3,4], simultaneously.

Specific conditions for the measurements of this KC are:

- acceleration amplitudes: preferably 50 m/s² to 100 m/s²
  a range of 2 m/s² to 200 m/s² is admissible.

- ambient temperature and accelerometer temperature during the calibration: (23 ± 2) ºC (actual values to be stated within tolerances of ± 0.3 ºC). The accelerometer temperature should be measured and reported.
- relative humidity: max. 75 %RH
- mounting torque of the accelerometer: (2.0 ± 0.1) N·m

Circulation Type, Schedule and Transportation

The transducers are circulated in a star type fashion with a measurement period of three weeks provided for each participant. In between two subsequent measurements at any participants laboratory the transducers are measured at the pilot lab in order to monitor the long term stability.The schedule is planned as follows:

Participant	Country ISO-Code	Transportation to Participant week from	Measurement		Transportation to Pilot week from	Monitoring measurements	
			from	to		from	to
PTB	DE		13.02.2017	05.03.2017	06.03.2017	13.02.2017	26.03.2017
DPLA	DK	27.03.2017	03.04.2017	23.04.2017	24.04.2017	01.05.2017	04.06.2017
METAS	CH	08.05.2017	15.05.2017	04.06.2017	05.06.2017	12.06.2017	16.07.2017
CEM	ES	26.06.2017	03.07.2017	23.07.2017	24.07.2017	31.07.2017	03.09.2017
NIST	US	28.08.2017	04.09.2017	24.09.2017	25.09.2017	02.10.2017	05.11.2017
CENAM	MX	13.11.2017	20.11.2017	10.12.2017	11.12.2017	18.12.2017	21.01.2018
NMIJ	JP	29.01.2018	05.02.2018	25.02.2018	26.02.2018	05.03.2018	18.03.2018
NIM	CN	19.03.2018	26.03.2018	08.04.2018	09.04.2018	16.04.2018	29.04.2018
INMETRO	BR	30.04.2018	07.05.2018	20.05.2018	21.05.2018	28.05.2018	10.06.2018
NMIA	AU	11.06.2018	18.06.2018	01.07.2018	02.07.2018	09.07.2018	22.07.2018
NMC/A*Star	SG	23.07.2018	30.07.2018	12.08.2018	13.08.2018	20.08.2018	02.09.2018
NMISA	ZA	03.09.2018	10.09.2018	23.09.2018	24.09.2018	01.10.2018	14.10.2018
VNIIM	RU	15.10.2018	22.10.2018	04.11.2018	05.11.2018	12.11.2018	25.11.2018
UkrMet	UA	26.11.2018	03.12.2018	16.12.2018	17.12.2018	24.12.2018	06.01.2019

The cost of transportation to and from a participating laboratory shall be covered by the participating laboratory.
For transportation, the artefacts are packed in a protective aluminium box, which in turn is put into a card-board container. The dimensions are 35 cm x 40 cm x 29 cm, the weight is approximately 3 kg.
The accelerometers have to be send by an international logistic service providing a tracking system. The transportation has to include an insurance covering a total value of 12 000,- € in case the set of accelerometers gets damaged or lost during transportation.
As an alternative the artefact may be hand carried by a member of the participating laboratory.

Handling, Measurement and Analysis Instructions

The participating laboratories have to observe the following instructions:

- The charge amplifier used for the measurement of the accelerometer's response has to be calibrated with equipment traceable to national measurement standards.
- The motion of the BB accelerometer should be measured with the laser directly on the (polished) reference surface of the transducer without any additional reflector or dummy mass (c.f. picture on page 2).
- The SE accelerometers ***shall be mounted together with the mounting adapter***, that comes attached to them. The combined SE accelerometer with adapter should be handled as a single mechanical unit for mounting. ***The mounting adapter must not be adjusted, loosened or removed.*** The mounting or dismounting torque

between the adapter and the shaker shall be applied to the unit via the mounting adapter. An appropriate crowfoot wrench with 3/8” square drive adaptation and 19 mm span is provided within the set.

- The motion of the SE accelerometers shall be measured on the top surface of the polished mounting adapter that comes attached to each, close to the accelerometer's housing (c.f. picture on page 2).
- The mounting surface of the BB accelerometer or the adapters in case of the SE accelerometers and the moving part of the exciter must be slightly lubricated before mounting.
- The cable between accelerometer and charge amplifier should be taken from the set of DUT delivered to the laboratory. It is a B&K super low-noise, 10-32 UNF (M) to 10-32 UNF (M), 1,2 m cable.
- In order to reduce the influence of non-rectilinear motion, the measurements should be performed for at least three different laser positions which are symmetrically distributed over the respective measurement surface.
- It is advised that the measurement results should be compiled from complete measurement series carried out at different days under nominally the same conditions, except that the BB accelerometer or adapter in case of an SE accelerometer is remounted and the cable reattached. The standard deviation of the subsequent measurements should be included in the report.
- For acceleration signals $a(t)$ of the form
$$a(t)=\hat{a}\cdot\cos(\omega t+\varphi_a) \qquad (1)$$
and the respective charge output signal of the transducer $q(t)$ of the form
$$q(t)=\hat{q}\cdot\cos(\omega t+\varphi_q) \qquad (2)$$
the phase is defined according to ISO 16063-1 as
$$\Delta\varphi=\varphi_q-\varphi_a . \qquad (3)$$
- For the measurement of the phase of the sensitivity the delay or phase characteristics of the interferometer channel(s) has to be taken into account, since the photo-diode-amplifier-system typically has a non-negligible influence on the result.

Communication of the Results to the Pilot Laboratory

Each participating laboratory will submit one printed and signed calibration report for each accelerometer to the pilot laboratory[1] including the following:

- a description of the calibration systems used and the mounting techniques for the accelerometer,
- a description of the calibration methods used, including information about the demodulation scheme,
- a documented record of the ambient conditions during measurements,
- the calibration results, including the relative expanded measurement uncertainty, and the applied coverage factor for each value,
- a detailed uncertainty budget for the system covering all components of measurement uncertainty (calculated according to GUM, [5, 6]). Including among others information on the type of uncertainty (A or B), assumed distribution function

1 A scanned copy sent by Email should suffice.

and repeatability component. (These information are necessary for the evaluation and linking of subsequent RMO KC).

In addition each participating laboratory will receive three electronic spreadsheets prepared by the pilot laboratory, where the calibration results have to be filled in following the structure given in the files. The use of the electronic spreadsheets for reporting is mandatory. The consistency between the results in electronic form and the printed and signed calibration report is the responsibility of the participating laboratory. The data submitted in the electronic spreadsheet shall be deemed the official results submitted for the comparison.

The results have to be submitted to the pilot laboratory within six weeks after the measurements.

The pilot laboratory will submit it's set of results to the executive secretary of CCAUV in advance to the first measurement of a participating laboratory.

Remarks on the Post Processing

- Presuming consistency of the results, the key comparison reference values and the degrees of equivalence will be calculated according to the established methods as a weighted mean as agreed upon already for CCAUV.V-K1.
- In case of damage or loss of any of the artefacts the KC will be evaluated as far in the schedule as possible, all further action concerning continuation will be decided in coordination with the participants.

References

[1] BIPM, “Recommendations from the Working Group on the Implementation and Operation of the CIPM MRA”, 23rd August 2016 http://www.bipm.org/utils/common/documents/CIPM-MRA-review/Recommendations-from-the-WG.pdf

[2] ISO 16063-1:1998 “Methods for the calibration of vibration and shock transducers -- Part 1: Basic concepts

[3] ISO 16063-11:1999 “Methods for the calibration of vibration and shock transducers -- Part 11: Primary vibration calibration by laser interferometry”

[4] ISO/IEC 17025:2005 “General requirements for the competence of testing and calibration laboratories”

[5] ISO/IEC Guide 98-3:2008 “Uncertainty of measurement -- Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)

[6] ISO/IEC Guide 98-3:2008/Suppl 1:2008 “Propagation of distributions using a Monte Carlo method”

Acknowledgement

The Artefacts were kindly committed by Brüel & Kjær to the pilot lab for the purpose of this comparison. They are especially selected from a larger production sample intended to provide the quality of “best measurement standards” in terms of the CIPM MRA.