Technical Protocol of SIM Key Comparison SIM.AUV.V-K3

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. One recent top-level KC in the field of Vibration metrology was CCAUV.V-K3, completed in the year 2016 and covering the frequency range from 0.1 Hz to 40 Hz.

This regional KC is intended to extend the results of CCAUV.V-K3 to other SIM NMIs who were unable to participate in CCAUV.V-K3. The SIM participants in CCAUV.V-K3 were INMETRO (Brazil) and CENAM (Mexico).

This regional KC will compare measurements of the complex sensitivity of accelerometers exposed to sinusoidal accelerations in the frequency range from 0.1 Hz to 40 Hz; the mandatory range is 0.4 Hz – 40 Hz. In addition, there is an extended range of 0.05 Hz – 0.1 Hz and 40 Hz – 200 Hz.

Specifically, the magnitude of the complex voltage sensitivity shall be given in millivolt per meter per second squared (mV/(m/s^2)) and phase shift in degrees (°) for the different measurement conditions specified. The reported complex sensitivities and associated uncertainties are then supposed to be used for the calculation of the degree of equivalence (DoE) between the participating NMI and the CIPM key comparison reference value.

These results are expected to serve as evidence for the registration of the CMCs of the participants considering primary calibration of vibration transducers [1].

Participants

1. NIST, U.S.A. (pilot institute)
2. CENAM, Mexico (linking laboratory)
3. INMETRO, Brazil (linking laboratory)
4. NRC, Canada

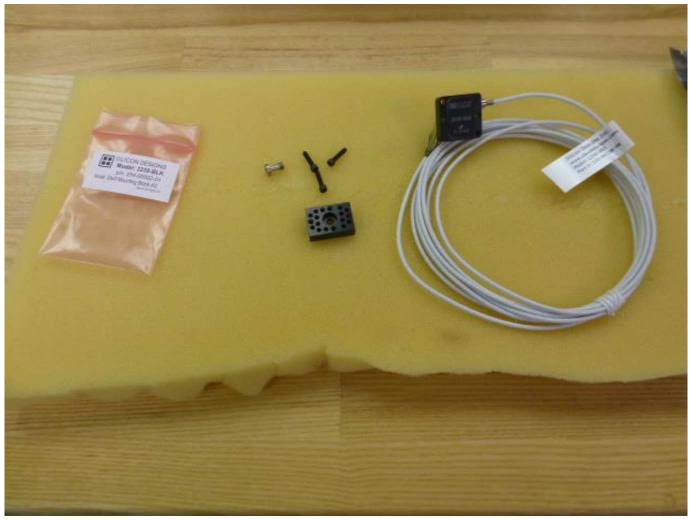
Devices under Test

Three accelerometer sets will be circulated among the participating laboratories. Each accelerometer is accompanied by a signal conditioner/power supply. The calibration should consider the combined system of accelerometer, cable, signal conditioner, and power supply (if separate) as a single device. Electronic copies of the data sheets for each accelerometer and its accompanying system components will be provided to KC participants.

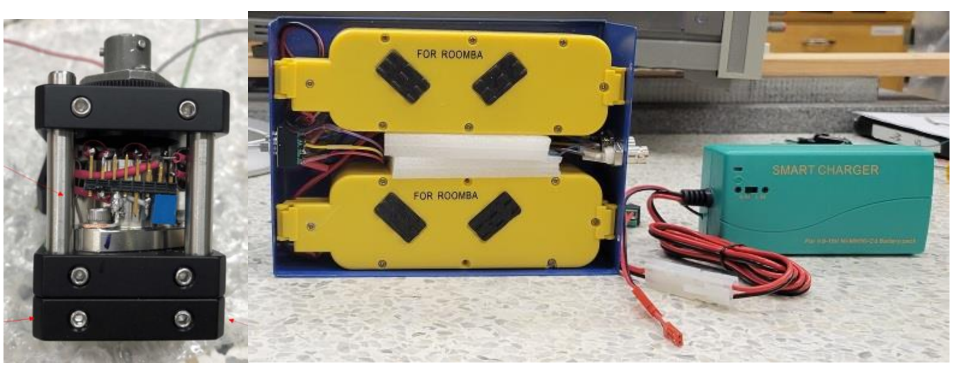
Due to size and weight, measurement of the third accelerometer listed (Wilcoxon 731A), is optional.

The individual transducers, and included equipment, are:

- Silicon Devices 2290-005 (SN: 51929)
  - Stud mounting block kit
  - SPEKTRA Supply Power supply (SN: 2023026)
  - Mass of 2290-005 = 16 g
  - Mass of 2290-005 + stud mounting block = 25.5 g
  - Nominal sensitivity = 80 mV/(m/s^2)



- FOG Photonics QA5108 (SN: HJA-02)
  - Power supply
  - Mass of FOG Photonics QA5108 + mounting adaptor =
  - Nominal sensitivity = 200 mV/(m/s^2)



(transducer package (left) shown with cover removed for viewing)

- Wilcoxon 731A (SN: 13481)
  - Wilcoxon P31 Power Supply (SN: 4022)
  - Cable
  - 3/8-16 mounting stud (mass = 8.1 g)
  - Mass of Wilcoxon 731A = 770.6 g
  - Nominal sensitivity = 1 V/(m/s^2)

Accelerometer Mounting

Participants should use their laboratory's mounting procedure for attaching the accelerometer to their calibration system. Note that the accelerometers have the following mounting provisions:

- Silicon Devices 2290-005 is mounted via one of two options:
    - Using a supplied adaptor plate that can be mounted to the shaker table using a UNF 10-32 stud and a nominal mounting torque of 2 N·m. The accelerometer to be attached to the adaptor plate using two UNC #4-40 or M3 (coarse thread) screws. If using UNC #4-40 screws, they should be tightened with a maximum torque of 0.55 N·m ; alternately, if using M3 (coarse thread), they should be tightened with a maximum torque of 0.61 N·m
    - Mounting directly to the shaker table two #4-40 or M3 screws. If using #4-40 screws, they should be tightened with a maximum torque of 0.55 N·m; alternatively, if using M3 (coarse thread), they should be tightened with a maximum torque of 0.61 N·m
- FOG Photonics QA5108
    - a participating lab can use one of the following mounting options:
        - The existing SM UNC 1/4"-20 adaptor and a UNC 1/4"-20 stud
        - Remove the existing SM UNC 1/4"-20 adaptor and replace it with the SM UNF 8-32 adaptor and UNF 8-32 stud
        - The existing SM UNC 1/4"-20 adaptor and a UNC 1/4"-20 to M6 stud
    - The hold depth cannot exceed 0.47 inch
    - Mount with a nominal mounting torque of 2 N·m
- Wilcoxon 731A is mounted via a UNC 3/8-16 stud
    - Important: The 731A should be gently hand tightened when attaching it to the shaker table

Measurement Conditions

The frequency range of the measurements are over the range of from 0.1 Hz to 40 Hz, which is the same as for CCAUV.V-K3, with the range of 0.4 Hz to 40 Hz being mandatory. Specifically, the laboratories are to measure at the following frequencies (all values in Hz):

0.1, 0.125, 0.16, 0.2, 0.25, 0.315, 0.4, 0.5, 0.63, 0.8, 1.0, 1.25, 1.6, 2.0, 2.5, 3.15, 4.0, 5.0, 6.3, 8.0, 10.0, 12.50, 16.0, 20.0, 25.0, 31.5, 40.0

Extended frequencies (all values in Hz):

0.05, 0.063, and 0.08; 50, 63, 80, 100, 125, 160, and 200

Only the frequencies covered by CCAUV.V-K3 will be published as part of the KC report; results from the extended frequencies are anticipated to be published as a separate technical report.

Each participant should use the calibration method(s) that is/are used by that participant for customer calibrations and for which the DoEs resulting from this comparison would apply.

The measurement conditions should be kept according to the laboratory's standard conditions for calibration of customers' accelerometers for claiming their best measurement capability or CMC where applicable.

Specific conditions for the measurements of this comparison are:

- acceleration amplitudes: a range of 0.05 m/s^2 to 30 m/s^2 is recommended.
- ambient temperature and accelerometer temperature during the calibration:
    - (23 ± 2) °C (actual values to be stated within tolerances of ± 0.3 °C).
    - relative humidity: max. 75 % RH

Practical Conditions for Implementation following 16063-11

The following is for the calibration of the accelerometers using laser interferometry in compliance with international standard ISO 16063-1:1998 [2] and ISO 16063-11:1999 [3].

The motion of the accelerometer should be measured following the procedures of the participating laboratory. Generally, this is implemented by directing the beam to the moving part of horizontal vibration exciter, close to the accelerometer's mounting surface, since the mounting (reference) surface is not directly accessible.

The mounting surface of the accelerometer and, following the participants standard procedure, the moving part of the exciter may be slightly lubricated before mounting and should be done if this is standard procedure in the participating laboratory.

Each accelerometer and associated power supply/signal conditioner pair should be measured using the supplied cable.

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 accelerometer is remounted and the cable re-attached. The standard deviation of the subsequent measurements should be included in the report.

Practical Conditions for Implementation via Rotation in Earth's Gravity

The Wilcoxon 731A should not be calibrated via rotation in earth's gravity, as this sensor is fragile and rated for 4.9 m/s² maximum acceleration.

Rotation in earth's gravity is a way to apply up to $\pm$ 1 g_{loc} sinusoidal acceleration to an accelerometer when the axis of rotation is parallel to the earth's surface, where g_{loc} is the local acceleration due to gravity (approximately 9.81 m/s^2; the actual value used should be included in the report). Lower accelerations can be accomplished with rotation at other angles relative to the earth's surface. Note that there will be a constant offset acceleration due to the rotation if the sensitive plane of the accelerometer is offset from the center of rotation. This method is the subject of various publications [4], [5] and a draft international standard incorporating this method is under development as ISO 16063-18 [6].

Participants interested in utilizing this method are encouraged to use this method in addition to measuring using linear sinusoidal acceleration.

Pilot Laboratory

The Pilot Laboratory for this SIM Key comparison is NIST. The physical artifacts and the written and signed reports should be sent to the following address:

NIST
Attention: Richard A. Allen
Building 233, Room B116
100 Bureau Drive, Stop 6833
Gaithersburg, MD 20899-6833
U.S.A.

The NIST contacts for this KC are:

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Circulation Type, Schedule and Transportation

The transducer set is circulated in a modified star pattern with a measurement period of four weeks provided for each participating laboratory and three weeks for each stability verification measurement by the pilot. At the beginning and the end of the circulation as well as between certain subsequent measurements of participating laboratories, the transducer set is measured at the pilot laboratory in order to monitor the stability of the transducer set.

The schedule is planned as follows (FOUR weeks measurement/THREE weeks transport):

Participant	Measurement (calendar week)	Transport to next Participant (calendar week)
NIST (Pilot)	17-20/2025	21-23/2025
CENAM (Linking: magnitude)	24-27/2025	28-30/2025
NIST	31-33/2025	34-36/2025
NRC	37-40/2025	41-43/2025
INMETRO (Linking)	44-47/2025	47-49/2025
NIST	50-52/2025	NA

Participants are asked to confirm receipt from the sending laboratory and notify next recipient when the artifacts are shipped, including any tracking information.

The cost of transportation to the next participating laboratory shall be covered by the participating laboratory. The transducers must be carefully packaged to avoid sudden shocks that may lead to damage or changes in sensitivity. The transducer set will be accompanied by a CARNET, which is to be used to facilitate international shipment, where applicable.

In the event that a delay in measurement or reporting results, the Participating Laboratory should promptly inform the Pilot Laboratory of the expected duration of the delay. The Pilot Laboratory will inform the other participating laboratories and develop a mutually acceptable modification to the schedule.

Communication of the Results to Pilot Laboratory

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

- a description of the calibration systems used for the comparison and the mounting techniques for the accelerometer
- a description of the calibration method(s) used
- 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 [7], [8]). Including, among others, information on the type of uncertainty (A or B), assumed distribution function and repeatability component, and description of how the uncertainty was determined.

In addition, the use of the electronic spreadsheets for reporting is mandatory. The format of spreadsheet will be provided by the pilot prior to circulation of the artifacts. 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 are to be submitted to the pilot laboratory within four weeks after the measurements have been completed.

The pilot laboratory will submit its set of results to the executive secretary of CCAUV in advance of the first measurement of the participating laboratory.

Post Processing

The key comparison reference value and the degrees of equivalence will be calculated as follows, taking advantage of recent work to provide easy-to-use and optimal analysis tools for KCs:
1. Use the NIST Decision Tree [9, 10] to analyze the data and determine the reference value using the optimal method indicated by the NIST Decision Tree.
2. Use the methods that were used in CCAUV.V-K3.
3. Decide whether it is appropriate to apply a simple expansion factor to the methods used in CCAUV.V-K3 in order to accommodate sensor drift and dark uncertainty, and if so, do so.
The results of these three approaches will be compared. In the event of disagreement among the results obtained by different means, the participants should collectively decide which results are best. Thus, a side-outcome of this comparison will be the effect of different methods of data

processing, as well as information on the relative effort required to implement the different procedures.
Based on the results of CCAUV.V-K3, the linking of phase results of SIM.AUV.V-K3 to CCAUV.V-K3 will be through INMETRO only.

References

[1] ISO/IEC 17025:2017 'General requirements for the competence of testing and calibration laboratories'

[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] J.S. Hilton, "Accelerometer Calibration with the Earth's Field Dynamic Calibrator", NBS Technical Note 517, March 1970.

[5] W. A. Wildhack and R. 0. Smith, "A Basic Method of Determining the Dynamic Characteristics of Accelerometers by Rotation", Paper No. 54-40-3, Instrument Society of America, 1954.

[6] For information on ISO Standards under development and/or to participate in ISO Standards development, please contact your national committee

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

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

[9] A. Possolo, A. Koepke, D. Newton, and M. Winchester, "Decision Tree for Key Comparisons", Journal of Research, National Institute of Standards and Technology, Gaithersburg, MD (2021). https://doi.org/10.6028/jres.126.007

[10] https://decisiontree.nist.gov/ [accessed April 9, 2025]