# Report on the Key Comparison APMP.AUV.V-K1.2

***Final Report***


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*2010-08-16*


**Abstract**

A third comparison of vibration acceleration APMP.AUV.V-K1.2 has been made within the Asia Pacific Metrology Programme (APMP) to include two national laboratories, the KIM-LIPI (Indonesia) and the NPLI (India). The pilot laboratory was the NIM (China) that was also used to link the results to the CCAUV.V-K1 comparison. The accelerations varied from 10 m s$^{-2}$ to 200 m s$^{-2}$ over the frequency range from 40 Hz to 5 kHz. The results demonstrate the agreement with the key comparison reference value and each other, within the expanded uncertainties.

# Tables of Contents

# 1 Introduction

This report presents the results of the third APMP comparison in the area of 'vibration', which in this case means sinusoidal acceleration.

This is an RMO comparison so it is not appropriate to calculate a key comparison reference value (KCRV) from the results of the participants. Instead in this report the relationship between the results of the participants and the results of the first CIPM comparison in the field of vibration CCAUV.V-K1 is calculated via a procedure of 'linking', which is described in section 8.1. It should be noted, that only one single linking laboratory, i.e. the pilot laboratory, was available for that process. Although this is recognized in general as not being the best solution, this does follow the agreed technical protocol.

Using this linking procedure, the results of the participants can be directly compared with the results of other comparisons, be it CCAUV.V-K1 itself or others that are similarly linked to the CCAUV.V-K1.

The Technical Protocol of May 2009 (c.f. App. A ) specifies in detail the aim and the task of the comparison, the conditions of measurement, the transfer standards used, measurement instructions, time schedule and other items. A brief summary is given in the following sections.

# 2 Participants

Three National Metrology Institutes (NMIs) from the APMP have participated in the comparison APMP.AUV.V-K1.2 (c.f. table 1).

Table 1: List of participating institutes

| Participant | Country | Calibration period |
|---|---|---|
| NIM | P. R. China | September, 2009 |
| KIM-LIPI | Indonesia | October, 2009 |
| NPLI | India | December, 2009 |

# 3 Task and Purpose of the Comparison

This third RMO-level comparison of the APMP in the field of vibration acceleration was carried out for reasons of different motivation.

- KIM-LIPI: The establishment of 'calibration and measurement capabilities' (CMC) for primary calibration systems which were only recently implemented and not yet readily available at the time of the APMP.AUV.V-K1 [1].

- NPLI: The technical improvement of their original primary calibration system, which required a comparison at the APMP level.

In order to provide the necessary means for a linking of the results to the CIPM comparison CCAUV.V-K1 [2], the NIM was requested to volunteer as the Pilot and Linking laboratory.

# 4 Conditions and Instructions of Measurement

The participating laboratories observed fully or to an appropriately large extent the conditions stated in the Technical Protocol, i.e.

- frequencies in Hz:
  40, 50, 63, 80, 100, 125, 160 (reference frequency), 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000.
- acceleration amplitudes:
  A range of 10 $m/s^2$ to 200 $m/s^2$ is admissible with 100 $m/s^2$ being the preferred value.
- ambient temperature and accelerometer 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

The comparison was performed in compliance with the “Guidelines for CIPM key comparisons” [3].

# 5 Transfer Standards as Artefacts

For the purpose of the comparison the pilot laboratory selected two accelerometers for which monitoring data of a long period were available and which data were not included in any published international cooperation work. Due to the short preparatory stage of the comparison a designated long term stability monitoring of the artefacts was not possible.

- One transfer standard accelerometer (single-ended), type 8305-001, S/N 2519436 (manufacturer: Brüel & Kjær), subsequently named SE-transducer
- One reference standard accelerometer (back-to-back) type 8305 S, S/N 2440139 (manufacturer: Brüel & Kjær), subsequently named BB-transducer

The investigation of the long-term stability was continued throughout the circulation period. The results of the NIM stability measurements and other individual data of the transfer standards are given in Section 7.

# 6 Circulation of the Artefacts

The transducers were circulated with a measurement period of four weeks provided for each participant. At the beginning and the end of the circulation as well as between two subsequent measurements of any participating laboratory, the transducers were measured at the pilot laboratory in order to assure the reference value and to monitor the stability of the transducers (c.f. section 7). If the quality of the mounting surface was degraded, the artefacts were re-lapped in order to provide optimum conditions for the following measurement.

# 7 Results of the Measurements

## 7.1 Monitoring of stability

Starting with the calibration data in April 2009, the artefacts were monitored during the preparatory period and the intervals of the comparison when they were back at the pilot laboratory. As a representative of the overall change, the measurements at the reference frequency (160 Hz) are given in the following tables.

Table 2: Charge sensitivities of the SE accelerometer at 160 Hz

during the monitoring measurements

| Month rel. to 4/2009 | $S_{qa}$ in pC/(m/s²) | rel. exp. Uncertainty in % |
|---|---|---|
| 0 | 0.1252 | 0.5 |
| 2 | 0.1251 | 0.5 |
| 3 | 0.1252 | 0.5 |
| 4 | 0.1253 | 0.5 |
| 5 | 0.1253 | 0.5 |
| 7 | 0.1254 | 0.5 |
| 10 | 0.1256 | 0.5 |

Table 3: Charge sensitivities of the BB accelerometer at 160 Hz

during the monitoring measurements

| Month rel. to 4/2009 | $S_{qa}$ in pC/(m/s²) | rel. exp. Uncertainty in % |
|---|---|---|
| 0 | 0.1279 | 0.5 |
| 2 | 0.1278 | 0.5 |
| 3 | 0.1280 | 0.5 |
| 4 | 0.1279 | 0.5 |
| 5 | 0.1280 | 0.5 |
| 7 | 0.1282 | 0.5 |
| 10 | 0.1284 | 0.5 |

These monitoring measurements can be summarized in the simplest way by the statistical properties given in Table 4. This analysis indicates that the stability of the artefacts was acceptable considering the uncertainty claimed although the transportation did have some negative influence.

Table 4: Mean and standard deviation of the charge sensitivity of the artefacts

calculated from the monitoring measurements

| Artefact | long term mean in pC/(m/s²) | rel. std. deviation in % |
|---|---|---|
| SE | 0.1253 | 0.14 |
| BB | 0.1280 | 0.16 |

## 7.2 Results of the Participants

### 7.2.1 Results of the Single-Ended Accelerometer SN 2519436

Table 5: reported calibration results in pC/(m/s²) of the participants for the SE transducer with expanded relative uncertainty ($k$ = 2) in %

| | NIM | | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|
| frequency in Hz | $S_{qa}$ in pC/(m/s²) | rel.exp. unc. in % | $S_{qa}$ in pC/(m/s²) | rel.exp. unc. in % | $S_{qa}$ in pC/(m/s²) | rel.exp. unc. in % |
| 40 | 0.1252 | 0.5 | 0.1254 | 0.75 | 0.1258 | 0.7 |
| 50 | 0.1253 | 0.5 | 0.1254 | 0.76 | 0.1258 | 0.7 |
| 63 | 0.1253 | 0.5 | 0.1254 | 0.76 | 0.1258 | 0.7 |
| 80 | 0.1253 | 0.5 | 0.1254 | 0.74 | 0.1258 | 0.7 |
| 100 | 0.1253 | 0.5 | 0.1254 | 0.77 | 0.1258 | 0.7 |
| 125 | 0.1253 | 0.5 | 0.1254 | 0.75 | 0.1258 | 0.7 |
| 160 | 0.1253 | 0.5 | 0.1254 | 0.73 | 0.1258 | 0.7 |
| 200 | 0.1253 | 0.5 | 0.1255 | 0.72 | 0.1258 | 0.7 |
| 250 | 0.1253 | 0.5 | 0.1255 | 0.74 | 0.1258 | 0.7 |
| 315 | 0.1253 | 0.5 | 0.1256 | 0.83 | 0.1258 | 0.7 |
| 400 | 0.1253 | 0.5 | 0.1257 | 0.85 | 0.1258 | 0.7 |
| 500 | 0.1253 | 0.5 | 0.1257 | 0.74 | 0.1258 | 0.7 |
| 630 | 0.1254 | 0.5 | 0.1257 | 0.72 | 0.1259 | 0.7 |
| 800 | 0.1254 | 0.5 | 0.1259 | 0.71 | 0.1260 | 0.7 |
| 1000 | 0.1255 | 0.5 | 0.1259 | 0.70 | 0.1260 | 0.7 |
| 1250 | 0.1256 | 0.5 | 0.1260 | 0.72 | 0.1261 | 0.7 |
| 1600 | 0.1257 | 0.5 | 0.1261 | 0.72 | 0.1263 | 0.7 |
| 2000 | 0.1259 | 0.5 | 0.1263 | 0.71 | 0.1265 | 1.0 |
| 2500 | 0.1263 | 0.5 | 0.1265 | 0.71 | 0.1269 | 1.0 |
| 3150 | 0.1268 | 0.5 | 0.1269 | 0.71 | 0.1273 | 1.0 |
| 4000 | 0.1276 | 0.5 | 0.1273 | 0.75 | 0.1282 | 1.0 |
| 5000 | 0.1291 | 0.5 | 0.1283 | 0.84 | 0.1294 | 1.2 |

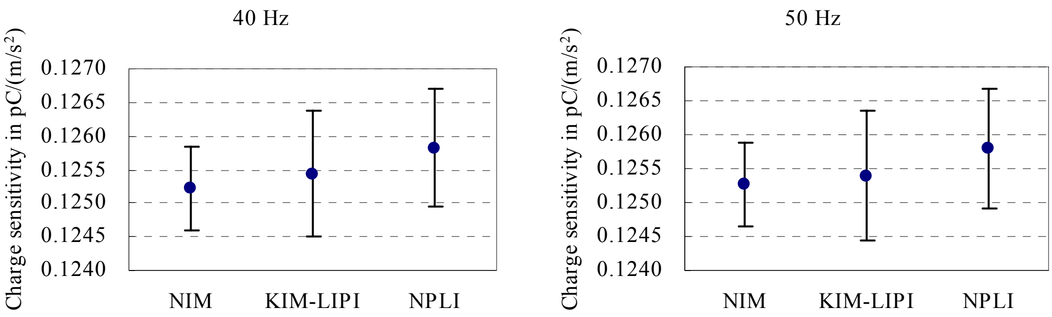


Fig. 1: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 40 Hz and 50 Hz excitation frequency with error bars representing the expanded uncertainty ($k = 2$)

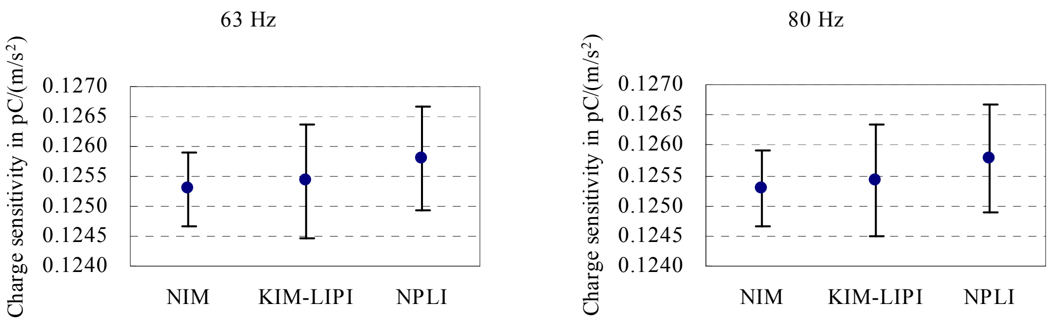


Fig. 2: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 63 Hz and 80 Hz excitation frequency with error bars representing the expanded uncertainty ($k = 2$)

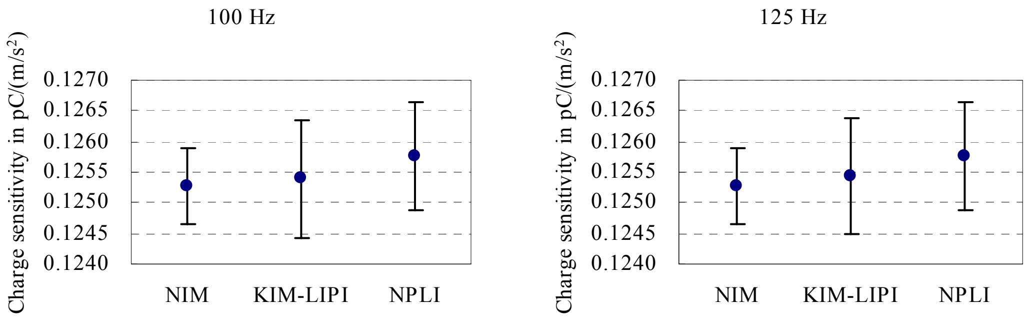


Fig. 3: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 100 Hz and 125 Hz excitation frequency with error bars representing the expanded uncertainty ($k = 2$)

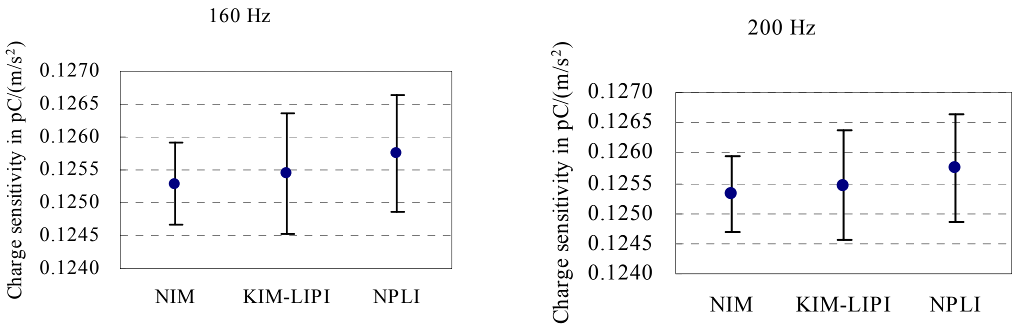


Fig. 4: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 160 Hz and 200 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

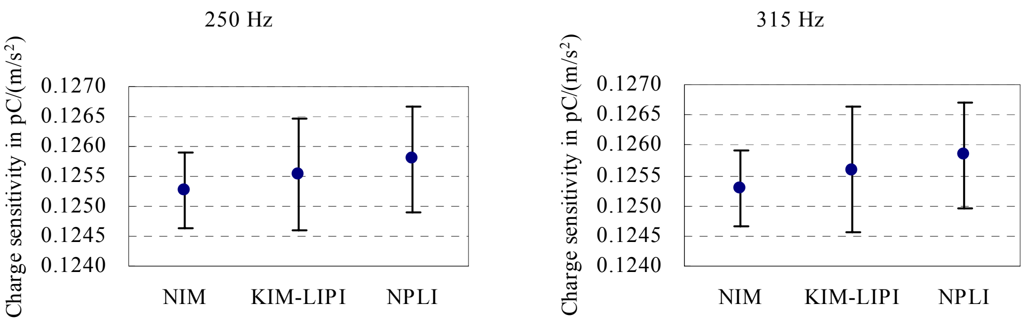


Fig. 5: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 250 Hz and 315 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

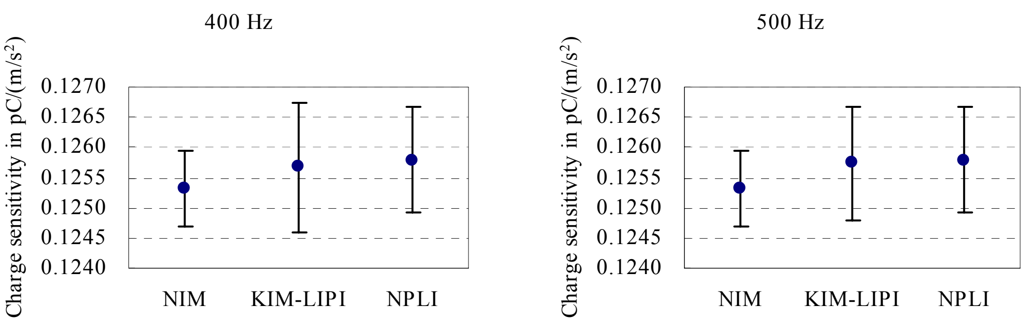


Fig. 6: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 400 Hz and 500 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

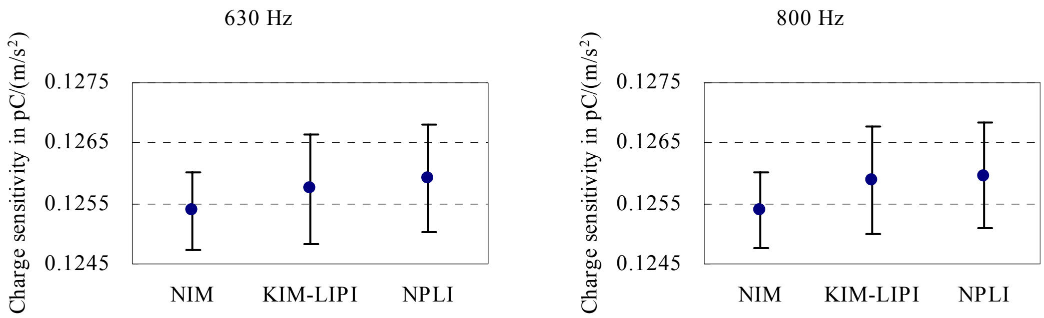


Fig. 7: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 630 Hz and 800 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

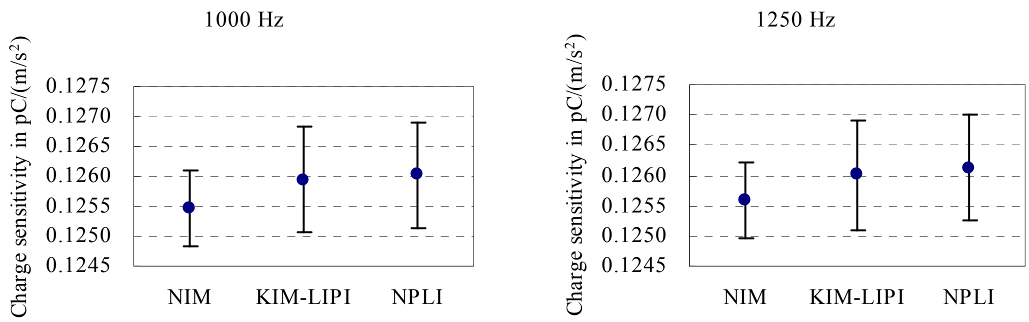


Fig. 8: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 1000 Hz and 1250 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

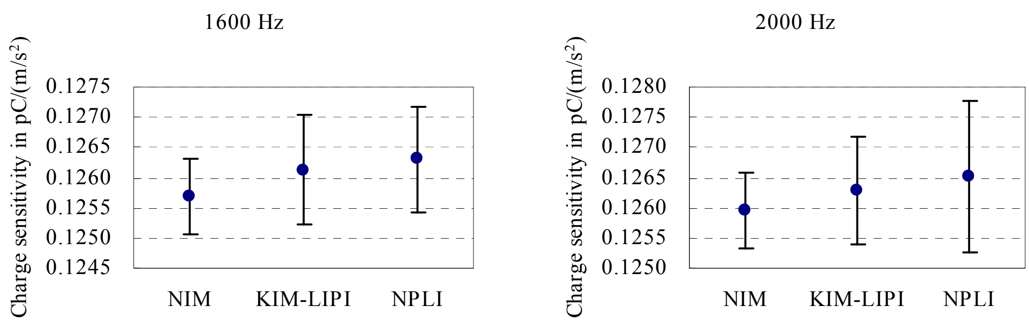


Fig. 9: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 1600 Hz and 2000 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

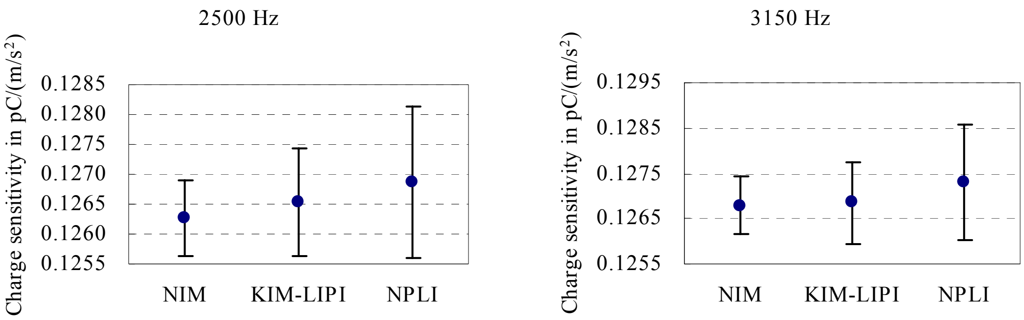


Fig. 10: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 2500 Hz and 3150 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

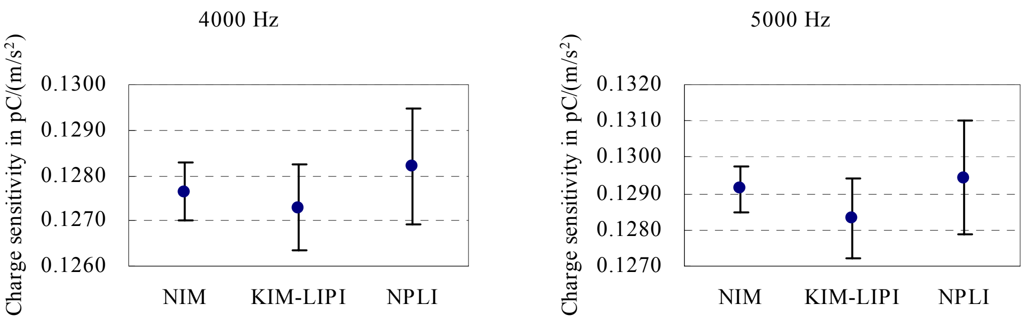


Fig. 11: Charge sensitivity of the SE transducer in pC/(m/s²) reported by the participants for 4000 Hz and 5000 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

### 7.2.2 Results of the Back-to-Back Accelerometer SN 2440139

Table 6: reported calibration results in pC/(m/s²) of the participants for the BB transducer with expanded relative uncertainty ($k$ = 2) in %

| | NIM | | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|
| frequency in Hz | $S_{qa}$ in pC/ (m/s²) | rel.exp. unc. in % | $S_{qa}$ in pC/ (m/s²) | rel.exp. unc. in % | $S_{qa}$ in pC/ (m/s²) | rel.exp. unc. in % |
| 40 | 0.1279 | 0.5 | 0.1275 | 0.69 | 0.1285 | 0.7 |
| 50 | 0.1279 | 0.5 | 0.1275 | 0.68 | 0.1285 | 0.7 |
| 63 | 0.1279 | 0.5 | 0.1276 | 0.68 | 0.1284 | 0.7 |
| 80 | 0.1279 | 0.5 | 0.1276 | 0.68 | 0.1284 | 0.7 |
| 100 | 0.1280 | 0.5 | 0.1277 | 0.68 | 0.1284 | 0.7 |
| 125 | 0.1280 | 0.5 | 0.1278 | 0.69 | 0.1284 | 0.7 |
| 160 | 0.1280 | 0.5 | 0.1278 | 0.68 | 0.1284 | 0.7 |
| 200 | 0.1280 | 0.5 | 0.1279 | 0.69 | 0.1284 | 0.7 |
| 250 | 0.1280 | 0.5 | 0.1279 | 0.71 | 0.1284 | 0.7 |
| 315 | 0.1279 | 0.5 | 0.1279 | 0.74 | 0.1285 | 0.7 |
| 400 | 0.1281 | 0.5 | 0.1279 | 0.71 | 0.1285 | 0.7 |
| 500 | 0.1281 | 0.5 | 0.1281 | 0.77 | 0.1284 | 0.7 |
| 630 | 0.1280 | 0.5 | 0.1281 | 0.74 | 0.1285 | 0.7 |
| 800 | 0.1281 | 0.5 | 0.1282 | 0.72 | 0.1285 | 0.7 |
| 1000 | 0.1281 | 0.5 | 0.1283 | 0.72 | 0.1286 | 0.7 |
| 1250 | 0.1282 | 0.5 | 0.1283 | 0.73 | 0.1287 | 0.7 |
| 1600 | 0.1283 | 0.5 | 0.1283 | 0.71 | 0.1288 | 0.7 |
| 2000 | 0.1284 | 0.5 | 0.1287 | 0.69 | 0.1290 | 1.0 |
| 2500 | 0.1286 | 0.5 | 0.1293 | 0.77 | 0.1293 | 1.0 |
| 3150 | 0.1291 | 0.5 | 0.1296 | 0.74 | 0.1299 | 1.0 |
| 4000 | 0.1296 | 0.5 | 0.1308 | 0.69 | 0.1305 | 1.0 |
| 5000 | 0.1305 | 0.5 | 0.1313 | 0.80 | 0.1315 | 1.2 |

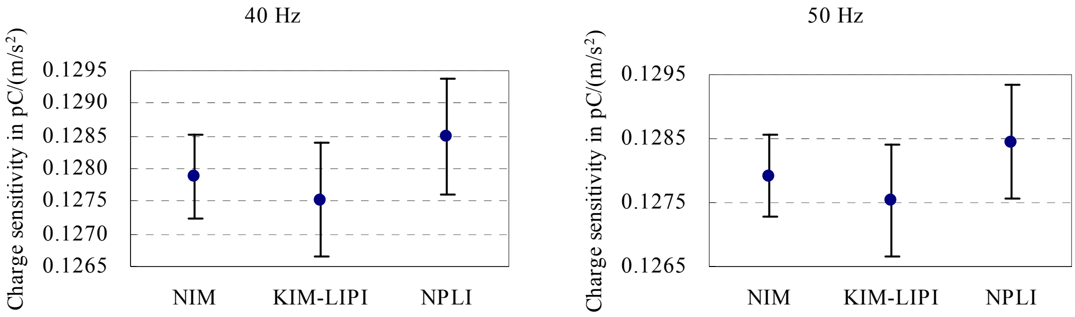


Fig. 12: Charge sensitivity of the BB transducer in pC/(m/s²) reported by the participants for 40 Hz and 50 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

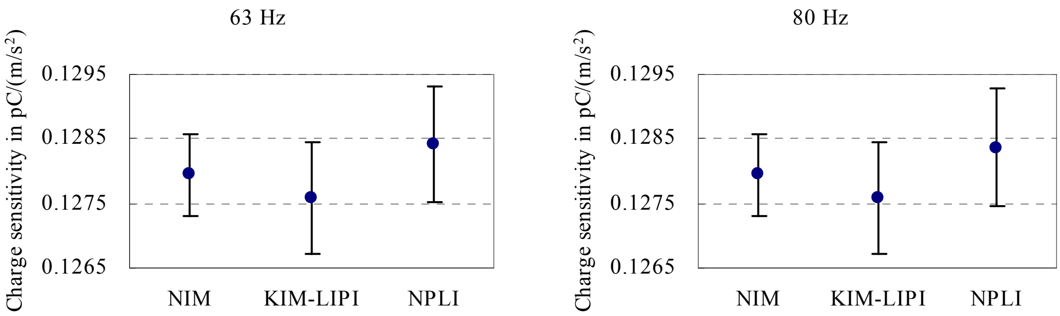


Fig. 13: Charge sensitivity of the BB transducer in pC/(m/s²) reported by the participants for 63 Hz and 80 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

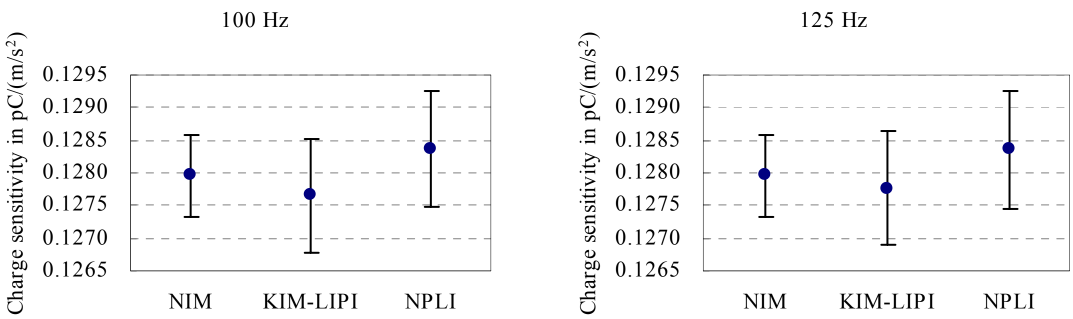


Fig. 14: Charge sensitivity of the BB transducer in pC/(m/s²) reported by the participants for 100 Hz and 125 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

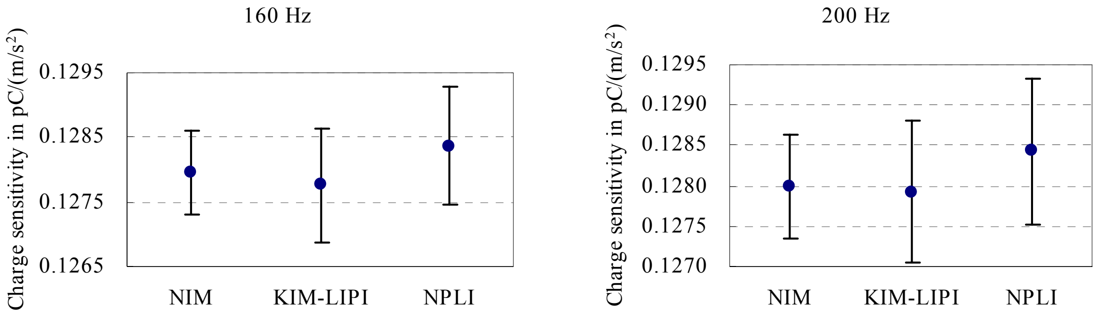


Fig. 15: Charge sensitivity of the BB transducer in pC/(m/s²) reported by the participants for 160 Hz and 200 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

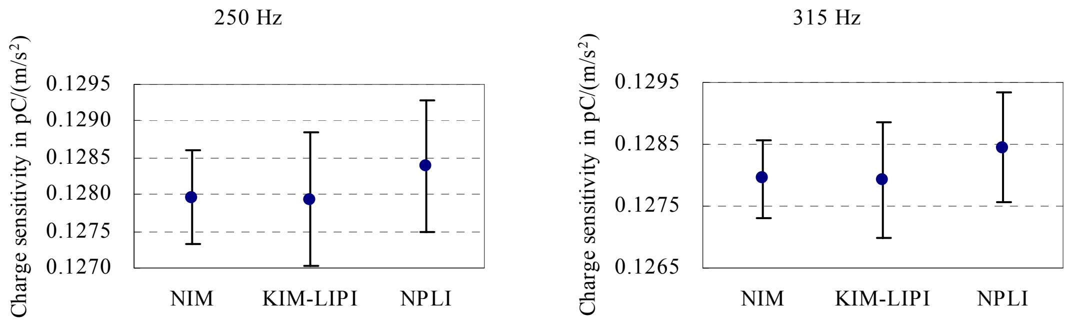


Fig. 16: Charge sensitivity of the BB transducer in pC/(m/s²) reported by the participants for 250 Hz and 315 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

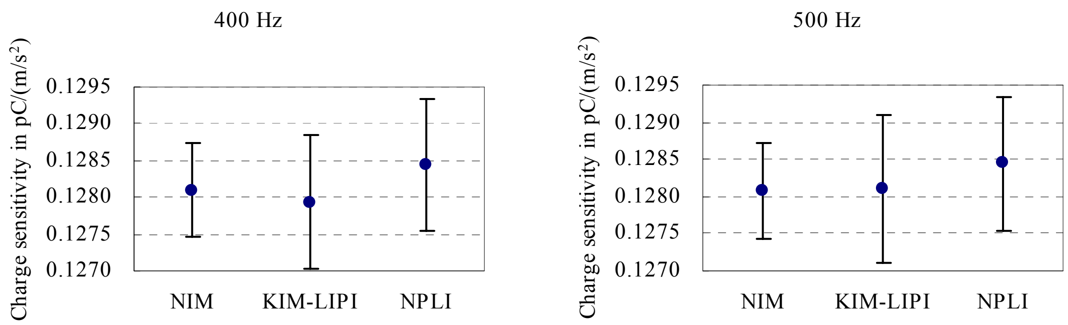


Fig. 17: Charge sensitivity of the BB transducer in pC/(m/s²) reported by the participants for 400 Hz and 500 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

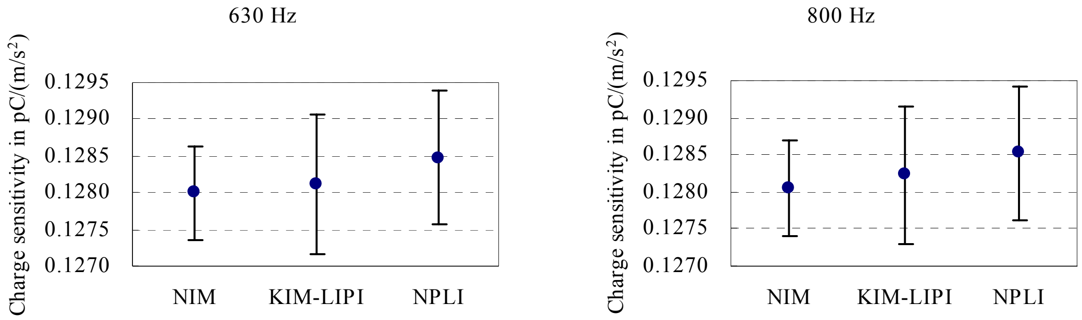


Fig. 18: Charge sensitivity of the BB transducer in pC/(m/s²) reported by the participants for 630 Hz and 800 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

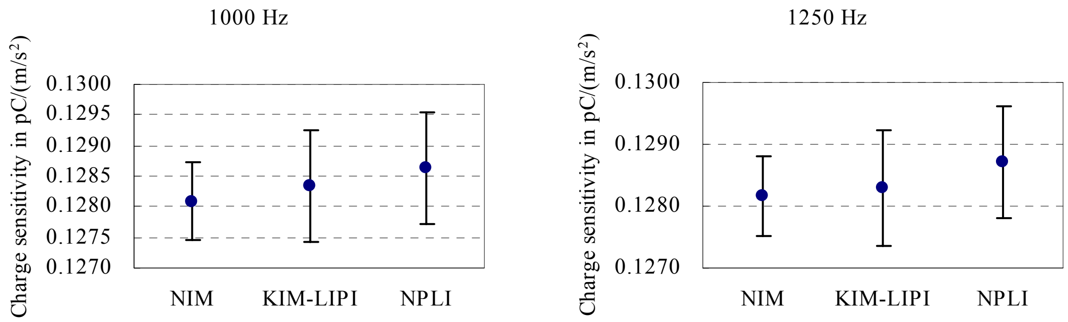


Fig. 19: Charge sensitivity of the BB transducer in pC/(m/s²) reported by the participants for 1000 Hz and 1250 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

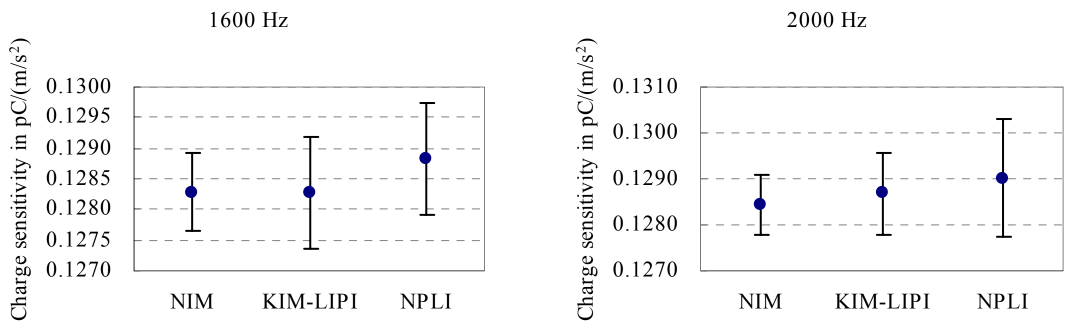


Fig. 20: Charge sensitivity of the BB transducer in pC/(m/s²) reported by the participants for 1600 Hz and 2000 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

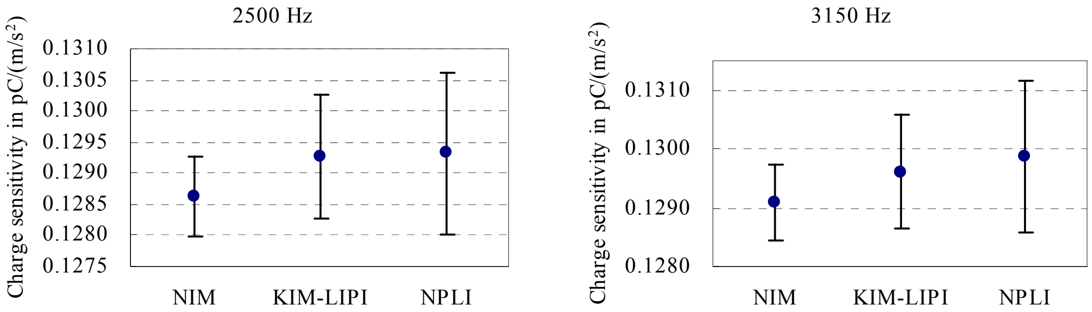


Fig. 21: Charge sensitivity of the BB transducer in pC/(m/s²) reported by the participants for 2500 Hz and 3150 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

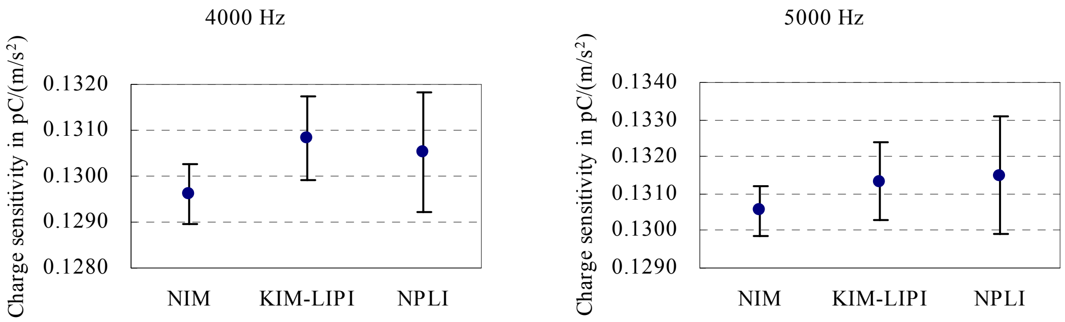


Fig. 22: Charge sensitivity of the BB transducer in pC/(m/s²) reported by the participants for 4000 Hz and 5000 Hz excitation frequency with error bars representing the expanded uncertainty ($k$ = 2)

## 7.3 Degrees of Equivalence between participants

In order to compare the individual results of the participating laboratories of this comparison with one another, the degrees of equivalence (DoE) of pairs of results with respect to a certain frequency were calculated. These DoE are each a pair of values of the difference $D_{ij}$ between the respective participants i and j and the combined expanded uncertainty $U_{ij}$ of this difference. These values are calculated for each frequency according to:

$$D_{ij} = x_i - x_j \tag{1}$$

$$U_{ij} = k \cdot \sqrt{u^2(x_i) + u^2(x_j)} \tag{2}$$

with a coverage factor of $k = 2$.

### 7.3.1 Tables of DoE between participants for the SE

Table 7: degrees of equivalence between the participants for the SE at 40 Hz and 50 Hz

| 40 Hz | KIM-LIPI | | NPLI | | 50 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 2.1 | 11.3 | 5.9 | 10.8 | NIM | 1.3 | 11.4 | 5.4 | 10.8 |
| KIM-LIPI | | | 3.8 | 12.9 | KIM-LIPI | | | 4.1 | 13.0 |

Table 8: degrees of equivalence between the participants for the SE at 63 Hz and 80 Hz

| 63 Hz | KIM-LIPI | | NPLI | | 80 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 1.4 | 11.4 | 5.2 | 10.8 | NIM | 1.5 | 11.2 | 5.1 | 10.8 |
| KIM-LIPI | | | 3.8 | 13.0 | KIM-LIPI | | | 3.6 | 12.8 |

Table 9: degrees of equivalence between the participants for the SE at 100 Hz and 125 Hz

| 100 Hz | KIM-LIPI | | NPLI | | 125 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 1.2 | 11.5 | 4.9 | 10.8 | NIM | 1.5 | 11.3 | 4.8 | 10.8 |
| KIM-LIPI | | | 3.7 | 13.1 | KIM-LIPI | | | 3.3 | 12.9 |

Table 10: degrees of equivalence between the participants for the SE at 160 Hz and 200 Hz

| 160 Hz | KIM-LIPI | | NPLI | | 200 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 1.6 | 11.1 | 4.6 | 10.8 | NIM | 1.5 | 11.0 | 4.4 | 10.8 |
| KIM-LIPI | | | 3.0 | 12.7 | KIM-LIPI | | | 2.9 | 12.6 |

Table 11: degrees of equivalence between the participants for the SE at 250 Hz and 315 Hz

| 250 Hz | KIM-LIPI | | NPLI | | 315 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i \rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i \rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j \downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j \downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 2.6 | 11.2 | 5.2 | 10.8 | NIM | 3.2 | 12.2 | 5.5 | 10.8 |
| KIM-LIPI | | | 2.6 | 12.8 | KIM-LIPI | | | 2.3 | 13.6 |

Table 12: degrees of equivalence between the participants for the SE at 400 Hz and 500 Hz

| 400 Hz | KIM-LIPI | | NPLI | | 500 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i \rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i \rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j \downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j \downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 3.6 | 12.4 | 4.8 | 10.8 | NIM | 4.1 | 11.2 | 4.6 | 10.8 |
| KIM-LIPI | | | 1.2 | 13.8 | KIM-LIPI | | | 0.5 | 12.8 |

Table 13: degrees of equivalence between the participants for the SE at 630 Hz and 800 Hz

| 630 Hz | KIM-LIPI | | NPLI | | 800 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i \rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i \rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j \downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j \downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 3.7 | 11.0 | 5.4 | 10.8 | NIM | 5.0 | 10.9 | 5.6 | 10.8 |
| KIM-LIPI | | | 1.6 | 12.6 | KIM-LIPI | | | 0.7 | 12.6 |

Table 14: degrees of equivalence between the participants for the SE at 1000 Hz and 1250 Hz

| 1000 Hz | KIM-LIPI | | NPLI | | 1250 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i \rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i \rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j \downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j \downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 4.7 | 10.8 | 5.5 | 10.8 | NIM | 4.3 | 11.0 | 5.5 | 10.8 |
| KIM-LIPI | | | 0.8 | 12.5 | KIM-LIPI | | | 1.2 | 12.7 |

Table 15: degrees of equivalence between the participants for the SE at 1600 Hz and 2000 Hz

| 1600 Hz | KIM-LIPI | | NPLI | | 2000 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 4.4 | 11.0 | 6.3 | 10.8 | NIM | 3.4 | 11.0 | 5.8 | 14.1 |
| KIM-LIPI | | | 1.8 | 12.7 | KIM-LIPI | | | 2.3 | 15.5 |

Table 16: degrees of equivalence between the participants for the SE at 2500 Hz and 3150 Hz

| 2500 Hz | KIM-LIPI | | NPLI | | 3150 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 2.8 | 11.0 | 6.0 | 14.2 | NIM | 0.6 | 11.0 | 5.0 | 14.2 |
| KIM-LIPI | | | 3.2 | 15.5 | KIM-LIPI | | | 4.3 | 15.6 |

Table 17: degrees of equivalence between the participants for the SE at 4000 Hz and 5000 Hz

| 4000 Hz | KIM-LIPI | | NPLI | | 5000 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | -3.4 | 11.5 | 5.5 | 14.3 | NIM | -8.1 | 12.6 | 3.1 | 16.8 |
| KIM-LIPI | | | 8.9 | 16.0 | KIM-LIPI | | | 11.3 | 18.9 |

### 7.3.2 Tables of DoE between participants for the BB

Table 18: degrees of equivalence between the participants for the BB at 40 Hz and 50 Hz

| 40 Hz | KIM-LIPI | | NPLI | | 50 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | -3.5 | 10.9 | 6.2 | 11.0 | NIM | -3.8 | 10.8 | 5.4 | 11.0 |
| KIM-LIPI | | | 9.7 | 12.6 | KIM-LIPI | | | 9.2 | 12.5 |

Table 19: degrees of equivalence between the participants for the BB at 63 Hz and 80 Hz

| 63 Hz | KIM-LIPI | | NPLI | | 80 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | -3.6 | 10.8 | 4.9 | 11.0 | NIM | -3.5 | 10.8 | 4.3 | 11.0 |
| KIM-LIPI | | | 8.4 | 12.5 | KIM-LIPI | | | 7.8 | 12.5 |

Table 20: degrees of equivalence between the participants for the BB at 100 Hz and 125 Hz

| 100 Hz | KIM-LIPI | | NPLI | | 125 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | -3.0 | 10.8 | 4.1 | 11.0 | NIM | -1.9 | 10.9 | 4.0 | 11.0 |
| KIM-LIPI | | | 7.1 | 12.5 | KIM-LIPI | | | 5.9 | 12.6 |

Table 21: degrees of equivalence between the participants for the BB at 160 Hz and 200 Hz

| 160 Hz | KIM-LIPI | | NPLI | | 200 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | -2.0 | 10.8 | 4.2 | 11.0 | NIM | -0.6 | 10.9 | 4.5 | 11.0 |
| KIM-LIPI | | | 6.2 | 12.5 | KIM-LIPI | | | 5.1 | 12.6 |

Table 22: degrees of equivalence between the participants for the BB at 250 Hz and 315 Hz

| 250 Hz | KIM-LIPI | | NPLI | | 315 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | -0.2 | 11.1 | 4.2 | 11.0 | NIM | -0.2 | 11.4 | 5.1 | 11.0 |
| KIM-LIPI | | | 4.4 | 12.8 | KIM-LIPI | | | 5.3 | 13.1 |

Table 23: degrees of equivalence between the participants for the BB at 400 Hz and 500 Hz

| 400 Hz | KIM-LIPI | | NPLI | | 500 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | -1.6 | 11.1 | 3.6 | 11.0 | NIM | 0.3 | 11.8 | 3.7 | 11.0 |
| KIM-LIPI | | | 5.2 | 12.8 | KIM-LIPI | | | 3.4 | 13.3 |

Table 24: degrees of equivalence between the participants for the BB at 630 Hz and 800 Hz

| 630 Hz | KIM-LIPI | | NPLI | | 800 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 1.3 | 11.4 | 4.9 | 11.0 | NIM | 1.8 | 11.2 | 4.8 | 11.0 |
| KIM-LIPI | | | 3.6 | 13.1 | KIM-LIPI | | | 3.0 | 12.9 |

Table 25: degrees of equivalence between the participants for the BB at 1000 Hz and 1250 Hz

| 1000 Hz | KIM-LIPI | | NPLI | | 1250 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 2.5 | 11.2 | 5.4 | 11.0 | NIM | 1.5 | 11.3 | 5.7 | 11.1 |
| KIM-LIPI | | | 3.0 | 12.9 | KIM-LIPI | | | 4.2 | 13.0 |

Table 26: degrees of equivalence between the participants for the BB at 1600 Hz and 2000 Hz

| 1600 Hz | KIM-LIPI | | NPLI | | 2000 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 0.0 | 11.1 | 5.5 | 11.1 | NIM | 2.4 | 11.0 | 5.7 | 14.4 |
| KIM-LIPI | | | 5.5 | 12.8 | KIM-LIPI | | | 3.3 | 15.7 |

Table 27: degrees of equivalence between the participants for the BB at 2500 Hz and 3150 Hz

| 2500 Hz | KIM-LIPI | | NPLI | | 3150 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 6.5 | 11.9 | 7.0 | 14.4 | NIM | 5.4 | 11.6 | 8.0 | 14.5 |
| KIM-LIPI | | | 0.5 | 16.3 | KIM-LIPI | | | 2.6 | 16.1 |

Table 28: degrees of equivalence between the participants for the BB at 4000 Hz and 5000 Hz

| 4000 Hz | KIM-LIPI | | NPLI | | 5000 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ | $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | | $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | | |
| NIM | 12.2 | 11.1 | 9.2 | 14.6 | NIM | 7.8 | 12.4 | 9.6 | 17.1 |
| KIM-LIPI | | | -3.1 | 15.9 | KIM-LIPI | | | 1.9 | 19.0 |

# 8 Linking

## 8.1 The Linking Procedure

In contrast to the linking procedure applied for APMP.AUV.V-K1 comparison, the equivalence between the results of this current APMP key comparison and the CCAUV.V-K1 was realized via an additive linking procedure. Since the pilot lab of this APMP key comparison, the NIM, had taken part in the subsequent CCAUV.V-K1.1, which in turn is linked to CCAUV.V-K1, the chain of linking can be established using the NIM's degrees of equivalence and their associated uncertainties, already published, relative to the CCAUV.V-K1 key comparison reference value.

The philosophy for this approach was to shift the results of the single linking laboratory (NIM) in APMP.AUV.V-K1.2 onto its linked results in the CCAUV.V-K1 in order to compensate for the different sensitivities of the devices under test in the two key comparisons. This shift together with the associated uncertainty is then applied as an additive term to all other participants in order to make their results comparable to those of all participants of the CCAUV.V-K1 comparison. This approach corresponds to that taken in [4].

Let $\delta(f)$ be the difference between the results of the linking lab in APMP.AUV.V-K1.2 $x_{NIM}^{APMP}(f)$ and its results in CCAUV.V-K1 $x_{NIM}^{CC}(f)$ for any single frequency $f$

$$\delta(f) = x_{NIM}^{CC}(f) - x_{NIM}^{APMP}(f) \tag{3}$$

Then the uncertainty of this difference is:

$$u_{\delta}^{2} = (u_{NIM}^{CC})^2 + (u_{NIM}^{APMP})^2 \tag{4}$$

The covariance of the different results of the linking lab is considered negligible in the above equation.

The degree of equivalence of a participant $i$ of this APMP key comparison with reference to a participant $j$ of the CCAUV.V-K1 comparison is then given by the two values, the difference $d_{ij}$ and the uncertainty $u_{ij}$ with

$$d_{ij} = x_i^{APMP} + \delta - x_j^{CC} \tag{5}$$

$$u_{ij}^{2} = (u_i^{APMP})^2 + u_{\delta}^{2} + (u_j^{CC})^2 \tag{6}$$

The degree of equivalence with respect to the CCAUV.V-K1 reference value (RV) is given by

$$d_i = x_i^{APMP} + \delta - x_{RV}^{CC} \tag{7}$$

$$u_i^{2} = (u_i^{APMP})^2 + u_{\delta}^{2} + (u_{RV}^{CC})^2 \tag{8}$$

provided that laboratory $i$ is not the linking laboratory.

## 8.2 Degrees of Equivalence with the CCAUV Reference Value

In order to perform a comparison of the APMP participants with the key comparison reference value (KCRV) of the CCAUV.V-K1 comparison, the differences between the linked results and their uncertainty is calculated. This gives the DoE relative to the KCRV. The following tables document this for the two transducers used in this comparison.

Table 29: degrees of equivalence of the participants with respect to the KCRV of CCAUV.V-K1 for the SE transducer

| frequency in Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|
| | $D_i$ | $U(D_i)$ | $D_i$ | $U(D_i)$ |
| | pC/(m/s²)·$10^{-4}$ | | pC/(m/s²)·$10^{-4}$ | |
| 40 | -0.1 | 13.1 | 3.7 | 12.7 |
| 80 | -0.8 | 13.0 | 2.8 | 12.7 |
| 160 | -0.2 | 11.5 | 2.8 | 11.2 |
| 800 | 3.2 | 12.8 | 3.8 | 12.7 |
| 2000 | 2.9 | 12.8 | 5.3 | 15.6 |

No DoE for 5000 Hz is available, because there was no reference value calculated beyond 2000 Hz for the single ended accelerometer in CCAUV.V-K1.

Table 30: degrees of equivalence of the participants with respect to the KCRV of CCAUV.V-K1 for the BB transducer

| frequency in Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|
| | $D_i$ | $U(D_i)$ | $D_i$ | $U(D_i)$ |
| | pC/(m/s²)·$10^{-4}$ | | pC/(m/s²)·$10^{-4}$ | |
| 40 | -3.8 | 12.7 | 5.9 | 12.8 |
| 80 | -2.9 | 12.6 | 4.9 | 12.8 |
| 160 | -1.8 | 11.2 | 4.4 | 11.4 |
| 800 | 1.0 | 13.0 | 4.0 | 12.8 |
| 2000 | 5.1 | 12.8 | 8.4 | 15.8 |
| 5000 | 11.1 | 14.1 | 12.9 | 18.3 |

## 8.3 Degrees of Equivalence with the participants of CCAUV.V-K1

A number of participants in the CCAUV.V-K1 comparison have changed the name of their laboratory in the intervening years. These are marked with an asterisk * in the tables that follow. The appropriate laboratory designations are given in the key comparison database (KCDB).

### 8.3.1 Tables of DoE relative to the participants of CCAUV.V-K1 for the SE

Table 31: degrees of equivalence of the participants with respect to the participants of CCAUV.V-K1 for the SE transducer at 40 Hz

| 40 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | $pC/(m/s^2)\cdot 10^{-4}$ | | $pC/(m/s^2)\cdot 10^{-4}$ | |
| PTB | -0.5 | 13.1 | 3.3 | 12.7 |
| BNM-CEST* | -1.3 | 13.5 | 2.5 | 13.1 |
| CSIRO-NML* | -1.3 | 13.3 | 2.5 | 12.8 |
| CMI | 2.2 | 13.4 | 6.0 | 13.0 |
| CSIR-NML* | -6.3 | 13.9 | -2.5 | 13.4 |
| CENAM | 0.4 | 13.5 | 4.2 | 13.1 |
| NRC | 2.1 | 13.2 | 5.9 | 12.8 |
| KRISS | 2.5 | 13.3 | 6.3 | 12.9 |
| NMIJ | 4.4 | 13.4 | 8.2 | 13.0 |
| VNIIM | 6.5 | 13.3 | 10.3 | 12.9 |
| NIST | -6.3 | 13.2 | -2.5 | 12.8 |
| NMi-VSL* | -0.8 | 14.4 | 3.0 | 12.8 |

Table 32: degrees of equivalence of the participants with respect to the participants of CCAUV.V-K1 for the SE transducer at 80 Hz

| 80 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | pC/(m/s²)·$10^{-4}$ | |
| PTB | -1.1 | 13.0 | 2.5 | 12.7 |
| BNM-CEST* | -4.0 | 13.4 | -0.4 | 13.1 |
| CSIRO-NML* | 0.0 | 13.1 | 3.6 | 12.8 |
| CMI | 0.5 | 13.3 | 4.1 | 13.0 |
| CSIR-NML* | -3.0 | 13.8 | 0.6 | 13.4 |
| CENAM | -0.5 | 13.4 | 3.1 | 13.1 |
| NRC | -4.7 | 13.1 | -1.1 | 12.8 |
| KRISS | 1.7 | 13.2 | 5.3 | 12.9 |
| NMIJ | 1.2 | 13.4 | 4.8 | 13.0 |
| VNIIM | 3.2 | 13.2 | 6.8 | 12.9 |
| NIST | -1.0 | 13.1 | 2.6 | 12.8 |
| NMi-VSL* | 0.9 | 13.1 | 4.5 | 12.8 |

Table 33: degrees of equivalence of the participants with respect to the participants of CCAUV.V-K1 for the SE transducer at 160 Hz

| 160 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | pC/(m/s²)·$10^{-4}$ | |
| PTB | -0.5 | 11.5 | 2.5 | 11.2 |
| BNM-CEST* | -3.3 | 11.9 | -0.3 | 11.6 |
| CSIRO-NML* | 0.7 | 11.6 | 3.7 | 11.4 |
| CMI | -0.3 | 11.8 | 2.7 | 11.6 |
| CSIR-NML* | 2.7 | 11.9 | 5.7 | 11.6 |
| CENAM | 1.1 | 11.9 | 4.1 | 11.6 |
| NRC | -1.7 | 11.6 | 1.3 | 11.4 |
| KRISS | 1.7 | 11.7 | 4.7 | 11.4 |
| NMIJ | 1.9 | 11.8 | 4.9 | 11.5 |
| VNIIM | 1.5 | 11.8 | 4.5 | 11.5 |
| NIST | -1.3 | 11.6 | 1.7 | 11.4 |
| NMi-VSL* | 0.2 | 11.7 | 3.2 | 11.4 |

Table 34: degrees of equivalence of the participants with respect to the participants of CCAUV.V-K1 for the SE transducer at 800 Hz

| 800 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | $pC/(m/s^2)\cdot 10^{-4}$ | | $pC/(m/s^2)\cdot 10^{-4}$ | |
| PTB | 3.5 | 12.8 | 4.1 | 12.7 |
| BNM-CEST* | 0.1 | 13.2 | 0.7 | 13.1 |
| CSIRO-NML* | 4.1 | 12.9 | 4.7 | 12.8 |
| CMI | 1.1 | 13.5 | 1.7 | 13.4 |
| CSIR-NML* | -0.9 | 13.3 | -0.3 | 13.3 |
| CENAM | 2.8 | 13.2 | 3.4 | 13.1 |
| NRC | 0.7 | 13.1 | 1.3 | 13.0 |
| KRISS | 5.1 | 13.0 | 5.7 | 12.9 |
| NMIJ | 6.1 | 13.5 | 6.7 | 13.4 |
| VNIIM | 7.9 | 13.1 | 8.5 | 13.0 |
| NIST | 1.1 | 13.9 | 1.7 | 13.8 |
| NMi-VSL* | -3.0 | 13.0 | -2.4 | 13.0 |

Table 35: degrees of equivalence of the participants with respect to the participants of CCAUV.V-K1 for the SE transducer at 2000 Hz

| 2000 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|
| $i \rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j \downarrow$ | pC/(m/s²)·$10^{-4}$ | | pC/(m/s²)·$10^{-4}$ | |
| PTB | 2.9 | 12.8 | 5.3 | 15.6 |
| BNM-CEST* | 2.7 | 13.2 | 5.1 | 15.9 |
| CSIRO-NML* | 3.7 | 12.9 | 6.1 | 15.7 |
| CMI | 1.2 | 13.4 | 3.6 | 16.1 |
| CSIR-NML* | -1.3 | 13.4 | 1.1 | 16.1 |
| CENAM | 2.2 | 13.8 | 4.6 | 16.4 |
| NRC | 6.0 | 13.5 | 8.4 | 16.2 |
| KRISS | 6.9 | 13.2 | 9.3 | 15.9 |
| NMIJ | -8.4 | 13.2 | -6.0 | 15.9 |
| VNIIM | 10.5 | 13.1 | 12.9 | 15.9 |
| NIST | 4.7 | 13.5 | 7.1 | 16.2 |
| NMi-VSL* | -2.4 | 14.3 | 0.0 | 16.9 |

### 8.3.2 Tables of DoE relative to the participants of CCAUV.V-K1 for the BB

Table 36: degrees of equivalence of the participants with respect to the participants of CCAUV.V-K1 for the BB transducer at 40 Hz

| 40 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | in pC/(m/s²)·$10^{-4}$ | |
| PTB | -4.5 | 12.7 | 5.2 | 12.8 |
| BNM-CEST* | -5.0 | 13.1 | 4.7 | 13.2 |
| CSIRO-NML* | -5.0 | 12.9 | 4.7 | 12.9 |
| CMI | -2.9 | 13.0 | 6.8 | 13.1 |
| CSIR-NML* | -13.0 | 13.9 | -3.3 | 13.5 |
| CENAM | -2.1 | 13.1 | 7.6 | 13.2 |
| NRC | -2.7 | 12.8 | 7.0 | 12.9 |
| KRISS | -2.7 | 12.9 | 7.0 | 13.0 |
| NMIJ | -0.9 | 12.9 | 8.8 | 13.2 |
| VNIIM | 1.6 | 12.9 | 11.3 | 13.1 |
| NIST | -5.0 | 12.8 | 4.7 | 12.9 |
| NMi-VSL* | -3.0 | 12.8 | 6.7 | 12.9 |

Table 37: degrees of equivalence of the participants with respect to the participants of CCAUV.V-K1 for the BB transducer at 80 Hz

| 80 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|
| $i \rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j \downarrow$ | pC/(m/s²)·$10^{-4}$ | | pC/(m/s²)·$10^{-4}$ | |
| PTB | -3.3 | 12.6 | 4.5 | 12.8 |
| BNM-CEST* | -5.1 | 13.0 | 2.7 | 13.2 |
| CSIRO-NML* | -3.1 | 12.7 | 4.7 | 12.9 |
| CMI | -3.1 | 12.9 | 4.7 | 13.1 |
| CSIR-NML* | 1.9 | 13.3 | 9.7 | 13.5 |
| CENAM | -1.8 | 13.0 | 6.0 | 13.2 |
| NRC | -6.8 | 12.7 | 1.0 | 12.9 |
| KRISS | -1.8 | 12.8 | 6.0 | 13.0 |
| NMIJ | -2.7 | 12.9 | 5.1 | 13.2 |
| VNIIM | 1.7 | 12.8 | 9.5 | 13.0 |
| NIST | -2.1 | 12.7 | 5.7 | 12.9 |
| NMi-VSL* | -1.2 | 12.7 | 6.6 | 12.9 |

Table 38: degrees of equivalence of the participants with respect to the participants of CCAUV.V-K1 for the BB transducer at 160 Hz

| 160 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | pC/(m/s²)·$10^{-4}$ | |
| PTB | -1.9 | 11.2 | 4.3 | 11.4 |
| BNM-CEST* | -2.5 | 11.6 | 3.7 | 11.8 |
| CSIRO-NML* | -1.5 | 11.3 | 4.7 | 11.5 |
| CMI | -1.5 | 11.5 | 4.7 | 11.7 |
| CSIR-NML* | -1.5 | 11.6 | 4.7 | 11.8 |
| CENAM | -1.5 | 11.6 | 4.7 | 11.8 |
| NRC | -3.0 | 11.3 | 3.2 | 11.5 |
| KRISS | -0.4 | 11.4 | 5.8 | 11.6 |
| NMIJ | -1.5 | 11.5 | 4.7 | 11.7 |
| VNIIM | -3.7 | 11.4 | 2.5 | 11.7 |
| NIST | -0.5 | 11.3 | 5.7 | 11.5 |
| NMi-VSL* | -1.5 | 11.4 | 4.7 | 11.6 |

Table 39: degrees of equivalence of the participants with respect to the participants of CCAUV.V-K1 for the BB transducer at 800 Hz

| 800 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | $pC/(m/s^2)\cdot 10^{-4}$ | | $pC/(m/s^2)\cdot 10^{-4}$ | |
| PTB | 1.4 | 13.0 | 4.4 | 12.8 |
| BNM-CEST* | -1.7 | 13.4 | 1.3 | 13.2 |
| CSIRO-NML* | 1.3 | 13.1 | 4.3 | 13.0 |
| CMI | 1.3 | 13.4 | 4.3 | 13.3 |
| CSIR-NML* | -0.7 | 13.4 | 2.3 | 13.2 |
| CENAM | 1.6 | 13.4 | 4.6 | 13.2 |
| NRC | -0.4 | 13.3 | 2.6 | 13.1 |
| KRISS | 1.8 | 13.2 | 4.8 | 13.0 |
| NMIJ | 2.2 | 13.4 | 5.2 | 13.2 |
| VNIIM | -2.5 | 13.3 | 0.5 | 13.1 |
| NIST | 4.3 | 14.1 | 7.3 | 13.9 |
| NMi-VSL* | -3.8 | 13.4 | -0.8 | 13.2 |

Table 40: degrees of equivalence of the participants with respect to the participants of CCAUV.V-K1 for the BB transducer at 2000 Hz

| 2000 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|
| $i\rightarrow$ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j\downarrow$ | pC/(m/s²)·$10^{-4}$ | | pC/(m/s²)·$10^{-4}$ | |
| PTB | 4.8 | 12.8 | 8.1 | 15.8 |
| BNM-CEST* | 3.4 | 13.1 | 6.7 | 16.1 |
| CSIRO-NML* | 5.4 | 12.9 | 8.7 | 15.9 |
| CMI | 5.8 | 13.1 | 9.1 | 16.1 |
| CSIR-NML* | 5.4 | 13.3 | 8.7 | 16.3 |
| CENAM | 4.3 | 13.7 | 7.6 | 16.6 |
| NRC | 4.4 | 13.4 | 7.7 | 16.4 |
| KRISS | 6.2 | 13.0 | 9.5 | 16.0 |
| NMIJ | 6.2 | 13.1 | 9.5 | 16.1 |
| VNIIM | -12.6 | 13.1 | -9.3 | 16.1 |
| NIST | 9.4 | 13.4 | 12.7 | 16.4 |
| NMi-VSL* | 7.2 | 13.0 | 10.5 | 16.0 |

Table 41: degrees of equivalence of the participants with respect to the participants of CCAUV.V-K1 for the BB transducer at 5000 Hz

| 5000 Hz | KIM-LIPI | | NPLI | |
|---|---|---|---|---|
| $i$→ | $D_{ij}$ | $U_{ij}$ | $D_{ij}$ | $U_{ij}$ |
| $j$↓ | pC/(m/s²)·$10^{-4}$ | | pC/(m/s²)·$10^{-4}$ | |
| PTB | 11.3 | 14.1 | 13.1 | 18.4 |
| BNM-CEST* | - | - | - | - |
| CSIRO-NML* | 9.7 | 14.3 | 11.5 | 18.5 |
| CMI | 11.2 | 14.5 | 13.0 | 18.7 |
| CSIR-NML* | 12.7 | 14.7 | 14.5 | 18.9 |
| CENAM | 11.6 | 14.9 | 13.4 | 19.0 |
| NRC | 11.7 | 15.7 | 13.5 | 19.6 |
| KRISS | 10.1 | 14.3 | 11.9 | 18.5 |
| NMIJ | 11.6 | 16.4 | 13.4 | 20.2 |
| VNIIM | -2.7 | 14.7 | -0.9 | 18.8 |
| NIST | 12.7 | 16.0 | 14.5 | 19.9 |
| NMi-VSL* | 11.8 | 28.2 | 13.6 | 30.5 |

# 9 References

[1] Shing Chen, Hans-Jürgen von Martens, 2001, *Final Report on Regional Key Comparison APMP.AUV.V-K1*, BIPM, 87 pp.

[2] Th. Bruns, 2010, Final report on the CIPM Key Comparison CCAUV.V-K1.1, *Metrologia* **47** *Technical Supplement* 09002, 120 pp.

[3] CIPM, 2003, *Guidelines for CIPM key comparisons*, BIPM, 9 pp.

[4] J. E. Decker, A. G. Steele, R. J. Douglas, 2008, Measurement science and the linking of CIPM and regional key comparisons, *Metrologia*, 2008, **45**, n°2, 223-232.

# Appendix A: Technical Protocol

National Institute of Metrology (NIM)

May 19th, 2009 (participants revised)

Mr. Qiao SUN

# Technical Protocol of the APMP Key Comparison APMP.AUV.V-K1.2

## 1 *Task and Purpose of the Comparison*

In the field of vibration and shock, this regional key comparison is organized in order to compare measurements of sinusoidal linear accelerations in the frequency range from 40Hz to 5 kHz. Moreover, the magnitude of the complex sensitivity calibration and measurement capabilities (CMCs) of the NMIs for accelerometer calibration are to be examined and compared and linked to the CIPM comparison CCAUV.V-K1. It is the task of the comparison to measure the magnitude of the complex sensitivity of two accelerometer standards (two piezoelectric accelerometers of back-to-back type and single-ended type) at different frequencies with acceleration amplitudes as specified in section 4. The results of this APMP KC will, after approval for equivalence, be linked to CCAUV.V-K1 as the foundation for the registration of 'calibration and measurement capabilities' (CMC) in the framework of the CIPM MRA.

The charge sensitivity is calculated as the ratio of the amplitude of the accelerometer output charge to the amplitude of the acceleration at its reference surface. The magnitude of the complex charge sensitivity shall be given in pico coulomb per metre per second squared ($pC/(m/s^2)$) for the different measurement conditions specified in section 4. A calibrated charge amplifier is to be used to measure the output charge of the accelerometer standards, applying appropriate electrical calibration methods.

For the calibration of the accelerometer standards, laser interferometry in compliance with method 1 or method 3 of the international standard ISO 16063-11:1999 has to be applied, in order to cover the entire frequency range.

The reported sensitivities and associated uncertainties will, after approval for equivalence, be then supposed to be used for the calculation of the 'degrees of equivalence' (DoE) between the participating NMIs and the key comparison reference value.

## 2 Pilot Laboratory

Pilot laboratory for this regional key comparison, which has also participated in CCAUV.V.K-1.1, is

Vibration and Shock Section
Mechanics and Acoustics Metrology Division
National Institute of Metrology, P.R. China
BeiSanHuanDongLu 18, ChaoYang District, 100013 Beijing, P.R. China

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

Contact Persons are

| SUN Qiao | LIU Aidong |
|---|---|
| Tel.: +86 10 64524623 | Tel.: +86 10 64524606 |
| e-mail: sunq@nim.ac.cn | e-mail: liuad@nim.ac.cn |
| Fax: +86 10 64218628 | |

## 3 Schedule

The schedule is planned as follows:

| NMIs | Date of receipt of artefacts from the previous participant | Period for calibration | Date of sending the artefacts to the next participant |
|---|---|---|---|
| **NIM** | | 2 weeks | September 20, 2009 |
| **KIM-LIPI** | October 01, 2009 | 4 weeks | October 29, 2009 |
| **NIM** | November 10, 2009 | 2 weeks | November 15, 2009 |
| **NPLI** | November 25, 2009 | 4 weeks | December 23, 2009 |
| **NIM** | January 03, 2010 | 2 weeks | |

**Note:** Date of sending the artefacts to the next participant is tentative. It is scheduled to take about 10 days to send the artefacts to the next participant.

Contact Person of KIM-LIPI is

| Achmad Suwandi | Denny Hermawanto |
|---|---|
| Tel.: +62 21 7560532 ext: 3074 | |
| e-mail: wandhini@yahoo.com | e-mail: d_3_nny@yahoo.com |
| Fax: +62 21 7560568 | |

The delivery address for the set of artifacts :

Indonesian Institute of Sciences, Research Center for Calibration, Instrumentation, and Metrology (Puslit KIM-LIPI)
Kompleks PUSPIPTEK Serpong Tangerang 15314, INDONESIA

Contact Person of NPLI is

| Ashok Kumar | Omkar Sharma |
|---|---|
| +91-11-45608380 | +91-11-45608317 |
| e-mail: akumar@nplindia.ernet.in | e-mail: osharma@nplindia.ernet.in |
| Fax: +91-11-45609310 | |

The delivery address for the set of artifacts :

Director,
National Physical Laboratory
Krishnan Road
New Delhi – 110 012 (India)
Attention: Mr. Omkar Sharma

# 4 *Device under Test and Measurement Conditions*

For the calibration task of this KC a set of two piezoelectric accelerometers will be circulated between the participating laboratories. The individual transducers being a 'sing ended' (SE) type, namely a Brüel & Kjær 8305-001 (SN: 2519436), and a 'back to back' (BB) type, namely a Brüel & Kjær 8305 S (SN: 2440139).

The accelerometers are to be calibrated of their complex charge sensitivity according to those procedures and conditions implemented by the NMI in conformance with ISO

16063-11 which provides magnitude 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 40 Hz to 5 kHz. Specifically the laboratories are supposed to measure at the following frequencies (all values in Hz).

40, 50, 63, 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000.

The charge amplifier (CA) used for the calibration is not provided within the set of artefacts, 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 customers' 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 [1,2,3], simultaneously.

Specific conditions for the measurements of this KC are:

- acceleration amplitudes: a range of 10 $m/s^2$ to 200 $m/s^2$ is admissible.
- ambient temperature and accelerometer temperature during the calibration: (23 ± 2)ºC (actual values to be stated within tolerances of ± 0.3ºC).
- relative humidity: max. 75 %
- mounting torque of the accelerometer: (2.0 ±0.1) N·m

# 5 *Circulation and Transportation*

The transducers are circulated with a measurement period of four weeks provided for each participant. At the beginning and the end of the circulation as well as between two subsequent measurements of any participating laboratory, the transducers are measured at the pilot lab in order to fix reference value and to monitor the stability of the transducers.

The cost of transportation to and from a participating laboratory shall be covered by the participating laboratory. The accelerometers have to be send by an international logistic service providing a tracking system. The transportation has to include an insurance covering a value of 9 000,- € in case the set of accelerometers gets damaged or lost during transportation.

## 6 Measurement and Analysis Instruction

The participating laboratories have to observe the following instructions:

- The charge amplifier used in the laboratory is to be calibrated with equipment traceable to national standards.
- The motion of the BB accelerometer should be measured with the laser directly on the (polished) top surface of the transducer without any additional reflector or dummy mass.
- The motion of the SE accelerometer should be measured on the moving part of the vibration exciter, close to the accelerometer's mounting surface, since the mounting (reference) surface is usually not directly accessible.
- The mounting surface of the accelerometer 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.
- 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 accelerometer is remounted and the cable reattached. The standard deviation of the subsequent measurements should be included in the report.

## 7 Communication of the Results to Pilot Laboratory

Each participating laboratory will submit one printed and signed calibration report for each accelerometer 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 methods 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 [4,5]). Including, among others, information on the type of uncertainty (A or B), assumed distribution function and repeatability component.

In addition each participating laboratory will receive two 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 its set of results to the executive secretary of CCAUV in advance to the first measurement of the participating laboratory.

## *8 Remarks on post processing*

Presuming consistency of the results, the degrees of equivalence will be calculated according to the established methods agreed upon already for CCAUV.V-K1. The results of this APMP KC will, after approval for equivalence, be linked to CCAUV.V-K1 via pilot laboratory as the foundation of the participating NMIs for their registration of 'calibration and measurement capabilities' (CMC) in the framework of the CIPM MRA.

# References

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

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

[3] ISO/IEC 17025:2005 'General requirements for the competence of testing and calibration laboratories'

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

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

# Appendix B: Uncertainty Budgets of the participants

## NIM:

Measurement uncertainties applicable for the sine approximation method used in APMP.AUV.V-K1.2 from 40 Hz to 5000 Hz:

Relative Total measurement uncertainty and Expanded measurement uncertainty ($k$ = 2) are:

| Frequency range<br>Hz | Relative total measurement uncertainty | Expanded measurement uncertainty |
|---|---|---|
| 40 ... 5 k | 0.23 % | **0.46 %** |

## Uncertainty budget for magnitude measurement results

| $i$ | **Standard uncertainty component** $u(x_i)$ | **Source of uncertainty** | **Uncertainty contribution** $u_i(y)$ |
|---|---|---|---|
| 1 | $u(\hat{u}_V)$ | accelerometer output voltage measurement (waveform recorder; e.g. ADC-resolution) | $3.0\times10^{-4}$ |
| 2 | $u(\hat{u}_F)$ | voltage filtering effect on accelerometer output amplitude measurement (frequency band limitation) | $5.0\times10^{-4}$ |
| 3 | $u(\hat{u}_D)$ | effect of voltage disturbance on accelerometer output voltage measurement (e.g. hum and noise) | $1.0\times10^{-3}$ |
| 4 | $u(\hat{u}_T)$ | effect of transverse, rocking and bending acceleration on accelerometer output voltage measurement (transverse sensitivity) | $1.5\times10^{-3}$ |
| 5 | $u(\hat{\varphi}_{M,Q})$ | effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90° nominal angle difference) | $1.0\times10^{-3}$ |
| 6 | $u(\hat{\varphi}_{M,F})$ | interferometer signal filtering effect on phase amplitude measurement (frequency band limitation) | $1.0\times10^{-5}$ |
| 7 | $u(\hat{\varphi}_{M,VD})$ | effect of voltage disturbance on phase amplitude measurement (e.g. random noise in the photoelectric measuring chains) | $1.0\times10^{-5}$ |
| 8 | $u(\hat{\varphi}_{M,MD})$ | effect of motion disturbance on phase amplitude measurement (e.g. drift; relative motion between the accelerometer reference surface and the spot sensed by the interferometer) | $1.0\times10^{-4}$ |
| 9 | $u(\hat{\varphi}_{M,PD})$ | effect of phase disturbance on phase amplitude measurement (e.g. phase noise of the interferometer signals) | $1.0\times10^{-5}$ |
| 10 | $u(\hat{\varphi}_{M,RE})$ | residual interferometric effects on phase amplitude measurement (interferometer function) | $5.0\times10^{-4}$ |
| 11 | $u(f_{FG})$ | vibration frequency measurement (frequency generator and indicator) | $1.0\times10^{-5}$ |
| 12 | $u(S_{RE})$ | residual effects on sensitivity measurement | $5.0\times10^{-4}$ |

**KIM-LIPI:**

Measurement uncertainties applicable for the sine approximation method used in APMP.AUV.V-K1.2 for SE from 40 Hz to 5000 Hz:

| No. | Components | Type | Dist | dof | Source | 40 | 50 | 63 |
|---|---|---|---|---|---|---|---|---|
| 1 | Acceleration Amplitude | | | | | 0.07624 | 0.07510 | 0.06626 |
| 1.1 | Signal Generator Frequency | B | rect | 30 | B&K | 0.00144 | 0.00144 | 0.00144 |
| 1.2 | Interferometer Signal Filtering Effect on Phase Measurement Amplitude | B | rect | 30 | B&K | 0.06455 | 0.06455 | 0.06455 |
| 1.3 | Laser Wavelength Stability | B | rect | 30 | B&K | 0.00093 | 0.00093 | 0.00093 |
| 1.4 | Motion Disturbance Effect | B | rect | 30 | experiment | 0.04053 | 0.03834 | 0.01484 |
| 2 | Voltage Amplitude | | | | | 0.06832 | 0.06828 | 0.06883 |
| 2.1 | Signal Generator Frequency | B | rect | 30 | B&K | 0.00144 | 0.00144 | 0.00144 |
| 2.2 | Voltage Measurement Error | B | rect | 30 | B&K | 0.06813 | 0.06813 | 0.06813 |
| 2.3 | Transverse Motion Effect | B | rect | 30 | experiment | 0.00496 | 0.00434 | 0.00969 |
| 3 | Charge Amplifier | | | | | 0.32263 | 0.31914 | 0.31914 |
| 3.1 | Standard Capacitor | B | rect | 30 | NMI | 0.04730 | 0.00242 | 0.00242 |
| 3.2 | Input Voltage | B | rect | 30 | B&K | 0.31754 | 0.31754 | 0.31754 |
| 3.3 | Output Voltage | B | rect | 30 | B&K | 0.03175 | 0.03175 | 0.03175 |
| 3.4 | Type A of Charge Amplifier | A | Normal | 5 | experiment | 0.00316 | 0.00244 | 0.00223 |
| | | | | | | 0.15749 | 0.16992 | 0.17579 |
| 4.1 | Type A (measurement) | A | Normal | 5 | experiment | 0.15749 | 0.16992 | 0.17579 |
| | Combined Uncertainty (Uc) | | | | | 0.37333 | 0.37554 | 0.37667 |
| | (ci.ui)^4/vi | | | | | 0.00046 | 0.00051 | 0.00053 |
| | Effective Degree of Freedom | | | | | 42 | 39 | 38 |
| | k Factor | | | | | 2.01824 | 2.02234 | 2.02461 |
| | Expanded Uncertainty (U95) | | | | | 0.75346 | 0.75946 | 0.76262 |
| | U95 round-up | | | | | 0.75 | 0.76 | 0.76 |

| No. | Components | 80 | 100 | 125 | 160 | 200 | 250 | 315 |
|---|---|---|---|---|---|---|---|---|
| 1 | Acceleration Amplitude | 0.06554 | 0.06567 | 0.06599 | 0.06637 | 0.06793 | 0.07820 | 0.07820 |
| 1.1 | Signal Generator Frequency | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 |
| 1.2 | Interferometer Signal Filtering Effect on Phase Measurement Amplitude | 0.06455 | 0.06455 | 0.06455 | 0.06455 | 0.06455 | 0.06455 | 0.06455 |
| 1.3 | Laser Wavelength Stability | 0.00093 | 0.00093 | 0.00093 | 0.00093 | 0.00093 | 0.00093 | 0.00093 |
| 1.4 | Motion Disturbance Effect | 0.01123 | 0.01191 | 0.01358 | 0.01533 | 0.02107 | 0.04411 | 0.04411 |
| 2 | Voltage Amplitude | 0.06881 | 0.06939 | 0.06964 | 0.06970 | 0.07143 | 0.10446 | 0.20527 |
| 2.1 | Signal Generator Frequency | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 |
| 2.2 | Voltage Measurement Error | 0.06813 | 0.06813 | 0.06813 | 0.06813 | 0.06813 | 0.06813 | 0.06813 |
| 2.3 | Transverse Motion Effect | 0.00959 | 0.01312 | 0.01438 | 0.01466 | 0.02143 | 0.07917 | 0.19363 |
| 3 | Charge Amplifier | 0.31914 | 0.31914 | 0.31914 | 0.31914 | 0.31914 | 0.31914 | 0.31914 |
| 3.1 | Standard Capacitor | 0.00242 | 0.00214 | 0.00214 | 0.00214 | 0.00214 | 0.00214 | 0.00214 |
| 3.2 | Input Voltage | 0.31754 | 0.31754 | 0.31754 | 0.31754 | 0.31754 | 0.31754 | 0.31754 |
| 3.3 | Output Voltage | 0.03175 | 0.03175 | 0.03175 | 0.03175 | 0.03175 | 0.03175 | 0.03175 |
| 3.4 | Type A of Charge Amplifier | 0.00237 | 0.00237 | 0.00233 | 0.00219 | 0.00229 | 0.00226 | 0.00209 |
| | | 0.15482 | 0.18041 | 0.15906 | 0.13590 | 0.13016 | 0.13042 | 0.14616 |
| 4.1 | Type A (measurement) | 0.15482 | 0.18041 | 0.15906 | 0.13590 | 0.13016 | 0.13042 | 0.14616 |
| | Combined Uncertainty (Uc) | 0.36723 | 0.37885 | 0.36926 | 0.35998 | 0.35848 | 0.36863 | 0.41409 |
| | $(ci.ui)^4/vi$ | 0.00046 | 0.00055 | 0.00047 | 0.00041 | 0.00040 | 0.00040 | 0.00048 |
| | Effective Degree of Freedom | 40 | 37 | 40 | 41 | 42 | 46 | 61 |
| | k Factor | 2.02117 | 2.02565 | 2.02157 | 2.01940 | 2.01878 | 2.01266 | 1.99935 |
| | Expanded Uncertainty (U95) | 0.74222 | 0.76742 | 0.74649 | 0.72694 | 0.72370 | 0.74193 | 0.82790 |
| | U95 round-up | 0.74 | 0.77 | 0.75 | 0.73 | 0.72 | 0.74 | 0.83 |

| No. | Components | 400 | 500 | 630 | 800 | 1000 | 1250 | 1600 |
|---|---|---|---|---|---|---|---|---|
| 1 | Acceleration Amplitude | 0.06478 | 0.06470 | 0.06473 | 0.06666 | 0.06485 | 0.06470 | 0.06588 |
| 1.1 | Signal Generator Frequency | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 |
| 1.2 | Interferometer Signal Filtering Effect on Phase Measurement Amplitude | 0.06455 | 0.06455 | 0.06455 | 0.06455 | 0.06455 | 0.06455 | 0.06455 |
| 1.3 | Laser Wavelength Stability | 0.00093 | 0.00093 | 0.00093 | 0.00093 | 0.00093 | 0.00093 | 0.00093 |
| 1.4 | Motion Disturbance Effect | 0.00510 | 0.00405 | 0.00450 | 0.01655 | 0.00598 | 0.00408 | 0.01303 |
| 2 | Voltage Amplitude | 0.24096 | 0.13416 | 0.10042 | 0.05773 | 0.05733 | 0.05878 | 0.05653 |
| 2.1 | Signal Generator Frequency | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 |
| 2.2 | Voltage Measurement Error | 0.06813 | 0.06813 | 0.04041 | 0.04041 | 0.04041 | 0.04041 | 0.03811 |
| 2.3 | Transverse Motion Effect | 0.23112 | 0.11556 | 0.09192 | 0.04119 | 0.04063 | 0.04265 | 0.04173 |
| 3 | Charge Amplifier | 0.31914 | 0.31914 | 0.31914 | 0.31914 | 0.31914 | 0.31914 | 0.31914 |
| 3.1 | Standard Capacitor | 0.00214 | 0.00214 | 0.00214 | 0.00214 | 0.00214 | 0.00214 | 0.00214 |
| 3.2 | Input Voltage | 0.31754 | 0.31754 | 0.31754 | 0.31754 | 0.31754 | 0.31754 | 0.31754 |
| 3.3 | Output Voltage | 0.03175 | 0.03175 | 0.03175 | 0.03175 | 0.03175 | 0.03175 | 0.03175 |
| 3.4 | Type A of Charge Amplifier | 0.00229 | 0.00204 | 0.00187 | 0.00220 | 0.00227 | 0.00221 | 0.00179 |
| | | 0.12843 | 0.09918 | 0.11429 | 0.11252 | 0.10356 | 0.13252 | 0.13063 |
| 4.1 | Type A (measurement) | 0.12843 | 0.09918 | 0.11429 | 0.11252 | 0.10356 | 0.13252 | 0.13063 |
| | Combined Uncertainty (Uc) | 0.42498 | 0.36588 | 0.35942 | 0.34970 | 0.34651 | 0.35645 | 0.35560 |
| | $(c_i.u_i)^4/v_i$ | 0.00049 | 0.00037 | 0.00038 | 0.00037 | 0.00036 | 0.00040 | 0.00040 |
| | Effective Degree of Freedom | 67 | 49 | 44 | 40 | 40 | 40 | 40 |
| | k Factor | 1.99624 | 2.00957 | 2.01491 | 2.02075 | 2.02150 | 2.02076 | 2.02082 |
| | Expanded Uncertainty (U95) | 0.84835 | 0.73527 | 0.72421 | 0.70665 | 0.70047 | 0.72029 | 0.71860 |
| | U95 round-up | 0.85 | 0.74 | 0.72 | 0.71 | 0.70 | 0.72 | 0.72 |

| No. | Components | 2000 | 2500 | 3150 | 4000 | 5000 |
|---|---|---|---|---|---|---|
| 1 | Acceleration Amplitude | 0.06553 | 0.06549 | 0.08520 | 0.06570 | 0.22127 |
| 1.1 | Signal Generator Frequency | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 |
| 1.2 | Interferometer Signal Filtering Effect on Phase Measurement Amplitude | 0.06455 | 0.06455 | 0.06455 | 0.06455 | 0.06455 |
| 1.3 | Laser Wavelength Stability | 0.00093 | 0.00093 | 0.00093 | 0.00093 | 0.00093 |
| 1.4 | Motion Disturbance Effect | 0.01115 | 0.01090 | 0.05558 | 0.01212 | 0.21164 |
| | | | | | | |
| 2 | Voltage Amplitude | 0.05851 | 0.05930 | 0.05879 | 0.05859 | 0.04855 |
| 2.1 | Signal Generator Frequency | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 |
| 2.2 | Voltage Measurement Error | 0.03811 | 0.03811 | 0.03811 | 0.03811 | 0.03811 |
| 2.3 | Transverse Motion Effect | 0.04438 | 0.04541 | 0.04475 | 0.04448 | 0.03005 |
| | | | | | | |
| 3 | Charge Amplifier | 0.31914 | 0.31914 | 0.31914 | 0.31914 | 0.31914 |
| 3.1 | Standard Capacitor | 0.00214 | 0.00214 | 0.00214 | 0.00214 | 0.00214 |
| 3.2 | Input Voltage | 0.31754 | 0.31754 | 0.31754 | 0.31754 | 0.31754 |
| 3.3 | Output Voltage | 0.03175 | 0.03175 | 0.03175 | 0.03175 | 0.03175 |
| 3.4 | Type A of Charge Amplifier | 0.00179 | 0.00165 | 0.00176 | 0.00206 | 0.00167 |
| | | 0.11302 | 0.11408 | 0.09730 | 0.16382 | 0.14751 |
| 4.1 | Type A (measurement) | 0.11302 | 0.11408 | 0.09730 | 0.16382 | 0.14751 |
| | | | | | | |
| | Combined Uncertainty (Uc) | 0.34977 | 0.35024 | 0.34933 | 0.36938 | 0.41824 |
| | $(ci.ui)^4/vi$ | 0.00037 | 0.00037 | 0.00036 | 0.00048 | 0.00050 |
| | Effective Degree of Freedom | 40 | 40 | 42 | 38 | 61 |
| | k Factor | 2.02079 | 2.02067 | 2.01868 | 2.02359 | 1.99960 |
| | Expanded Uncertainty (U95) | 0.70682 | 0.70772 | 0.70519 | 0.74747 | 0.83632 |
| | U95 round-up | 0.71 | 0.71 | 0.71 | 0.75 | 0.84 |

Measurement uncertainties applicable for the sine approximation method used in APMP.AUV.V-K1.2 for BB from 40 Hz to 5000 Hz:

| No. | Components | Type | Dist | dof | Source | 40 | 50 | 63 |
|---|---|---|---|---|---|---|---|---|
| 1 | Acceleration Amplitude | | | | | 0.07624 | 0.07510 | 0.06626 |
| 1.1 | Signal Generator Frequency | B | rect | 30 | B&K | 0.00144 | 0.00144 | 0.00144 |
| 1.2 | Interferometer Signal Filtering Effect on Phase Measurement Amplitude | B | rect | 30 | B&K | 0.06455 | 0.06455 | 0.06455 |
| 1.3 | Laser Wavelength Stability | B | rect | 30 | B&K | 0.00093 | 0.00093 | 0.00093 |
| 1.4 | Motion Disturbance Effect | B | rect | 30 | experiment | 0.04053 | 0.03834 | 0.01484 |
| 2 | Voltage Amplitude | | | | | 0.06832 | 0.06828 | 0.06883 |
| 2.1 | Signal Generator Frequency | B | rect | 30 | B&K | 0.00144 | 0.00144 | 0.00144 |
| 2.2 | Voltage Measurement Error | B | rect | 30 | B&K | 0.06813 | 0.06813 | 0.06813 |
| 2.3 | Transverse Motion Effect | B | rect | 30 | experiment | 0.00496 | 0.00434 | 0.00969 |
| 3 | Charge Amplifier | | | | | 0.32263 | 0.31914 | 0.31914 |
| 3.1 | Standard Capacitor | B | rect | 30 | NMI | 0.04730 | 0.00242 | 0.00242 |
| 3.2 | Input Voltage | B | rect | 30 | B&K | 0.31754 | 0.31754 | 0.31754 |
| 3.3 | Output Voltage | B | rect | 30 | B&K | 0.03175 | 0.03175 | 0.03175 |
| 3.4 | Type A of Charge Amplifier | A | Normal | 5 | experiment | 0.00316 | 0.00244 | 0.00223 |
| | | | | | | 0.04142 | 0.02766 | 0.01578 |
| 4.1 | Type A (measurement) | A | Normal | 5 | experiment | 0.04142 | 0.02766 | 0.01578 |
| | Combined Uncertainty (Uc) | | | | | 0.34101 | 0.33604 | 0.33351 |
| | (ci ui)^4/vi | | | | | 0.00034 | 0.00034 | 0.00034 |
| | Effective Degree of Freedom | | | | | 40 | 37 | 36 |
| | k Factor | | | | | 2.02167 | 2.02539 | 2.02742 |
| | Expanded Uncertainty (U95) | | | | | 0.68940 | 0.68061 | 0.67617 |
| | U95 round-up | | | | | 0.69 | 0.68 | 0.68 |

| No. | Components | 80 | 100 | 125 | 160 | 200 | 250 | 315 |
|---|---|---|---|---|---|---|---|---|
| 1 | Acceleration Amplitude | 0.06554 | 0.06567 | 0.06599 | 0.06637 | 0.06793 | 0.07820 | 0.07820 |
| 1.1 | Signal Generator Frequency | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 |
| 1.2 | Interferometer Signal Filtering Effect on Phase Measurement Amplitude | 0.06455 | 0.06455 | 0.06455 | 0.06455 | 0.06455 | 0.06455 | 0.06455 |
| 1.3 | Laser Wavelength Stability | 0.00093 | 0.00093 | 0.00093 | 0.00093 | 0.00093 | 0.00093 | 0.00093 |
| 1.4 | Motion Disturbance Effect | 0.01123 | 0.01191 | 0.01358 | 0.01533 | 0.02107 | 0.04411 | 0.04411 |
| | | | | | | | | |
| 2 | Voltage Amplitude | 0.06881 | 0.06939 | 0.06964 | 0.06970 | 0.07143 | 0.08702 | 0.08297 |
| 2.1 | Signal Generator Frequency | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 |
| 2.2 | Voltage Measurement Error | 0.06813 | 0.06813 | 0.06813 | 0.06813 | 0.06813 | 0.06813 | 0.06813 |
| 2.3 | Transverse Motion Effect | 0.00959 | 0.01312 | 0.01438 | 0.01466 | 0.02143 | 0.05412 | 0.04734 |
| | | | | | | | | |
| 3 | Charge Amplifier | 0.31914 | 0.31914 | 0.31914 | 0.31914 | 0.31914 | 0.31914 | 0.31914 |
| 3.1 | Standard Capacitor | 0.00242 | 0.00214 | 0.00214 | 0.00214 | 0.00214 | 0.00214 | 0.00214 |
| 3.2 | Input Voltage | 0.31754 | 0.31754 | 0.31754 | 0.31754 | 0.31754 | 0.31754 | 0.31754 |
| 3.3 | Output Voltage | 0.03175 | 0.03175 | 0.03175 | 0.03175 | 0.03175 | 0.03175 | 0.03175 |
| 3.4 | Type A of Charge Amplifier | 0.00237 | 0.00237 | 0.00233 | 0.00219 | 0.00229 | 0.00226 | 0.00209 |
| | | 0.04151 | 0.04988 | 0.06398 | 0.00833 | 0.06548 | 0.10119 | 0.13806 |
| 4.1 | Type A (measurement) | 0.04151 | 0.04988 | 0.06398 | 0.00833 | 0.06548 | 0.10119 | 0.13806 |
| | | | | | | | | |
| | Combined Uncertainty (Uc) | 0.33557 | 0.33685 | 0.33934 | 0.33344 | 0.34038 | 0.35465 | 0.36594 |
| | (ci.ui)^4/vi | 0.00034 | 0.00034 | 0.00034 | 0.00034 | 0.00034 | 0.00036 | 0.00041 |
| | Effective Degree of Freedom | 37 | 38 | 39 | 36 | 39 | 44 | 43 |
| | k Factor | 2.02584 | 2.02495 | 2.02340 | 2.02748 | 2.02267 | 2.01572 | 2.01618 |
| | Expanded Uncertainty (U95) | 0.67981 | 0.68210 | 0.68662 | 0.67605 | 0.68847 | 0.71488 | 0.73779 |
| | U95 round-up | 0.68 | 0.68 | 0.69 | 0.68 | 0.69 | 0.71 | 0.74 |

| No. | Components | 400 | 500 | 630 | 800 | 1000 | 1250 | 1600 |
|---|---|---|---|---|---|---|---|---|
| 1 | Acceleration Amplitude | 0.06478 | 0.06470 | 0.06473 | 0.06666 | 0.06485 | 0.06470 | 0.06588 |
| 1.1 | Signal Generator Frequency | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 |
| 1.2 | Interferometer Signal Filtering Effect on Phase Measurement Amplitude | 0.06455 | 0.06455 | 0.06455 | 0.06455 | 0.06455 | 0.06455 | 0.06455 |
| 1.3 | Laser Wavelength Stability | 0.00093 | 0.00093 | 0.00093 | 0.00093 | 0.00093 | 0.00093 | 0.00093 |
| 1.4 | Motion Disturbance Effect | 0.00510 | 0.00405 | 0.00450 | 0.01655 | 0.00598 | 0.00408 | 0.01303 |
| 2 | Voltage Amplitude | 0.07100 | 0.06890 | 0.05199 | 0.05382 | 0.05237 | 0.05541 | 0.05311 |
| 2.1 | Signal Generator Frequency | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 |
| 2.2 | Voltage Measurement Error | 0.06813 | 0.06813 | 0.04041 | 0.04041 | 0.04041 | 0.04041 | 0.03811 |
| 2.3 | Transverse Motion Effect | 0.01994 | 0.01020 | 0.03267 | 0.03552 | 0.03327 | 0.03789 | 0.03696 |
| 3 | Charge Amplifier | 0.31914 | 0.31914 | 0.31914 | 0.31914 | 0.31914 | 0.31914 | 0.31914 |
| 3.1 | Standard Capacitor | 0.00214 | 0.00214 | 0.00214 | 0.00214 | 0.00214 | 0.00214 | 0.00214 |
| 3.2 | Input Voltage | 0.31754 | 0.31754 | 0.31754 | 0.31754 | 0.31754 | 0.31754 | 0.31754 |
| 3.3 | Output Voltage | 0.03175 | 0.03175 | 0.03175 | 0.03175 | 0.03175 | 0.03175 | 0.03175 |
| 3.4 | Type A of Charge Amplifier | 0.00229 | 0.00204 | 0.00187 | 0.00220 | 0.00227 | 0.00221 | 0.00179 |
| | | 0.10700 | 0.18314 | 0.15602 | 0.12875 | 0.12786 | 0.14416 | 0.12682 |
| 4.1 | Type A (measurement) | 0.10700 | 0.18314 | 0.15602 | 0.12875 | 0.12786 | 0.14416 | 0.12682 |
| | Combined Uncertainty (Uc) | 0.35005 | 0.37990 | 0.36481 | 0.35464 | 0.35376 | 0.36040 | 0.35369 |
| | $(ci.ui)^4/vi$ | 0.00037 | 0.00057 | 0.00046 | 0.00039 | 0.00039 | 0.00043 | 0.00039 |
| | Effective Degree of Freedom | 41 | 37 | 39 | 40 | 40 | 40 | 40 |
| | k Factor | 2.01960 | 2.02649 | 2.02329 | 2.02097 | 2.02135 | 2.02174 | 2.02113 |
| | Expanded Uncertainty (U95) | 0.70697 | 0.76986 | 0.73811 | 0.71671 | 0.71508 | 0.72864 | 0.71485 |
| | U95 round-up | 0.71 | 0.77 | 0.74 | 0.72 | 0.72 | 0.73 | 0.71 |

| No. | Components | 2000 | 2500 | 3150 | 4000 | 5000 |
|---|---|---|---|---|---|---|
| 1 | Acceleration Amplitude | 0.06553 | 0.06549 | 0.08520 | 0.06570 | 0.22127 |
| 1.1 | Signal Generator Frequency | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 |
| 1.2 | Interferometer Signal Filtering Effect on Phase Measurement Amplitude | 0.06455 | 0.06455 | 0.06455 | 0.06455 | 0.06455 |
| 1.3 | Laser Wavelength Stability | 0.00093 | 0.00093 | 0.00093 | 0.00093 | 0.00093 |
| 1.4 | Motion Disturbance Effect | 0.01115 | 0.01090 | 0.05558 | 0.01212 | 0.21164 |
| 2 | Voltage Amplitude | 0.05513 | 0.05275 | 0.05152 | 0.05095 | 0.04855 |
| 2.1 | Signal Generator Frequency | 0.00144 | 0.00144 | 0.00144 | 0.00144 | 0.00144 |
| 2.2 | Voltage Measurement Error | 0.03811 | 0.03811 | 0.03811 | 0.03811 | 0.03811 |
| 2.3 | Transverse Motion Effect | 0.03982 | 0.03645 | 0.03464 | 0.03380 | 0.03005 |
| 3 | Charge Amplifier | 0.31914 | 0.31914 | 0.31914 | 0.31914 | 0.31914 |
| 3.1 | Standard Capacitor | 0.00214 | 0.00214 | 0.00214 | 0.00214 | 0.00214 |
| 3.2 | Input Voltage | 0.31754 | 0.31754 | 0.31754 | 0.31754 | 0.31754 |
| 3.3 | Output Voltage | 0.03175 | 0.03175 | 0.03175 | 0.03175 | 0.03175 |
| 3.4 | Type A of Charge Amplifier | 0.00179 | 0.00165 | 0.00176 | 0.00206 | 0.00167 |
| | | 0.07688 | 0.18717 | 0.15389 | 0.08145 | 0.07112 |
| 4.1 | Type A (measurement) | 0.07688 | 0.18717 | 0.15389 | 0.08145 | 0.07112 |
| | Combined Uncertainty (Uc) | 0.33925 | 0.37941 | 0.36803 | 0.33970 | 0.39778 |
| | $(ci.ui)^4/vi$ | 0.00035 | 0.00059 | 0.00045 | 0.00035 | 0.00041 |
| | Effective Degree of Freedom | 38 | 35 | 41 | 38 | 61 |
| | k Factor | 2.02405 | 2.02928 | 2.02021 | 2.02404 | 1.99976 |
| | Expanded Uncertainty (U95) | 0.68667 | 0.76993 | 0.74350 | 0.68757 | 0.79545 |
| | U95 round-up | 0.69 | 0.77 | 0.74 | 0.69 | 0.80 |

## NPLI:

Measurement uncertainties applicable for the sine approximation method used in APMP.AUV.V-K1.2 from 40 Hz to 5000 Hz:

| No. | Description | standard uncertainty | Probability distribution | Factor $x_i$ | Sensitivity coefficient | 160 Hz | 10 Hz to <2 kHz | 2 kHz to 4 kHz | >4kHz to 5 kHz |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Accelerometer Output voltage measurement & effect of rocking, transverse and bending acceleration | 0.20 | Rectangular | 0.5774 | 1 | 0.100 | 0.180 | 0.100 | 0.100 |
| 2 | Drift, manufacturer specification < 0.05% per year | 0.05 | Rectangular | 0.5774 | 1 | 0.029 | 0.029 | 0.029 | 0.029 |
| 3 | Sensitivity of conditioning amplifier calibration | 0.25 | Normal | 0.5000 | 1 | 0.130 | 0.200 | 0.130 | 0.130 |
| 4 | Influence of mounting parameters on transducer to be calibrated | 0.05 | Rectangular | 0.5774 | 1 | 0.029 | 0.115 | 0.017 | 0.017 |
| 5 | Effect of motion disturbance on displacement measurement (incl distortion, tilt, rotation) | 0.05 | Rectangular | 0.5774 | 1 | 0.029 | 0.029 | 0.029 | 0.029 |
| 6 | Effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation) | 0.03 | Rectangular | 0.5774 | 1 | 0.020 | 0.020 | 0.020 | 0.020 |
| 7 | Effect of phase & voltage disturbance on phase amplitude measurement, hum & noise) | 0.05 | Rectangular | 0.5774 | 1 | 0.030 | 0.030 | 0.030 | 0.030 |
| 8 | Magnetic field of exciter | 0.03 | Rectangular | 0.5774 | 1 | 0.020 | 0.020 | 0.020 | 0.020 |
| 9 | Gravitational effects | 0.03 | Rectangular | 0.5774 | 1 | 0.020 | 0.020 | 0.020 | 0.020 |
| 10 | Relative motion (accelerometer reference surface & spot sensed by the interferometer) | 0.05 | Rectangular | 0.5774 | 1 | 0.020 | 0.020 | 0.040 | 0.040 |
| 11 | Non linearity of transducer | 0.03 | Rectangular | 0.5774 | 1 | 0.017 | 0.017 | 0.017 | 0.017 |
| 12 | Non linearity of preamplifier | 0.02 | Rectangular | 0.5774 | 1 | 0.010 | 0.010 | 0.010 | 0.010 |
| 13 | Temperature variation | 0.30 | Rectangular | 0.5774 | 1 | 0.173 | 0.173 | 0.173 | 0.173 |
| 14 | Environmental effects | 0.03 | Rectangular | 0.5774 | 1 | 0.017 | 0.017 | 0.017 | 0.017 |
| 15 | Base strain | 0.05 | Rectangular | 0.5774 | 1 | 0.029 | 0.029 | 0.029 | 0.029 |
| 16 | Transverse acceleration | 0.30 | Rectangular | 0.5774 | 1 | 0.070 | 0.070 | 0.300 | 0.300 |
| 17 | Residual effects | 0.10 | Rectangular | 0.5774 | 1 | 0.060 | 0.060 | 0.060 | 0.100 |
| 18 | Repeatability | 0.005 | Type-A | 0.447 | 1 | 0.002 | 0.002 | 0.05 | 0.22 |
| | **Combined uncertainty** | | $k = 1$ | | | **0.27** | **0.35** | **0.48** | **0.6** |
| | **Expanded uncertainty** | | $k = 2$ | | | **0.54** | **0.70** | **0.96** | **1.20** |