Final Report on the

# Supplementary Comparison

# EURAMET.AUV.V-S2

Summary

The supplementary comparison EURAMET.AUV.V-S2 has been carried out within the framework of the CIPM MRA. The specific task of this comparison is the measurement of the magnitude and phase of the sensitivity of single-ended accelerometers in the medium frequency domain (10 Hz to 10000 Hz). The sensitivity is calculated as the ratio of the amplitude of the output of the accelerometer to the amplitude of the acceleration at its reference surface with secondary means in accordance with ISO 16063-21 "Methods for the calibration of vibration and shock transducers - Part 21: Vibration calibration by comparison to a reference transducer" [1]. The participating NMIs are BEV (Austria), and METAS (Switzerland). BEV (Austria) was the pilot laboratory of this bilateral comparison. The measurements took place between November 2021 and January 2022. A single-ended accelerometer was circulated. This report includes the measurement results, information about calibration methods, and the analysis leading to the assignation of equivalence degrees.

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# 1 Introduction

The EURAMET.AUV.V-S2 is a supplementary comparison realised under the auspices of the EURAMET TC-AUV in the framework of the CIPM MRA. Since there are only two participants (BEV, Austria and METAS, Switzerland), it is a bilateral comparison and a sequel to the supplementary comparison EURAMET.AUV.V-S1 [2].

One standard was circulated among the two laboratories. The accelerometer was calibrated for magnitude of their complex charge sensitivity according to those procedures and conditions implemented by BEV in conformance with ISO 16063-21 [1]. METAS provided primary calibration according to ISO 16063-11 “Methods for the calibration of vibration and shock transducers - Part 11: Primary vibration calibration by laser interferometry” [3] as reference values for the magnitude. The frequency range of the measurements was agreed to be from 10 Hz to 10 kHz.

BEV (Austria) piloted the comparison. The participants are listed in Table 1. The measurements took place between November 2021 and January 2022. This report includes the measurement results, information about calibration methods, and the analysis leading to the assignation of equivalence degrees.

**Table 1. List of participating institutes**

| Participant (alphabetical order) | Acronym | Country | Country code |
|---|---|---|---|
| Bundesamt für Eich- und Vermessungswesen | BEV | Austria | AT |
| Eidgenössisches Institut für Metrologie | METAS | Switzerland | CH |

# 2 Scope

The technical protocol for the supplementary comparison EURAMET.AUV.V-S2 was approved by both participants (Appendix B).

The specific task of this RMO comparison is to measure the magnitude of the charge sensitivity of an accelerometer at specified frequencies with secondary means according to ISO 16063-21 “Methods for the calibration of vibration and shock transducers - Part 21: Vibration calibration by comparison to a reference transducer” [1]. METAS provided primary calibration according to ISO 16063-11 “Methods for the calibration of vibration and shock transducers - Part 11: Primary vibration calibration by laser interferometry” [3] as reference values for the magnitude. The reported sensitivities and associated uncertainties are used for the calculation of the degree of equivalnce (DoE) between BEV and the primary calibration value of METAS.

One piezoelectric accelerometer was circulated:

- Endevco 2270M8 (SN: 14612) “single ended” (SE) type with nominal sensitivity 0.22 pC/(m/s$^2$)


Endevco 2270M8 type accelerometer

In the following this transducer is referred to as “2270M8”.

The frequency range of the measurements was agreed to be from 10 Hz to 10 kHz. Specifically, the laboratories were 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, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000, 6300, 8000, 10000

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

Specific conditions for the measurements of this comparison were:

- Acceleration amplitudes: preferably 50 m/s² to 100 m/s², a range of 2 m/s² to 200 m/s² was admissible.
- Ambient temperature during the calibration:
  (23 ± 2) ºC (actual values to be stated within tolerances of ± 0.3 ºC).
- Relative humidity: max. 75 %
- Mounting torque of the accelerometer: (2.0 ± 0.1) N·m

# 3 Stability of travelling standard

METAS has monitored the transfer accelerometer before and after transportation to and from BEV. The monitoring consisted of magnitude calibrations according to ISO 16063-11 [3]. The measurement schedule was:

METAS→ BEV→ METAS

According to ISO 16063-21 a rectangular probability distribution is assumed for the quantity “drift of the magnitude of an accelerometer”. At each frequency $f$, the estimator for the mean $\bar{S}(f)$ of the magnitude of all monitoring measurements is then given as:

$$\bar{S}(f) = \frac{S_1(f) + S_2(f)}{2}$$

Where $S_1(f)$ and $S_2(f)$ are the monitoring measurements before and after transportation at each frequency. To deduce a significant drift of an accelerometer for each monitoring measurement an $\varepsilon_i$ number is defined as:

$$\varepsilon_i(f) = \frac{|S_i(f) - \bar{S}(f)|}{U_{S_i}(f)}$$

Where $S_i(f)$ is the magnitude of the single monitoring measurement $i$ and $U_{S_i}(f)$ is the expanded uncertainty of $S_i(f)$. As long as $\varepsilon_i(f) \leq 1$, $\forall i$, $\forall f$ is valid, no significant drift can be deduced by means of the primary calibration at METAS. It is sufficient to calculate $\varepsilon_{max}(f) = \max_{i=1,2} \varepsilon_i(f)$ for each frequency and check, if $\varepsilon_{max}(f) \leq 1$.

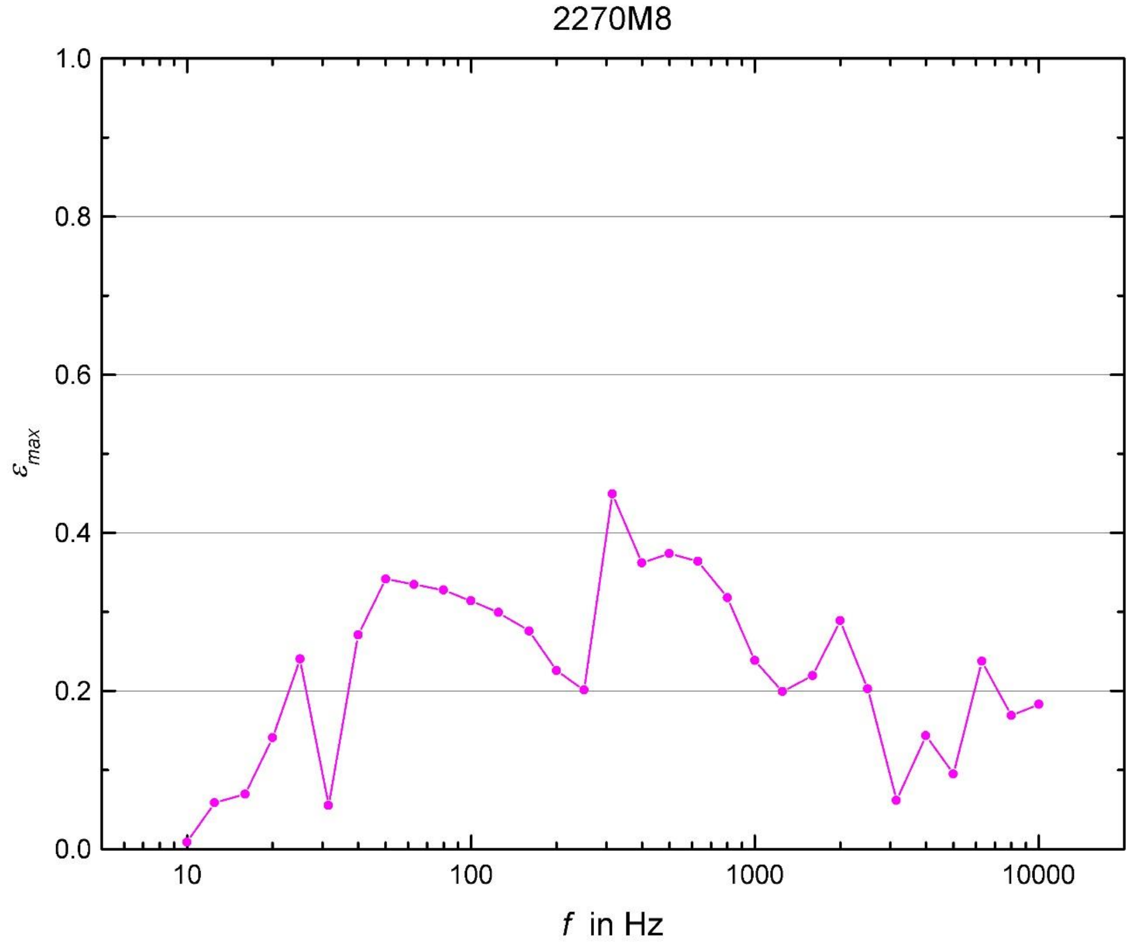


**Figure 1. Maximum values of $\varepsilon$ for accelerometer 2270M8 and all frequencies $f$.**

Fig. 1 clearly indicates no considerable drift of the transfer standard.

## 4 Calibration methods

Measurements at BEV were done according to ISO 16063-21. At METAS primary calibration was done according to ISO 16063-11. Table 2 shows details about instrumentation. At BEV grease was applied on both surfaces of the back-to-back transducer.

**Table 2. Measurement instrumentation of BEV and METAS. BB (back-to-back) means the reference sensor of the measurement system, while SE (single ended) stands for the transfer standard.**

| | BEV | METAS |
|---|---|---|
| **Reference Transducer BB** | B&K 8305 | n/a |
| **Traceability BB** | PTB | primary |
| **Recalibration Interval BB** | 3 years | n/a |
| **Shaker** | SPEKTRA SE-09 | SPEKTRA SE-10 |
| **Power Amplifier** | SPEKTRA PA 14-500 | SPEKTRA PA 14-180 |
| **Shaker Source** | HP 33120A | SPEKTRA SRS-35 |
| **Mounting Technique BB** | Screw | n/a |
| **Mounting Technique SE** | Screw | Screw |
| **Grease** | slightly greased | slightly greased |
| **Torque** | 2 N·m | 2 N·m |
| **Charge Amp. BB** | B&K 2635 | n/a |
| **Charge Amp. SE** | B&K 2525 | SPEKTRA SRS-35 |
| **Voltmeter BB** | NI PXI-4464 | n/a |
| **Voltmeter SE** | NI PXI-4464 | SPEKTRA SRS-35 |

# 5 Results

The following tables and figures show the reported results of the participants for the transducer 2270M8. The uncertainty budgets of each participant are presented in Appendix A. Table 3 explains the quantities and symbols of the results tables.

**Table 3. Quantities of results tables**

| Quantity | Symbol | Unit | Representation |
|---|---|---|---|
| Sensitivity magnitude | $S$ | $\mathrm{pC/(m\ s^{-2})}$ | x.xxxxx |
| Expanded relative uncertainty | $U_S$ | % | x.xx |

**Table 4. Sensitivity magnitude and expanded relative uncertainty for accelerometer 2270M8.**

| $f$ in Hz | BEV $S$ in $\frac{\mathrm{pC}}{(\mathrm{m\,s^{-2}})}$ | BEV $U_S$ in % | METAS $S$ in $\frac{\mathrm{pC}}{(\mathrm{m\,s^{-2}})}$ | METAS $U_S$ in % |
|---|---|---|---|---|
| 10.0 | 0.19367 | 0.90 | 0.19405 | 0.22 |
| 12.5 | 0.19353 | 0.90 | 0.19386 | 0.22 |
| 16.0 | 0.19355 | 0.90 | 0.19380 | 0.22 |
| 20.0 | 0.19353 | 0.90 | 0.19373 | 0.19 |
| 25.0 | 0.19354 | 0.90 | 0.19367 | 0.19 |
| 31.5 | 0.19348 | 0.70 | 0.19365 | 0.21 |
| 40.0 | 0.19336 | 0.70 | 0.19364 | 0.19 |
| 63.0 | 0.19330 | 0.70 | 0.19364 | 0.19 |
| 80.0 | 0.19330 | 0.70 | 0.19363 | 0.19 |
| 100 | 0.19337 | 0.70 | 0.19359 | 0.19 |
| 125 | 0.19354 | 0.70 | 0.19358 | 0.19 |
| 160 | 0.19352 | 0.70 | 0.19359 | 0.20 |
| 200 | 0.19353 | 0.70 | 0.19358 | 0.20 |
| 250 | 0.19348 | 0.70 | 0.19356 | 0.21 |
| 315 | 0.19340 | 0.70 | 0.19347 | 0.20 |
| 400 | 0.19332 | 0.70 | 0.19339 | 0.24 |
| 500 | 0.19342 | 0.70 | 0.19348 | 0.21 |
| 630 | 0.19320 | 0.70 | 0.19348 | 0.21 |
| 800 | 0.19329 | 0.70 | 0.19344 | 0.21 |
| 1000 | 0.19343 | 0.70 | 0.19346 | 0.24 |
| 1250 | 0.19340 | 0.70 | 0.19336 | 0.24 |
| 1600 | 0.19353 | 0.70 | 0.19351 | 0.23 |
| 2000 | 0.19352 | 0.70 | 0.19359 | 0.24 |
| 2500 | 0.19376 | 0.70 | 0.19388 | 0.23 |
| 3150 | 0.19407 | 0.70 | 0.19407 | 0.24 |
| 4000 | 0.19445 | 0.70 | 0.19442 | 0.24 |
| 5000 | 0.19513 | 1.20 | 0.19544 | 0.24 |
| 6300 | 0.19602 | 1.20 | 0.19634 | 0.68 |
| 8000 | 0.19793 | 1.20 | 0.19819 | 0.68 |
| 10000 | 0.20020 | 1.20 | 0.20129 | 0.68 |

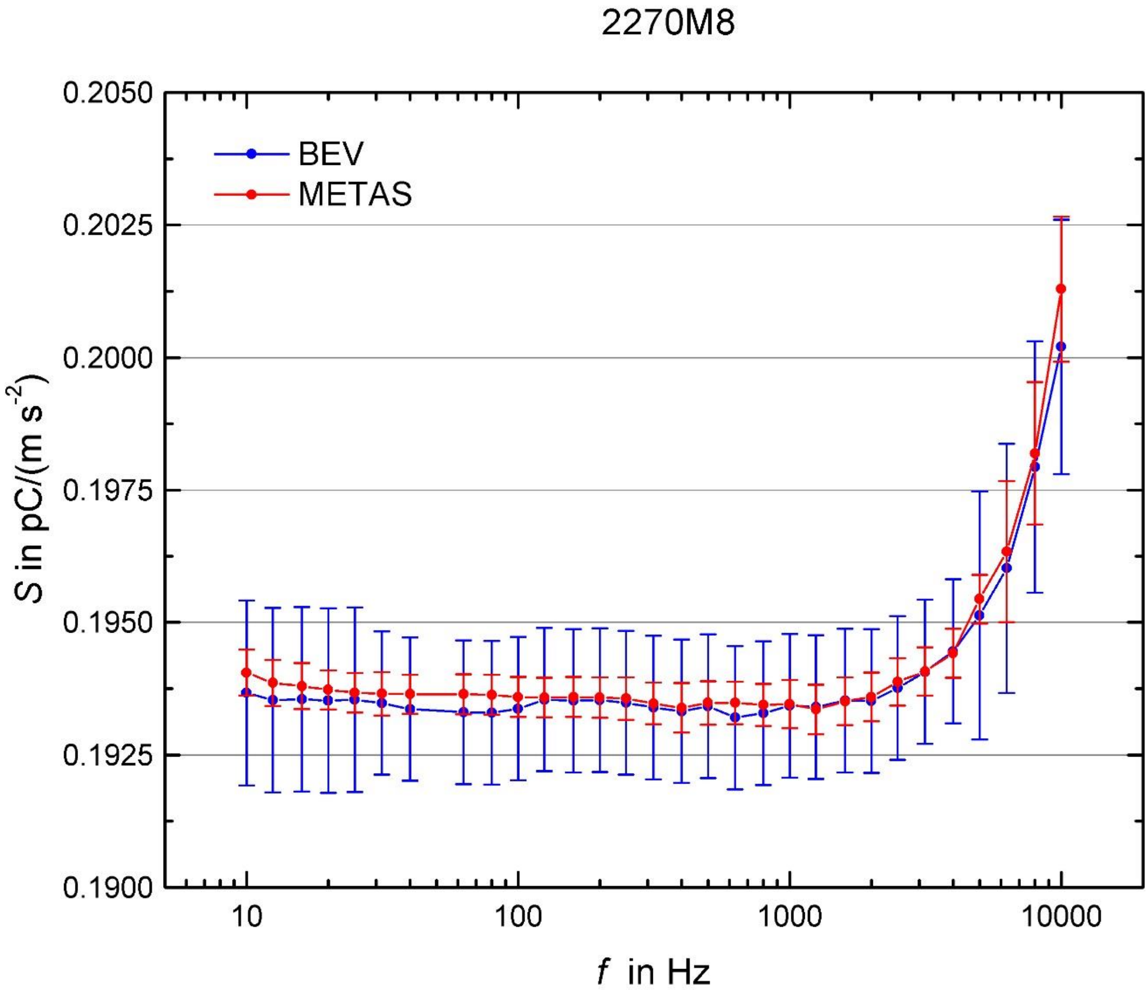


**Figure 2. Sensitivity magnitude, accelerometer 2270M8**

## 6 Degrees of equivalence

As decided in the protocol (Appendix B) and according to [4] the primary measurements at METAS are used as reference values of this comparison. Degrees of equivalence (DoE) $D$ were calculated at each frequency $f$ for sensitivity magnitude $S$:

$$D_{S,BEV}(f) = S_{BEV}(f) - S_{METAS}(f)$$

Since BEV is not traceable to METAS, no correlations have to be taken into account for uncertainty calculations of DoE. Principally, one must not do uncertainty calculations with expanded uncertainties, but under the present circumstances the simplest way to gain the expanded uncertainties of the DoE is:

$$U_{D_{S,BEV}}(f) = \frac{1}{100} \cdot \sqrt{S_{BEV}^2 U_{S_{BEV}}^2(f) + S_{METAS}^2 U_{S_{METAS}}^2(f)}$$

Where $U_{S_{BEV}}(f)$ and $U_{S_{METAS}}(f)$ are relative uncertainties in %.

The calculations were done without any intermediate rounding. In the following DoE tables results with $|D_j(f)| > U_{D_j}(f)$ would be marked by a yellow background. Table 5 explains the quantities and symbols presented in the DoE tables.

**Table 5. Quantities of DoE tables**

| Quantity | Symbol | Unit | Representation |
|---|---|---|---|
| DoE of Sensitivity magnitude | $D_S$ | $\mathrm{fC/(m\ s^{-2})}$ | x.xx |
| Expanded Uncertainty | $U_{D_S}$ | $\mathrm{fC/(m\ s^{-2})}$ | x.xx |

**Table 6. DoE of sensitivity magnitude and expanded uncertainty for accelerometer 2270M8**

| | BEV | |
|---|---|---|
| $f$ in Hz | $D_S$ in $\frac{\mathrm{fC}}{(\mathrm{m\ s^{-2}})}$ | $U_{D_S}$ in $\frac{\mathrm{fC}}{(\mathrm{m\ s^{-2}})}$ |
| 10.0 | -0.38 | 1.80 |
| 12.5 | -0.33 | 1.80 |
| 16.0 | -0.25 | 1.80 |
| 20.0 | -0.20 | 1.78 |
| 25.0 | -0.13 | 1.78 |
| 31.5 | -0.17 | 1.41 |
| 40.0 | -0.28 | 1.40 |
| 63.0 | -0.34 | 1.40 |
| 80.0 | -0.34 | 1.40 |
| 100 | -0.22 | 1.40 |
| 125 | -0.04 | 1.41 |
| 160 | -0.07 | 1.41 |
| 200 | -0.05 | 1.41 |
| 250 | -0.08 | 1.41 |
| 315 | -0.08 | 1.41 |
| 400 | -0.07 | 1.43 |
| 500 | -0.06 | 1.41 |
| 630 | -0.28 | 1.41 |
| 800 | -0.15 | 1.41 |
| 1000 | -0.03 | 1.43 |
| 1250 | 0.05 | 1.43 |
| 1600 | 0.01 | 1.43 |
| 2000 | -0.08 | 1.43 |
| 2500 | -0.12 | 1.43 |
| 3150 | 0.00 | 1.43 |
| 4000 | 0.04 | 1.44 |
| 5000 | -0.31 | 2.39 |
| 6300 | -0.31 | 2.70 |
| 8000 | -0.26 | 2.73 |
| 10000 | -1.09 | 2.77 |

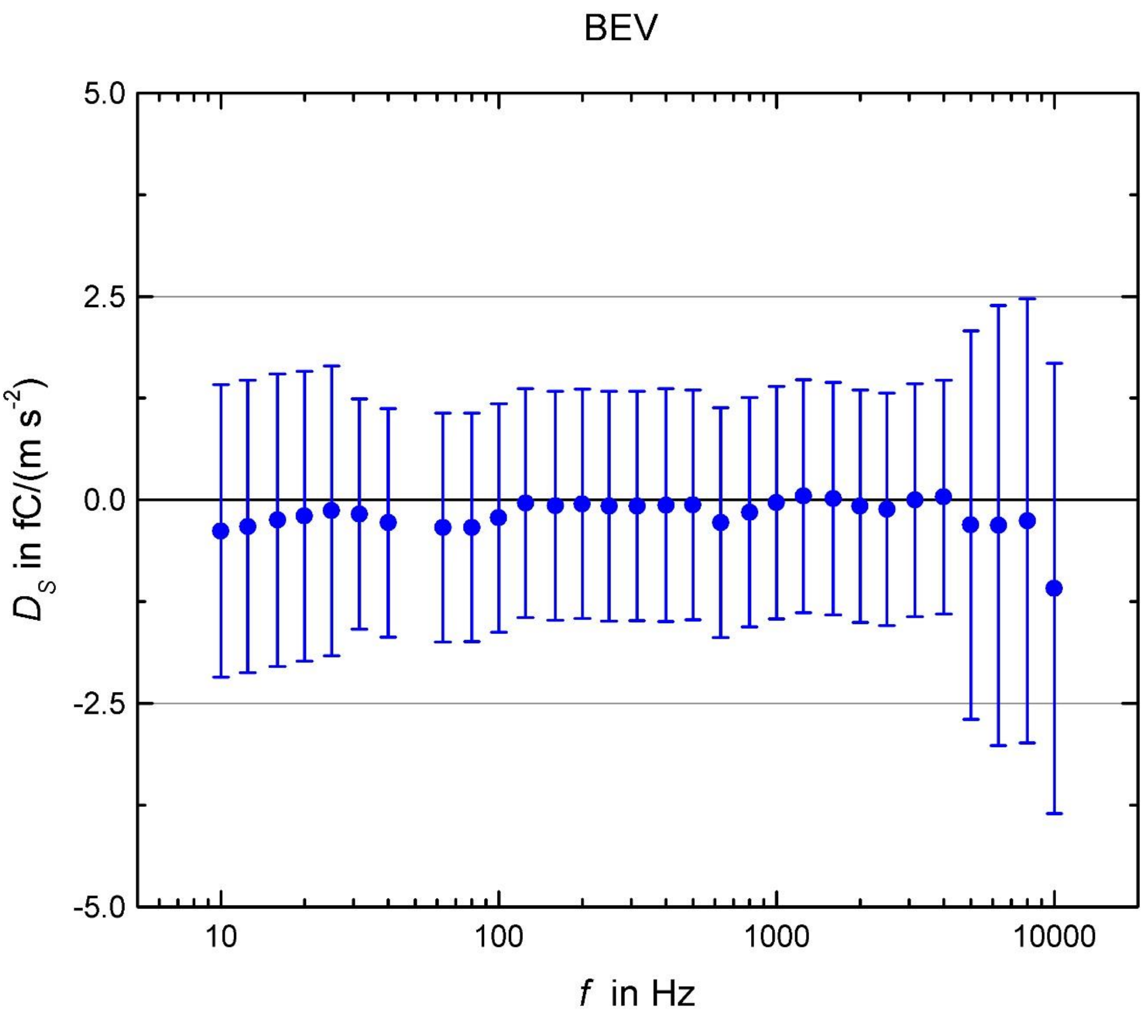


**Figure 3. BEV DoE of sensitivity magnitude, accelerometer 2270M8**

## 7 Conclusions

The aim of the bilateral supplementary comparison EURAMET.AUV.V-S2 was to establish reliable equivalence between national metrology institutes for the calibration of accelerometers with secondary means according to ISO 16063-21 [1]. The comparison was a sequel to the supplementary comparison EURAMET.AUV.V-S1 [2]. One single ended accelerometer was circulated among the participants. The results of primary calibrations according to ISO 16063-11 [3] at METAS were used as reference values for the analysis of the results of the secondary calibrations.

One aspect of the comparison task was the complementation of the measurement chain with a local charge amplifier calibrated by the participant. Due to this requirement the consistency of the SC results demonstrates the associated capability of calibration of magnitude of the complex transfer function of charge amplifiers. In addition, this capability could be expected to be valid for other kinds of measuring amplifiers as well, including voltage amplifiers.

Overall, the supplementary comparison EURAMET.AUV.V-S2 can be considered successful for the participants.

# 8 References


[1] ISO 16063-21:2003 Methods for the calibration of vibration and shock transducers - Part 21: Vibration calibration by comparison to a reference transducer

[2] Final Report on the Supplementary Comparison EURAMET.AUV.V-S1, Peter Rosenkranz et al 2022 Metrologia 59 09001

[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 17043:2010 Conformity assessment - General requirements for proficiency testing

## Appendix A - Uncertainty budgets

The uncertainty budgets of each laboratory are given below as submitted by each participant. Minor editing of the contents and a small amount of reformatting has been performed.

### *a) BEV*

| Measurement uncertainty sensitivity magnitude $S$ | | Frequency range | | | |
|---|---|---|---|---|---|
| Uncertainty contribution | Distribution | 10 Hz ≤ $f$ ≤ 25 Hz | 25 Hz < $f$ ≤ 1 kHz | 1 kHz < $f$ ≤ 4 kHz | 4 kHz < $f$ ≤ 10 kHz |
| Combined uncertainty of reference transducer | normal | 0.100 | 0.100 | 0.150 | 0.200 |
| Reference transducer drift over 3 years | rect | 0.020 | 0.020 | 0.020 | 0.030 |
| Charge amplifier amplification ratio | normal | 0.141 | 0.141 | 0.141 | 0.141 |
| Charge amplifier drift | rect | 0.071 | 0.071 | 0.071 | 0.071 |
| Voltage ratio | normal | 0.007 | 0.007 | 0.007 | 0.007 |
| Voltmeter drift | rect | 0.014 | 0.014 | 0.014 | 0.014 |
| Effect of Hum&noise | rect | 0.040 | 0.012 | 0.012 | 0.012 |
| Effect of distortion | rect | 0.115 | 0.058 | 0.058 | 0.058 |
| Effect of transverse, rocking and bending vibration | rect | 0.029 | 0.029 | 0.087 | 0.231 |
| Effect of base strain | rect | 0.029 | 0.029 | 0.029 | 0.029 |
| Effect of mounting parameters (torque, cable fixing, etc.) | rect | 0.346 | 0.173 | 0.173 | 0.404 |
| Effect of relative motion | rect | 0.058 | 0.029 | 0.029 | 0.029 |
| Effect of temperature | rect | 0.115 | 0.115 | 0.115 | 0.115 |
| Effect of acceleration stability during measurement | rect | 0.058 | 0.058 | 0.058 | 0.058 |
| Effect of gravitation | rect | 0.029 | 0.029 | 0.029 | 0.029 |
| Effect of magnetic field from exciter | rect | 0.029 | 0.029 | 0.029 | 0.029 |
| Effect of other environmental parameters | rect | 0.029 | 0.029 | 0.029 | 0.029 |
| Residual effects (e.g. random effect in repeated measurements; etc.) | rect | 0.029 | 0.029 | 0.029 | 0.029 |
| Relative uncertainty $u_S$ % | | 0.442 | 0.303 | 0.333 | 0.555 |
| **Expanded relative uncertainty $U_S$ %** | | **0.9** | **0.7** | **0.7** | **1.2** |

## b) METAS

Due to the actual type A uncertainties of the 2270M8 sensor, the uncertainties of the results in table 4 differ slightly from the values in the uncertainty budget.

**Measurement uncertainty budget for the primary calibration of accelerometers, type B&K 8305, single ended, (amplitude)**

| uncertainty contribution | | | | | frequency range / Hz | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 5 - < 20 | 20 - < 63 | 63 - < 1 k | 1 k - < 5 k | 5 k - 10 k | >10 k - 15 k | >15 k - 10 k |
| Component | | Distribution | Factor | Evaluation Type | contribution | contribution | contribution | contribution | contribution | contribution | contribution |
| electrical measurement | including charge amplifier calibration | normal | 2.00 | Type B | 3.00E-04 | 3.00E-04 | 3.00E-04 | 3.00E-04 | 3.00E-04 | 5.00E-04 | 5.00E-04 |
| frequency | including the influence of speed to acceleration conversion | rectangular | 1.73 | Type B | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 |
| signal conditioner gain | including level non-linearity | normal | 2.00 | Type B | 2.00E-04 | 2.00E-04 | 2.00E-04 | 2.00E-04 | 2.00E-04 | 2.00E-04 | 2.00E-04 |
| signal conditioner frequency response | including frequency non-linearity | normal | 2.00 | Type B | 5.00E-04 | 5.00E-04 | 5.00E-04 | 5.00E-04 | 2.00E-03 | 4.00E-03 | 4.00E-03 |
| transverse motion | typical values for 8305-type of transducer | rectangular | 1.73 | Type B | 1.40E-04 | 1.40E-04 | 1.40E-04 | 7.00E-04 | 2.50E-03 | 7.00E-03 | 7.00E-03 |
| contribution of harmonics | nonlinearities affecting mechanical excitation | rectangular | 1.73 | Type B | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| hum | max. tolerated contribution of powerline hum | rectangular | 1.73 | Type B | 1.00E-04 | 1.00E-04 | 1.00E-04 | 1.00E-04 | 1.00E-04 | 1.00E-04 | 1.00E-04 |
| noise | broadband noise (including DUT, mechanical, electrical contributions) | normal | 2.00 | Type B | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 |
| position dependence | reproducibility and averaging from different measurement positions * (determined for each calibration) | rectangular | 1.73 | Type A* | 2.10E-05 | 2.94E-05 | 5.22E-04 | 2.70E-04 | 4.30E-04 | 4.65E-04 | 1.96E-03 |
| transducer mounting | including reproducibility of mounting torque | rectangular | 1.73 | Type A | 7.00E-05 | 7.00E-05 | 1.40E-04 | 5.00E-04 | 1.00E-03 | 2.00E-03 | 2.00E-03 |
| cable fixture | including connector strain and triboelectric effects | rectangular | 1.73 | Type B | 9.00E-04 | 7.00E-04 | 7.00E-04 | 3.50E-04 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| relative motion | including imperfections of the laser vibration isolation | rectangular | 1.73 | Type B | 1.00E-04 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 |
| thermal stability | combinde effect on laser reference, signal acquisition and DUT | rectangular | 1.73 | Type B | 1.50E-05 | 1.50E-05 | 1.50E-05 | 1.50E-05 | 1.50E-05 | 1.50E-05 | 1.50E-05 |
| linearity | additional effects of non-linearity | rectangular | 1.73 | Type B | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 |
| reference signal | instabilities affecting the velocity signal after demodulation | rectangular | 1.73 | Type B | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 | 1.00E-05 |
| residual components | | rectangular | 1.73 | Type B | 1.00E-04 | 1.00E-04 | 1.00E-04 | 1.00E-04 | 1.00E-04 | 1.00E-04 | 1.00E-04 |
| relative standard uncertainty | | | | | 1.12E-03 | 9.57E-04 | 1.10E-03 | 1.16E-03 | 3.40E-03 | 8.34E-03 | 8.55E-03 |
| expanded uncertainty | | | | | 2.23E-03 | 1.91E-03 | 2.19E-03 | 2.31E-03 | 6.81E-03 | 1.67E-02 | 1.71E-02 |
| expanded uncertainty (%) | | | | | **0.22** | **0.19** | **0.22** | **0.23** | **0.7** | **1.7** | **1.7** |

# Appendix B - Technical protocol

## 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 Metrology Institutes (NMI).

The specific task of this RMO comparison is to measure the magnitude of the charge sensitivity of an accelerometer at specified frequencies with secondary means *i.e.* according to ISO 16063-21 “Methods for the calibration of vibration and shock transducers - Part 21: Vibration calibration by comparison to a reference transducer”. METAS will perform a primary calibration according to ISO 16063-11 “Methods for the calibration of vibration and shock transducers – Part 11: Primary vibration calibration by laser interferometry”. The results of the METAS calibration will provide the reference value. The reported sensitivities and associated uncertainties are then supposed to be used for the calculation of the DoE between the participating NMI and the primary calibration value of METAS.

## Pilot and Co Pilot Laboratories

Pilot laboratory for this Supplementary RMO Comparison is

BEV, Austria
Arltgasse 35
1160 Wien, Austria

Contact Person:

Peter Rosenkranz
Phone: +43 1 21110 826515
E-mail: peter.rosenkranz@bev.gv.at

The delivery address for the artifact and the written and signed reports is:

METAS, Switzerland
Lindenweg 50
3003 Bern-Wabern

Contact Person:

Christian Hof
Phone: +41 58 387 0750
E-mail: christian.hof@metas.ch

## Devices under Test and Measurement Conditions

For the calibration task of this supplementary comparison a piezoelectric accelerometer will be circulated among the participating laboratories:

• Endevco 2270M8 (SN: 14612) “single ended” (SE) type


Fig. 1. Endevco 2270 type accelerometer

The accelerometer is to be calibrated for magnitude of the complex charge sensitivity according to those procedures and conditions implemented by the NMI in conformance with ISO 16063-21. If phase calibration is desired, it may be included since METAS will perform a primary calibration according to ISO 16063-11, including phase calibration.

The sensitivities reported shall be for the accelerometer alone, excluding any effects from the charge amplifier. The frequency range of the measurements was agreed to be from 10 Hz to 10 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, 1 600, 2 000, 2 500, 3 150, 4 000, 5 000, 6 300, 8 000, 10 000

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

The charge amplifier (CA) used for the calibration is not provided within the set of the artifact, it must therefore be provided by the individual participant.

The measurement condition should be kept according to the laboratory's standard conditions for calibration of customer accelerometers for claiming their best achievable CMC. This presumes that these conditions comply with those defined by the applicable ISO documentary standards [1, 2], simultaneously.

Specific conditions for the measurements of this comparison 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 during the calibration:
  (23 ± 2) ºC (actual values to be stated within tolerances of ± 0.3 ºC).
- Relative humidity: max. 75 %rh
- Mounting torque of the accelerometer: (2.0 ± 0.1) N·m

## Circulation Type, Schedule and Transportation

A measurement period of three weeks is provided for each participant plus one week for transportation. The transducers are measured at METAS in order to monitor the long-term stability. The schedule is planned as follows starting in fall 2021:

METAS→ BEV→ METAS

For transportation, the artifact is packed in a protective box, which in turn is put into a card-board container. The cost of transportation shall be covered by the participating laboratories, except METAS. The accelerometers have to be sent by an international logistic service providing a tracking system. The transportation has to include an insurance covering a total value of € 6.000, in case the accelerometer gets damaged or lost during transportation. As an alternative the artifact 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:

- Any instrument used for the measurement of the accelerometer's response has to be calibrated with equipment traceable to national measurement standards.
- The mounting surface of the accelerometers and the moving part of the exciter must be slightly lubricated before mounting.
- The cable between accelerometer and charge amplifier must be a Brüel & Kjaer, 10-32 UNF (M) to 10-32 UNF (M) 1.2 m cable (Fig.2).

**Fig. 2**. Brüel & Kjaer, 10-32 UNF (M) to 10-32 UNF (M) 1.2 m cable

**Note:**

In contrast to almost simultaneously performed CCAUV.V-K5 no mechanical adapter is provided and none should be used for the single-ended accelerometer calibration. This is, because, opposed to the Laser measurement in primary calibration the accuracy of the secondary calibration relies on the direct proximity of the reference surfaces of reference accelerometer and device under test. Where, for single ended calibration the reference surface is typically given by a back-to-back reference or by an instrumented and calibrated shaker armature.

## Communication of the Results to the Pilot Laboratory

Each participating laboratory will submit one printed and signed calibration report to METAS including the following:

- a description of the calibration systems used and the mounting techniques for the accelerometer,
- a description of the calibration methods used,
- a description of the mounting method (simple screw, tripod, etc.) of the transfer standards to the reference sensor and the type of reference sensor (back-to-back sensor, built-in sensor of the shaker, etc.),
- 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, [2]). Including among others

information on the type of uncertainty (A or B), assumed distribution function and repeatability component,
- A record of the traceability chain of the laboratories' used reference accelerometers up to the primary source of acceleration traceability.

In addition, each participating laboratory will receive an electronic spreadsheet 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 spreadsheet 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.

Ensuring formally the impartiality may be a delicate issue - particularly with bilateral comparisons. In order to tackle this issue, the participants will submit their respective measurement results to an independent third party, which will in the present case be the EURAMET TC-AUV Chair, before exchanging them. They will only be shared with the pilot laboratory for further analysis, once all the measurements are completed.

Results have to be submitted to the EURAMET TC-AUV Chair within six weeks after completion of measurements.

## Remarks on the Post Processing

- Presuming consistency of the results, calculation of the results will be done according to EN ISO 17043:2010, Annex B.3.1.3 e), formula B.5 [3]. The report will include the DoE to the primary calibration value of METAS.
- In case of damage or loss of the artifact the comparison 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] ISO 16063-21:2003 “Methods for the calibration of vibration and shock transducers - Part 21: Vibration calibration by comparison to a reference transducer”

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

[3] ISO/IEC 17043:2010 “Conformity assessment - General requirements for proficiency testing”