# Final Report on the CIPM Key Comparison

# CCAUV.V-K1.1

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#### ABSTRACT

This report of the CCAUV.V-K1.1 key comparison (KC) presents the final results of the second, follow-up CIPM comparison in the area of vibration, in this case defined as sinusoidal acceleration. The relation between the results of the participants in this follow-up comparison and the results of the first CIPM comparison in the field of vibration CCAUV.V-K1 is calculated via a procedure using one linking laboratory and is fully described. Using this linking, the results of the participants can be directly compared with the results of other comparisons like CCAUV.V-K1.

Supplementing the scope of the original CIPM comparison the frequency range of the reported KC was extended up to 10 kHz and the measurand phase was included for some of the participants.

The Technical Protocol that was used is included as Appendix A and the full uncertainty budgets are given in Appendix B.

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# **1** Introduction

This report presents the results of the second CIPM comparison in the area of "vibration", what in this case means sinusoidal acceleration. It is the final report which is published in the KCDB of the BIPM.

The participants agreed to the results circulated confidentially in the draft A report. The calculus applied for this linking process is identical to that already used and described in the final report of the EUROMET.AUV.V-K1 comparison. Using this the results of the participants can be directly compared to the results of other comparisons, be it CCAUV.V-K1 itself or others, which are linked to it as well. This comparison can be considered as an amendment to CCAUV.V-K1, which is performed to link the participants from different RMOs to the Key Comparison Reference value of CCAUV.V-K1

The Technical Protocol (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 and other items. A brief survey is given in the following sections.

# 2 Participants

Four National Metrology Institutes (NMIs) from 3 RMO participated in the comparison CCAUV.V-K1.1 (c.f. table 1).

Participant number	Participant (laboratory name)*	Acronym	Country	Country Code	Calibration period
1	Physikalisch-Technische Bundesanstalt	РТВ	Germany	DE	05/2006
2	National Institute of Metrology of China	NIM	China	CN	11/2006
3	National Physics Laboratory of India	NPLI	India	IN	12/2006
4	National Institute of Metrology, Standardization and Industrial Quality	INMETRO	Brazil	BR	08/2007

#### Table 1: List of participating institutes

## 3 Task and Purpose of the Comparison

This second CIPM-level comparison in the field of acceleration was carried out in order to provide the necessary information for the acceptance of CMC entries for the participants 2 to 4.

In order to provide the necessary means for a linking of the results to the CIPM comparison CCAUV.V-K1 [1]. PTB was requested to volunteer as Pilot- and Linking laboratory.

### **4** Conditions and Instructions of Measurement

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

• frequencies in Hz:

40, 80, 160 (reference frequency), 800, 2000, 5000 and additional frequencies down to 10 Hz and up to 10 kHz provided that they are included in the third octave series.

- amplitudes: A range of 10 m/s<sup>2</sup> to 200 m/s<sup>2</sup> was allowed with 100 m/s<sup>2</sup> being the preferred value.
- ambient temperature and accelerometer temperature during the calibration: 23 °C ± 2 K (actual values should be stated within tolerances of ± 0.3 K).
- relative humidity: max. 75%
- mounting torque of the accelerometer: (2 ± 0.1) N·m

The comparison was performed in compliance with the "Guidelines for CIPM key comparisons" [2].

# 5 Transfer Standards as Artefacts

For the purpose of the comparison the pilot laboratory selected two accelerometers 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 WH 2335, S/N 1610168 (manufacturer: Brüel & Kjær) named SE-transducer subsequently (owner PTB)
- One reference standard accelerometer (back-to-back) type 8305, S/N 748376 (manufacturer: Brüel & Kjær) named **B2B**-transducer subsequently (owner NIM)

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

# 6 Circulation of the Artefacts

The circulation Type of this comparison was a star type, i.e. between the measurements at each participant's laboratory the artefacts were checked for stability (c.f. section 7.2) and the state of the mounting surface. If the quality of the mounting surface was degraded the

artefacts were re-lapped in order to provide optimum conditions for the following participant.

### 7 Results of the Measurements

#### 7.1 Transverse Sensitivity

The sensitivity of the accelerometers towards a transverse excitation i.e. in a direction parallel to the mounting surface or orthogonal to their geometric axis was investigated in dedicated measurements.

For this investigation the artefacts were mounted to a mounting block on top off the slip table of PTB's 3-axis vibration exciter. The mounting block was equipped with two reference accelerometers pointing in x- and y-direction which were primary calibrated just before the measurements. Then the x- and y-exciters of the facility were driven synchronously with sinusoidal current of varying amplitude but zero phase difference. The amplitude was varied in a way that with successive runs the slip-table was performing sinusoidal rectilinear motions in different directions with a constant magnitude of acceleration amplitude of 60 m/s<sup>2</sup> at 40 Hz.

As usual the results are presented here in relative way as a fraction of the nominal sensitivity. The relative expanded uncertainty (k = 2) of this relative transverse sensitivity is estimated to be less than 10 %. Figures 1 and 2 give a graphical view of the results. The values of maximum transverse sensitivity are summarized in table 2.



Fig. 1: relative transverse sensitivity of the SE accelerometer in % of the nominal sensitivity, polar representation left, Cartesian representation right.

#### Transverse Sensitivity



Fig. 2: relative transverse sensitivity of the B2B accelerometer in % of the nominal sensitivity, polar representation left, cartesian representation right.

# Table 2: maximum transverse sensitivity of the artefacts a a percentage of the nominal sensitivity

Artefact	max. rel. transverse sensitivity in %
SE	< 2,5
B2B	< 0,5

#### 7.2 Monitoring of stability

Starting with calibration data in autumn 2005 the artefacts were monitored during the period of the comparison by calibrations at those times when they were back at the pilot laboratory. As a representative of the overall change the measurements at reference frequency (160 Hz) are given in the following tables.

Table 3: Charge sensitivities of the SE
accelerometer at 160 Hz during the
monitoring measurements (rel. std.
uncertainty ( <i>k</i> = 1) <i>u</i> = 0,05 %)

Month rel. to 10/2005	S <sub>qa</sub> in pC/(m/s²)	rel. exp. uncertainty in %
0	0,13069	0,1
2	0,13088	0,1
4	0,13079	0,1
5	0,13066	0,1
7	0,13064	0,1
8	0,13071	0,1
9	0,13065	0,1
11	0,13069	0,1
17	0,13040	0,1
18	0,13046	0,1
19	0,13046	0,1

Table 4: Charge sensitivities of the B2B accelerometer at 160 Hz during the monitoring measurements (rel. std. uncertainty (k = 1) u = 0.05 %)

Month rel. to 2/2005	S <sub>qa</sub> in pC/(m/s²)	rel. exp. uncertainty in %		
0	0,12606	0,1		
14	0,12606	0,1		
15	0,12600	0,1		
32	0,12604	0,1		

This monitoring measurements can in the simplest way be summarized by the following statistical properties. However, a graphical representation (c.f. fig. 3Fehler: Referenz nicht gefunden and 4) may suggest that the stability of the SE artefact was not as good as was originally hoped for, while the B2B artefact showed excellent long term stability.

 Table 5: 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	0,13064	0,11
B2B	0,12604	0,02

### 7.3 Drift Analysis

From the monitoring data given in section 7.2 it appears that the SE transducers actual sensitivity might have drifted during the measurement period. In order to take this into account a linear least squares fit was applied to the monitoring data over time. The linear model is described by

$$S(t) = S_0 + D \cdot (t - t_0)$$
(1).

The model parameters  $S_0$  and D as well as the respective co-variance matrix are fitted according to [3].

In order to check consistency the Chi-squared was calculated for the respective model and compared to the maximum  $X^2$  of p = 0.05 and the respective degree of freedom v.

Artefact	S₀ in pC/ (m/s²)	s(S₀) in pC/ (m/s²)	D in (pC/(m/s²)) per month	s(D) in (pC/(m/s²)) per month	ν	χ²	$\begin{array}{c} \text{maximum} \\ \chi^2 \end{array}$	rel. std. dev. in %
SE	0,13082	3,5e-5	-1,94e-5	3,2e-6	9	12,4	16,92	0,056

Table 6: Model parameters for the linear drift of the linear drift of the artefacts.

For the SE the drift stated in table 6 converts to a relative value of approx. -0,18 % per year. For a direct comparison of the fitted linear drift to the model of constant sensitivity (c.f. table 5) the standard deviation of the measurements with respect to the values estimated by the model is calculated in the last column.

The monitoring data for both artefacts as well as the drift estimate for the SE are depicted in the figures 3 and 4 below.



time in month Fig. 3: Charge sensitivities in pC/(m/s<sup>2</sup>) of the SE accelerometer at 160 Hz over time in months during the monitoring measurements. Uncertainty bars for the exp. uncertainty (k = 2). And line (blue) of the fitted drift estimate with the confidence limits of the fit (grey).





It was agreed between the participants to use corrected (detrended) values for the calculation of the DOEs for the SE transducer, which means that according to relative time with respect to the comparison period the values reported from the participating laboratories are added to a certain drift value which increases the magnitude the later the participants measurements were in the schedule of the comparison (c. f. section 6). In addition the uncertainty stated by the participant would be increased by the uncertainty of this estimated drift value using a sum of squares. Only after this correction the DoE were determined. The correction for all frequencies was taken as a scaling factor (very close to unity) calculated from the drift at 160 Hz.

The uncertainty of the correction is calculated according to the laws of uncertainty propagation from the partial derivatives of the model equation (1).

$$U(S(t)) = \sqrt{\left(\frac{\partial S}{\partial S_0}\right)^2} s^2(S_0) + \left(\frac{\partial S}{\partial D}\right)^2 s^2(D) + \left(\frac{\partial S}{\partial S_0}\frac{\partial S}{\partial D}\right) cov(S_0, D)$$
(2)

The components of the uncertainty calculation and its result in absolute and relative terms are summarized in table (7).

Table 7: summary of the terms	ocurring in the uncertainty propagation of the drift model
which is proposed for	correction.

partial derivatives	$\left(\frac{\partial S}{\partial S_0}\right)^2 = 1$	$\left(\frac{\partial S}{\partial D}\right)^2 = (t - t_0)^2$	$\frac{\partial S}{\partial S_0} \frac{\partial S}{\partial D} = t - t_0$
variances	1,22e-9	1,0e-11	-9,1e-11
max. U(S)	4,64·10⁻⁵ pC/(m/s²)		rel. 0,03 %

Due to the second and third term of the quadratic sum in eq. (2) the uncertainty of the correction is depending on the time when the measurement has taken place in the course of the comparison.

In this report of the key comparison both results (with and without correction) will be presented for each laboratory.

# 7.4 Original Results of the Participants for the Magnitude of the complex Sensitivity

In the Following the results of the participating Institutes are given as reported first in a compact tabulated form and additionally in graphical representation for each artefact and frequency. The proposed correction is not applied so far.

#### 7.4.1 The Single-Ended Accelerometer SN 1610168

	P	ГВ	N	М	NPLI		INMETRO	
frequency	S <sub>qa</sub> in pC/ (m/s²)	rel. exp. unc. in %						
10	0,13058	0,10	0,13068	0,50	0,13070	1,00	0,13052	0,34
12,5	0,13055	0,10	0,13075	0,50	-	-	0,13053	0,34
16	0,13061	0,10	0,13076	0,50	-	-	0,13054	0,34
20	0,13060	0,10	0,13073	0,50	0,13070	0,70	0,13053	0,34
25	0,13064	0,10	0,13069	0,50	-	-	0,13053	0,24
31,5	0,13059	0,10	0,13074	0,50	-	-	0,13054	0,24
40	0,13061	0,10	0,13072	0,50	0,13070	0,70	0,13050	0,24
50	0,13062	0,10	0,13073	0,50	-	-	0,13047	0,24
63	0,13060	0,10	0,13071	0,50	-	-	0,13050	0,24
80	0,13061	0,10	0,13072	0,50	0,13080	0,70	0,13051	0,24
100	0,13062	0,10	0,13068	0,50	0,13080	0,70	0,13052	0,24
125	0,13062	0,10	0,13069	0,50	-	-	0,13051	0,24
160	0,13066	0,10	0,13073	0,20	0,13090	0,70	0,13048	0,24
200	0,13066	0,10	0,13075	0,50	0,13070	0,70	0,13051	0,24
250	0,13066	0,10	0,13079	0,50	-	-	0,13050	0,24
315	0,13095	0,10	0,13078	0,50	-	-	0,13052	0,24
400	0,13075	0,10	0,13077	0,50	-	-	0,13056	0,24
500	0,13072	0,10	0,13079	0,50	0,13060	0,70	0,13051	0,24
630	0,13072	0,10	0,13085	0,50	-	-	0,13058	0,24
800	0,13074	0,10	0,13080	0,50	0,13070	0,70	0,13060	0,24
1000	0,13079	0,10	0,13087	0,50	0,13070	0,70	0,13069	0,24
1250	0,13090	0,10	0,13097	0,50	-	-	0,13077	0,34
1600	0,13108	0,10	0,13109	0,50	-	-	0,13095	0,34
2000	0,13133	0,10	0,13126	0,50	0,13060	0,70	0,13116	0,34
2500	0,13161	0,10	0,13171	0,50	-	-	0,13149	0,50
3150	0,13215	0,10	0,13225	0,50	-	-	013200	0,50
4000	0,13309	0,10	0,13299	0,50	0,13060	1,00	0,13301	0,50
5000	0,13442	0,10	0,13428	0,50	0,13130	1,00	0,13432	1,00
6300	0,13670	0,30	0,13648	1,0	-	-	0,13620	1,50
8000	0,14064	0,30	0,14077	1,00	-	-	0,13950	1,50
10000	0,14676	0,30	0,14624	1,00	-	-	0,14639	1,50

Table 8: reported calibration results in  $pC/(m/s^2)$  of the participants for the SE transducer with expanded relative uncertainty (k = 2) in %.



Fig. 5: Charge sensitivity of the SE transducer in  $pC/(m/s^2)$  reported by the participants for 10 Hz and 12,5 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 6: Charge sensitivity of the SE transducer in  $pC/(m/s^2)$  reported by the participants for 16 Hz and 20 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 7: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) reported by the participants for 25 Hz and 31,5 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 8: Charge sensitivity of the SE transducer in  $pC/(m/s^2)$  reported by the participants for 40 Hz and 50 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 9: Charge sensitivity of the SE transducer in  $pC/(m/s^2)$  reported by the participants for 63 Hz and 80 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 10: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) reported by the participants for 100 Hz and 125 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 11: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) reported by the participants for 160 Hz and 200 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 12: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) reported by the participants for 250 Hz and 315 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 13: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) reported by the participants for 400 Hz and 500 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 14: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) reported by the participants for 630 Hz and 800 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 15: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) reported by the participants for 1000 Hz and 1250 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 16: Charge sensitivity of the SE transducer in  $pC/(m/s^2)$  reported by the participants for 1600 Hz and 2000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 17: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) reported by the participants for 2500 Hz and 3150 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 18: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) reported by the participants for 4000 Hz and 5000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 19: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) reported by the participants for 6300 Hz and 8000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 20: Charge sensitivity of the SE transducer in  $pC/(m/s^2)$  reported by the participants for 10000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).

#### 7.4.2 The Single-Ended Accelerometer SN 1610168 after Drift Correction

In order to correct the data for the time dependent drift in sensitivity the model introduced in Eq. 2 was used. For that purpose the time dependant part of the equation was subtracted from the reported result  $x_i$  of the participant *i* with the formula

$$\boldsymbol{x}_{i}^{\text{corr}} = \boldsymbol{x}_{i} - \boldsymbol{D} \cdot \boldsymbol{t}_{i} \tag{3}$$

where *D* is the slope of the fitted model,  $t_i$  denotes the time of the measurement (in month since beginning of the monitoring, c.f. table 1) and  $x_i^{corr}$  is the corrected result.

The standard uncertainty attributed to the corrected result is calculated with the sum of squares according to

$$U_i^{\text{corr}} = \sqrt{U_i^2 + U^2(\mathcal{S}(t_i))}$$
(4)

where  $U(S(t_i))$  is calculated from Eq. (2). It should be noted, that due to the calculation with absolute values for the correction and it's uncertainty it happens in some cases, that the resulting relative uncertainty is somewhat smaller than that originally stated by the laboratory. However, the amount in such cases is negligible.

PTB NIM NPLI **INMETRO**  $S_{qa}$  in rel. exp.  $S_{qa}$  in rel. exp.  $S_{qa}$  in rel. exp. S<sub>aa</sub> in rel. exp. pC/ pC/ unc. pC/ unc. pC/ unc. frequency unc.  $(m/s^2)$ in %  $(m/s^2)$ in %  $(m/s^2)$ in %  $(m/s^2)$ in % 0,13071 0,1048 0,13093 0,5003 0,13097 0,9987 0,13095 0,3459 10 12.5 0.13068 0,1048 0.13100 0.5003 \_ 0,13096 0.3459 16 0,13075 0,1048 0,13101 0,5003 -0,13097 0,3459 \_ 20 0,13073 0,1048 0,13098 0,5003 0.13097 0.6996 0.13096 0.3459 25 0,13077 0,1048 0,13094 0,5003 \_ 0,13096 0,2490 \_ 0,13073 0,1048 0,13097 0,2490 31.5 0,13099 0.5003 \_ \_ 0,13075 0,1048 40 0,13097 0,5003 0,13097 0,6996 0,13093 0,2490 0,13090 0,2490 50 0,13076 0,1048 0,13098 0,5003 \_ \_ 0,13093 0,2490 63 0,13073 0,1048 0,13096 0,5003 \_ -80 0,13074 0,1048 0,13097 0,5003 0,13094 0,2490 0,13107 0,6996 100 0,13075 0,1048 0,13093 0,5003 0,13107 0,6996 0,13095 0,2490 125 0,13075 0,1048 0,13094 0,5003 0,13094 0,2490 \_ \_ 160 0,13080 0,1048 0,13098 0,2027 0,13117 0,6996 0,13091 0,2490 200 0,13080 0,1048 0,13100 0,5003 0.13097 0.6996 0,13094 0.2490 0,13079 0,1048 0,13104 0,5003 0,13093 0,2490 250 \_ -315 0,13108 0,1048 0,13103 0,5003 0,13095 0,2490 --400 0,13088 0,1048 0,13102 0,5003 \_ 0,13099 0,2490 -500 0,13086 0,1048 0,13104 0,5003 0.13087 0.6996 0,13094 0,2490 630 0.13085 0.1048 0.13110 0.5003 -0.13101 0.2490 \_ 800 0,13087 0,1048 0,13105 0,5003 0.13097 0.6996 0,13103 0,2490 0,13093 0,1048 0,13112 0,13112 1000 0.5003 0.13097 0.6996 0,2490 0,1048 1250 0,13104 0,13122 0,5003 -0,13120 0,3459 -1600 0,13122 0,1048 0,13134 0,5003 \_ \_ 0,13138 0,3458 2000 0,13146 0,1048 0,13151 0,6996 0,13159 0,3458 0,5003 0,13087 2500 0.13175 0,1048 0,13197 0,5003 \_ 0,13192 0,5031 \_ 3150 0,13228 0,1047 0,13251 0,5003 0,13243 0,5030 \_ 0,13323 0,1047 4000 0,13325 0,5003 0,13087 0,9987 0,13345 0,5030 5000 0,13456 0,1046 0,13454 0,5002 0,13157 0,9986 0,13476 0,9990 6300 0,3012 0,13684 0,13674 0,9986 \_ \_ 0,13665 1,4966 8000 0,14079 0,3011 0,14104 0,9986 \_ \_ 0,13996 1,4965 10000 0.14691 0,3010 0,14652 0,9986 \_ \_ 0,14687 1,4964

# Table 9: calibration results in pC/(m/s<sup>2</sup>) of the participants for the SE transducer after correction of the drift with expanded relative uncertainty (k = 2) in %.



Fig. 21: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 10 Hz and 12,5 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 22: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 16 Hz and 20 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 23: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 25 Hz and 31 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 24: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 40 Hz and 50 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 25: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 63 Hz and 80 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 26: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 100 Hz and 125 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 27: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 160 Hz and 200 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 28: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 250 Hz and 315 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 29: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 400 Hz and 500 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 30: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 630 Hz and 800 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 31: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 1000 Hz and 1250 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 32: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 1600 Hz and 2000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 33: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 2500 Hz and 3150 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 34: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 4000 Hz and 5000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 35: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 6300 Hz and 8000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



# Fig. 36: Charge sensitivity of the SE transducer in pC/(m/s<sup>2</sup>) after correction of the drift for 10000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).

#### 7.4.3 Consistency of Results for the SE-Accelerometer

In order to check for consistency of the data a Chi-squared test was performed (c.f. [4]). This test revealed that for high frequencies the data were inconsistent if all participants results were included. This was already suggested by the outliers in fig. 18, an indication of the cause for the inconsistency can be drawn by elimination of each laboratory in turn from the chi-squared test and re-checking with only the remaining participants. The results from this testing before drift correction are shown in Table 10. For those frequencies,

where the data were consistent, columns 5 to 8 indicate which laboratory did report (+) results for the respective frequency and which did not (-). Table 11 shows the consistency after application of the drift correction.

Table 10: results of the consistency test for the reported results with the columns: frequency,  $X^2_{max}$  limit for *n*-1 degrees of freedom (*df*),  $X^2$  calculated from the reported results,  $X^2$  calculated from the reported results excluding the participant named in the header,  $X^2_{max}$  limit for *n*-2 degrees of freedom (*df*)

frequency in Hz	num. of particip. <i>n</i>	$\begin{array}{c} X^2_{max} \\ (df = n-1) \end{array}$	calculated X <sup>2</sup>	X <sup>2</sup> without PTB	X <sup>2</sup> without NIM	X <sup>2</sup> without NPLI	X <sup>2</sup> without INMETRO	$\begin{array}{c} X^{2}_{max} \\ (df = n-2) \end{array}$
10	4	9,49	0,2	+	+	+	+	
12,5	3	7,81	0,38	+	+	-	+	
16	3	7,81	0,31	+	+	-	+	
20	4	9,49	0,31	+	+	+	+	
25	3	7,81	0,44	+	+	-	+	
31,5	3	7,81	0,31	+	+	-	+	
40	4	9,49	0,61	+	+	+	+	
50	3	7,81	0,94	+	+	-	+	
63	3	7,81	0,48	+	+	-	+	
80	4	9,49	0,67	+	+	+	+	
100	4	9,49	0,56	+	+	+	+	
125	3	7,81	0,46	+	+	-	+	
160	4	9,49	1,88	+	+	+	+	
200	4	9,49	0,91	+	+	+	+	
250	3	7,81	1,08	+	+	-	+	
315	3	7,81	6,39	+	+	-	+	
400	3	7,81	1,25	+	+	-	+	
500	4	9,49	1,71	+	+	+	+	
630	3	7,81	0,86	+	+	-	+	
800	4	9,49	0,7	+	+	+	+	
1000	4	9,49	0,48	+	+	+	+	
1250	3	7,81	0,39	+	+	-	+	
1600	3	7,81	0,33	+	+	-	+	
2000	4	9,49	2,91	+	+	+	+	
2500	3	7,81	0,23	+	+	-	+	
3150	3	7,81	0,29	+	+	-	+	
4000	4	9,49	14,45	11,96	14,4	0,13	14,43	5,99
5000	4	9,49	22,49	17,13	22,39	0,19	22,48	5,99
6300	3	7,81	0,30	+	+	-	+	
8000	3	7,81	1,2	+	+	-	+	
10000	3	7,81	0,54	+	+	-	+	

Table 11: results of the consistency test after Drift correction for the detrended results with the columns: frequency,  $X^2_{max}$  limit for *n*-1 degrees of freedom (*df*),  $X^2$  calculated from the reported results,  $X^2$  calculated from the reported results excluding the participant named in the header,  $X^2_{max}$  limit for *n*-2 degrees of freedom (*df*)

frequency in Hz	num. of particip. <i>n</i>	$\begin{array}{c} X^{2}_{max} \\ (df = n-1) \end{array}$	calculated X <sup>2</sup>	X <sup>2</sup> without PTB	X <sup>2</sup> without NIM	X <sup>2</sup> without NPLI	X <sup>2</sup> without INMETRO	$\begin{array}{c} X^{2}_{max} \\ (df = n-2) \end{array}$
10	4	9,49	1,48	+	+	+	+	
12,5	3	7,81	2,13	+	+	-	+	
16	3	7,81	1,41	+	+	-	+	
20	4	9,49	1,62	+	+	+	+	
25	3	7,81	1,28	+	+	-	+	
31,5	3	7,81	2,35	+	+	-	+	
40	4	9,49	1,59	+	+	+	+	
50	3	7,81	1,02	+	+	-	+	
63	3	7,81	1,56	+	+	-	+	
80	4	9,49	1,98	+	+	+	+	
100	4	9,49	1,82	+	+	+	+	
125	3	7,81	1,36	+	+	-	+	
160	4	9,49	2,20	+	+	+	+	
200	4	9,49	1,06	+	+	+	+	
250	3	7,81	1,06	+	+	-	+	
315	3	7,81	0,58	+	+	-	+	
400	3	7,81	0,48	+	+	-	+	
500	4	9,49	0,47	+	+	+	+	
630	3	7,81	1,23	+	+	-	+	
800	4	9,49	1,04	+	+	+	+	
1000	4	9,49	1,39	+	+	+	+	
1250	3	7,81	0,71	+	+	-	+	
1600	3	7,81	0,56	+	+	-	+	
2000	4	9,49	2,00	+	+	+	+	
2500	3	7,81	0,66	+	+	-	+	
3150	3	7,81	0,61	+	+	-	+	
4000	4	9,49	13,37	12,85	13,36	0,41	12,86	5,99
5000	4	9,49	20,57	17,44	20,57	0,09	20,46	5,99
6300	3	7,81	0,05	+	+	-	+	
8000	3	7,81	0,76	+	+	-	+	
10000	3	7,81	0,26	+	+	-	+	

#### 7.4.4 The Back-to-Back Accelerometer S/N 2161771

This section presents the results for the B2B accelerometer in the equivalent way as section 7.4.1.

	РТВ		NIM		NPLI		INMETRO	
frequency	S <sub>qa</sub> in pC/ (m/s²)	rel. exp. unc. in %						
10	0,12606	0,10	0,12589	0,50	0,12620	1,00	0,12604	0,34
12,5	0,12616	0,10	0,12592	0,50	-	-	0,12604	0,34
16	0,12602	0,10	0,12599	0,50	-	-	0,12603	0,34
20	0,12601	0,10	0,12594	0,50	0,12610	0,70	0,12601	0,34
25	0,12609	0,10	0,12598	0,50	-	-	0,12602	0,24
31,5	0,12605	0,10	0,12603	0,50	-	-	0,12603	0,24
40	0,12598	0,10	0,12601	0,50	0,12610	0,70	0,12598	0,24
50	0,12586	0,10	0,12562	0,50	-	-	0,12596	0,24
63	0,12598	0,10	0,12584	0,50	-	-	0,12599	0,24
80	0,12600	0,10	0,12594	0,50	0,12620	0,70	0,12600	0,24
100	0,12597	0,10	0,12599	0,50	0,12620	0,70	0,12601	0,24
125	0,12601	0,10	0,12600	0,50	-	-	0,12601	0,24
160	0,12606	0,10	0,12604	0,20	0,12630	0,70	0,12603	0,24
200	0,12617	0,10	0,12606	0,50	0,12610	0,70	0,12604	0,24
250	0,12601	0,10	0,12601	0,50	-	-	0,12603	0,24
315	0,12619	0,10	0,12609	0,50	-	-	0,12605	0,24
400	0,12610	0,10	0,12611	0,50	-	-	0,12609	0,24
500	0,12606	0,10	0,12613	0,50	0,12600	0,70	0,12612	0,24
630	0,12608	0,10	0,12624	0,50	-	-	0,12614	0,24
800	0,12614	0,10	0,12622	0,50	0,12600	0,70	0,12616	0,24
1000	0,12630	0,10	0,12625	0,50	0,12600	0,70	0,12624	0,24
1250	0,12646	0,10	0,12635	0,50	-	-	0,12630	0,34
1600	0,12660	0,10	0,12639	0,50	-	-	0,12645	0,34
2000	0,12680	0,10	0,12653	0,50	0,12560	0,70	0,12659	0,34
2500	0,12710	0,10	0,12681	0,50	-	-	0,12684	0,50
3150	0,12738	0,10	0,12722	0,50	-	-	0,12718	0,50
4000	0,12804	0,10	0,12769	0,50	0,12600	1,00	0,12784	0,50
5000	0,12884	0,10	0,12851	0,50	0,12380	1,00	0,12857	1,00
6300	0,13022	0,30	0,12975	1,00	-	-	0,13016	1,50
8000	0,13281	0,30	0,13279	1,00	-	-	0,13257	1,50
10000	0,13679	0,30	0,13697	1,00	-	-	0,13664	1,50

Table 12: reported calibration results in pC/(m/s<sup>2</sup>) of the participants for the B2B transducer with expanded relative uncertainty (k = 2) in %.



Fig. 37: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 10 Hz and 12,5 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 38: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 16 Hz and 20 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 39: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 25 Hz and 31,5 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 40: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 40 Hz and 50 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).


Fig. 41: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 63 Hz and 80 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 42: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 100 Hz and 125 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 43: Charge sensitivity of the B2B transducer in  $pC/(m/s^2)$  reported by the participants for 160 Hz and 200 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 44: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 250 Hz and 315 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 45: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 400 Hz and 500 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 46: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 630 Hz and 800 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 47: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 1000 Hz and 1250 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 48: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 1600 Hz and 2000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 49: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 2500 Hz and 3150 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 50: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 4000 Hz and 5000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 51: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 6300 Hz and 8000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 52: Charge sensitivity of the B2B transducer in pC/(m/s<sup>2</sup>) reported by the participants for 10000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).

#### 7.4.5 Consistency of Results for the B2B-Accelerometer

In order to check for consistency of the data the same statistical test as described already in 7.4.3 was performed for the B2B accelerometer results. In case of inconsistency, again an indication of the cause can be drawn by elimination each laboratory in turn from the chi-squared test and checking for the three others. The results from this testing are shown in table 13.

Table 13: results of the consistency test after Drift correction for the reported results with the columns: frequency,  $X_{max}^2$  limit for *n*-1 degrees of freedom (*df*),  $X^2$  calculated from the reported results,  $X^2$  calculated from the reported results excluding the participant named in the header,  $X_{max}^2$  limit for *n*-2 degrees of freedom (*df*)

frequency in Hz	num. of particip. <i>n</i>	$\begin{array}{c} X^2_{max} \\ (df = n-1) \end{array}$	calculated X <sup>2</sup>	X <sup>2</sup> without PTB	X <sup>2</sup> without NIM	X <sup>2</sup> without NPLI	X <sup>2</sup> without INMETRO	$\begin{array}{c} X^{2}_{max} \\ (df = n-2) \end{array}$
10	4	9,49	0,34	+	+	+	+	
12,5	3	7,81	0,81	+	+	-	+	
16	3	7,81	0,01	+	+	-	+	
20	4	9,49	0,09	+	+	+	+	
25	3	7,81	0,28	+	+	-	+	
31,5	3	7,81	0,02	+	+	-	+	
40	4	9,49	0,08	+	+	+	+	
50	3	7,81	1,01	+	+	-	+	
63	3	7,81	0,2	+	+	-	+	
80	4	9,49	0,24	+	+	+	+	
100	4	9,49	0,31	+	+	+	+	
125	3	7,81	0	+	+	-	+	
160	4	9,49	0,35	+	+	+	+	
200	4	9,49	0,72	+	+	+	+	
250	3	7,81	0,01	+	+	-	+	
315	3	7,81	0,79	+	+	-	+	
400	3	7,81	0,01	+	+	-	+	
500	4	9,49	0,2	+	+	+	+	
630	3	7,81	0,36	+	+	-	+	
800	4	9,49	0,18	+	+	+	+	
1000	4	9,49	0,57	+	+	+	+	
1250	3	7,81	0,6	+	+	-	+	
1600	3	7,81	0,83	+	+	-	+	
2000	4	9,49	8,5	+	+	+	+	
2500	3	7,81	1,4	+	+	-	+	
3150	3	7,81	0,6	+	+	-	+	
4000	4	9,49	11,66	7,06	10,68	1,48	11,4	5,99
5000	4	9,49	66,4	47,88	65,7	1,17	66,29	5,99
6300	3	7,81	0,5	+	+	-	+	
8000	3	7,81	0,06	+	+	-	+	
10000	3	7,81	0,09	+	+	-	+	

# 7.5 Results of the Participants for the Phase of the complex Sensitivity

#### 7.5.1 Phase Measurement Results of the SE-Accelerometer

Three of the four participating laboratories were able to measure phase shift with their facilities. As an amendment, it was agreed that this results were supposed to be stated as well in the laboratories calibration report. They will be reported here as well and taken under consideration for the forthcoming analysis of degrees of equivalence DoE.

For acceleration signals a(t) of the form

$$a(t) = \hat{a} \cdot \cos(\omega t + \varphi_a) \tag{5}$$

and the respective charge output signal q(t) of the transducer of the form

$$q(t) = \hat{q} \cdot \cos(\omega t + \varphi_q) \tag{6}$$

the phase shift is defined according to ISO 16063-1 as

$$\Delta \varphi = \varphi_{qa} = \varphi_q - \varphi_a^{-}. \tag{7}$$

#### PTB NIM NPLI **INMETRO** exp. exp. exp. exp. $arphi_{ ext{qa}}$ in $arphi_{ ext{qa}}$ in $arphi_{ ext{qa}}$ in $arphi_{ ext{qa}}$ in frequency unc. unc. unc. unc. 1° 1° 1° 1° in 1° in 1° in 1° in 1° -0,13 0,20 0,50 -0,02 0,50 10 -0,05 -\_ 0.01 0.20 0.50 -0,01 0.50 12.5 -0.06 -\_ -0,07 0,20 0,50 -0,01 0,50 16 -0,05 --0,20 0,50 20 0,09 -0,06 0,50 -0,01 \_ \_ 25 0,00 0,20 -0,05 0,50 -0,01 0,50 --0,50 -0.02 0.20 0.50 -0.01 31.5 -0.05 \_ -40 -0,12 0,20 -0,04 0,50 \_ -0,00 0,50 0,23 0,20 0,50 0,50 50 -0,07 0,00 \_ --0,01 0,50 0,50 63 0,20 -0,07 --0,00 80 -0.01 0.20 -0.06 0.50 0,01 0.50 \_ \_ 100 -0,02 0,20 -0,05 0,50 -0,01 0,50 \_ 125 -0,02 0,20 -0,05 0,50 0,01 0,50 -\_ 160 -0,01 0,20 -0,05 0,20 -0,01 0,50 --200 -0,04 0,20 -0,05 0,50 0,02 0,50 \_ \_ 250 -0,01 0,20 0,04 0,50 0,03 0,50 \_ -315 -0.02 0,20 -0.06 0.50 0.04 0.50 \_ \_ 400 -0.03 0.20 -0,07 0.50 -0,00 0.50 -500 -0,04 0,20 -0,08 0,50 0,05 0,50 \_ \_ -0.02 -0.1 0.05 0.50 630 0.20 0.50 \_ -800 -0.05 0,20 -0.13 0.50 --0.04 0.50 1000 -0,04 0.20 -0,15 0.50 0,04 0.50 --1250 -0,08 -0,18 0,75 1,00 0,50 --0,05 1600 -0,11 0,50 -0,26 0,75 \_ \_ 0,06 1,00 2000 -0,13 0,50 -0,29 0,75 0,05 1,00 -\_ 2500 -0,3 0,50 -0,36 0,75 0,06 1,00 \_ \_ 3150 -0,17 0,50 -0,43 0,75 1,00 -\_ 0,09 4000 -0,33 0,50 -0,55 0,75 \_ -0.06 1.00 5000 -0,39 1,00 0,50 -0,69 0,75 \_ \_ 0,03 6300 -0,38 0,50 -0,83 1,00 0,16 1,50 \_ \_ 8000 -0,51 0,50 -1,00 1,00 \_ \_ 0,01 1,50 10000 -1,03 0,50 -1,42 1,00 0,12 1,50 \_ \_

# Table 14: reported calibration results in 1° of the participants for the phase shift $\varphi_{qa}$ of the SE transducer with expanded uncertainty (*k* = 2) in 1°.



Fig. 53: Phase shift of the SE transducer in 1° reported by the participants for 10 Hz and 12,5 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 54: Phase shift of the SE transducer in 1° reported by the participants for 16 Hz and 20 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 55: Phase shift of the SE transducer in 1° reported by the participants for 25 Hz and 31,5 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 56: Phase shift of the SE transducer in 1° reported by the participants for 40 Hz and 50 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 57: Phase shift of the SE transducer in 1° reported by the participants for 63 Hz and 80 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 58: Phase shift of the SE transducer in 1° reported by the participants for 100 Hz and 125 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 59: Phase shift of the SE transducer in 1° reported by the participants for 160 Hz and 200 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 60: Phase shift of the SE transducer in 1° reported by the participants for 250 Hz and 315 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 61: Phase shift of the SE transducer in 1° reported by the participants for 400 Hz and 500 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 62: Phase shift of the SE transducer in 1° reported by the participants for 630 Hz and 800 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 63: Phase shift of the SE transducer in 1° reported by the participants for 1000 Hz and 1250 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 64: Phase shift of the SE transducer in 1° reported by the participants for 1600 Hz and 2000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 65: Phase shift of the SE transducer in 1° reported by the participants for 2500 Hz and 3150 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 66: Phase shift of the SE transducer in 1° reported by the participants for 4000 Hz and 5000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 67: Phase shift of the SE transducer in 1° reported by the participants for 6300 Hz and 8000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 68: Phase shift of the SE transducer in 1° reported by the participants for 10000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).

### 7.5.2 Consistency of Phase shift Results for the SE-Accelerometer

In the same way as is was performed and reported above for the results of the magnitude of sensitivity the consistency check of all results was done for the phase shift measurements as well.

Table 15:	results of the consistency test for the reported results of phase shift with the
	columns: frequency, $X_{max}^2$ limit for <i>n</i> -1 degrees of freedom ( <i>df</i> ), $X^2$ calculated from
	the reported results, $X^2$ calculated from the reported results excluding the
	participant named in the header

frequency in Hz	num. of particip. <i>n</i>	$\begin{array}{c} X^{2}_{max} \\ (df = n-1) \end{array}$	calculated X <sup>2</sup>	X <sup>2</sup> without PTB	X <sup>2</sup> without NIM	X <sup>2</sup> without NPLI	X <sup>2</sup> without INMETRO
10	3	7,81	0,22	+	+	-	+
12,5	3	7,81	0,06	+	+	-	+
16	3	7,81	0,05	+	+	-	+
20	3	7,81	0,41	+	+	-	+
25	3	7,81	0,03	+	+	-	+
31,5	3	7,81	0,01	+	+	-	+
40	3	7,81	0,25	+	+	-	+
50	3	7,81	1,75	+	+	-	+
63	3	7,81	0,06	+	+	-	+
80	3	7,81	0,05	+	+	-	+
100	3	7,81	0,03	+	+	-	+
125	3	7,81	0,03	+	+	-	+
160	3	7,81	0,07	+	+	-	+
200	3	7,81	0,05	+	+	-	+
250	3	7,81	0,05	+	+	-	+
315	3	7,81	0,08	+	+	-	+
400	3	7,81	0,03	+	+	-	+
500	3	7,81	0,15	+	+	-	+
630	3	7,81	0,19	+	+	-	+
800	3	7,81	0,24	+	+	-	+
1000	3	7,81	0,28	+	+	-	+
1250	3	7,81	0,13	+	+	-	+
1600	3	7,81	0,27	+	+	-	+
2000	3	7,81	0,30	+	+	-	+
2500	3	7,81	0,50	+	+	-	+
3150	3	7,81	0,73	+	+	-	+
4000	3	7,81	0,96	+	+	-	+
5000	3	7,81	1,33	+	+	-	+
6300	3	7,81	1,29	+	+	-	+
8000	3	7,81	1,41	+	+	-	+
10000	3	7,81	2,94	+	+	-	+

#### 7.5.3 Phase Measurement Results of the B2B-Accelerometer

	P.	ТВ	N	IM	NPLI		INMETRO	
frequency	$arphi_{ ext{qa}}$ in 1°	exp. unc. in 1°	$arphi_{ ext{qa}}$ in 1°	exp. unc. in 1°	$arphi_{ ext{qa}}$ in $1^\circ$	exp. unc. in 1°	$arphi_{ ext{qa}}$ in 1°	exp. unc. in 1°
10	-0,02	0,20	-0,03	0,50	-	-	-0,03	0,50
12,5	-0,03	0,20	-0,04	0,50	-	-	-0,02	0,50
16	-0,05	0,20	0,00	0,50	-	-	-0,02	0,50
20	-0,03	0,20	-0,03	0,50	-	-	0,00	0,50
25	-0,01	0,20	-0,01	0,50	-	-	0,00	0,50
31,5	-0,01	0,20	-0,01	0,50	-	-	0,00	0,50
40	-0,03	0,20	-0,02	0,50	-	-	0,01	0,50
50	-0,09	0,20	-0,05	0,50	-	-	0,01	0,50
63	-0,03	0,20	-0,04	0,50	-	-	0,01	0,50
80	-0,03	0,20	-0,03	0,50	-	-	0,02	0,50
100	-0,02	0,20	-0,02	0,50	-	-	0,03	0,50
125	-0,02	0,20	-0,02	0,50	-	-	0,03	0,50
160	-0,07	0,20	-0,01	0,20	-	-	0,03	0,50
200	-0,10	0,20	-0,01	0,50	-	-	0,04	0,50
250	0,06	0,20	0,06	0,50	-	-	0,06	0,50
315	0,08	0,20	-0,02	0,50	-	-	0,07	0,50
400	0,02	0,20	-0,03	0,50	-	-	0,02	0,50
500	0,01	0,20	-0,04	0,50	-	-	0,07	0,50
630	0,04	0,20	-0,05	0,50	-	-	0,08	0,50
800	-0,01	0,20	-0,09	0,50	-	-	0,08	0,50
1000	-0,02	0,20	-0,12	0,50	-	-	0,08	0,50
1250	-0,03	0,50	-0,16	0,75	-	-	0,09	1,00
1600	0,10	0,50	-0,19	0,75	-	-	0,10	1,00
2000	-0,06	0,50	-0,27	0,75	-	-	0,09	1,00
2500	-0,15	0,50	-0,35	0,75	-	-	0,10	1,00
3150	-0,10	0,50	-0,45	0,75	-	-	0,12	1,00
4000	-0,21	0,50	-0,58	0,75	-	-	0,14	1,00
5000	-0,13	0,50	-0,72	0,75	-	-	0,14	1,00
6300	-0,28	0,50	-0,86	1,00	-	-	0,18	1,50
8000	-0,40	0,50	-1,47	1,00	-	-	0,14	1,50
10000	-0,39	0,50	-1,59	1,00	-	-	0,38	1,50

Table 16: reported calibration results in 1° of the participants for the phase shift  $\varphi_{qa}$  of the B2B transducer with expanded uncertainty (*k* = 2) in 1°.



Fig. 69: Phase shift of the B2B transducer in 1° reported by the participants for 10 Hz and 12,5 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 70: Phase shift of the B2B transducer in 1° reported by the participants for 16 Hz and 20 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 71: Phase shift of the B2B transducer in 1° reported by the participants for 25 Hz and 31,5 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 72: Phase shift of the B2B transducer in 1° reported by the participants for 40 Hz and 50 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 73: Phase shift of the B2B transducer in 1° reported by the participants for 63 Hz and 80 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 74: Phase shift of the B2B transducer in 1° reported by the participants for 100 Hz and 125 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 75: Phase shift of the B2B transducer in 1° reported by the participants for 160 Hz and 200 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 76: Phase shift of the B2B transducer in 1° reported by the participants for 250 Hz and 315 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 77: Phase shift of the B2B transducer in 1° reported by the participants for 400 Hz and 500 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 78: Phase shift of the B2B transducer in 1° reported by the participants for 630 Hz and 800 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 79: Phase shift of the B2B transducer in 1° reported by the participants for 1000 Hz and 1250 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 80: Phase shift of the B2B transducer in 1° reported by the participants for 1600 Hz and 2000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 81: Phase shift of the B2B transducer in 1° reported by the participants for 2500 Hz and 3150 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 82: Phase shift of the B2B transducer in 1° reported by the participants for 4000 Hz and 5000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 83: Phase shift of the B2B transducer in 1° reported by the participants for 6300 Hz and 8000 Hz excitation frequency with error bars representing the expanded uncertainty (k = 2).



Fig. 84: Phase shift of the B2B transducer in  $1^{\circ}$  reported by the participants for 10000 Hz a excitation frequency with error bars representing the expanded uncertainty (k = 2).

#### 7.5.4 Consistency of Results for the B2B-Accelerometer

Table 17: results of the consistency test for the reported results of phase shift with the columns: frequency,  $X_{max}^2$  limit for *n*-1 degrees of freedom (*df*),  $X^2$  calculated from the reported results,  $X^2$  calculated from the reported results excluding the participant named in the header,  $X_{max}^2$  limit for *n*-2 degrees of freedom (*df*)

			,	11104		5		/
frequency in Hz	num. of particip. <i>n</i>	$\begin{array}{c} X^2_{max} \\ (df = n-1) \end{array}$	calculated X <sup>2</sup>	X <sup>2</sup> without PTB	X <sup>2</sup> without NIM	X <sup>2</sup> without NPLI	X <sup>2</sup> without INMETRO	$X^{2}_{max}$ ( <i>df</i> = n-2)
10	3	7,81	0,003	+	+	-	+	
12,5	3	7,81	0,005	+	+	-	+	
16	3	7,81	0,03	+	+	-	+	
20	3	7,81	0,01	+	+	-	+	
25	3	7,81	0,003	+	+	-	+	
31,5	3	7,81	0,003	+	+	-	+	
40	3	7,81	0,02	+	+	-	+	
50	3	7,81	0,14	+	+	-	+	
63	3	7,81	0,02	+	+	-	+	
80	3	7,81	0,03	+	+	-	+	
100	3	7,81	0,04	+	+	-	+	
125	3	7,81	0,03	+	+	-	+	
160	3	7,81	0,27	+	+	-	+	
200	3	7,81	0,31	+	+	-	+	
250	3	7,81	0,0002	+	+	-	+	
315	3	7,81	0,15	+	+	-	+	
400	3	7,81	0,04	+	+	-	+	
500	3	7,81	0,1	+	+	-	+	
630	3	7,81	0,16	+	+	-	+	
800	3	7,81	0,22	+	+	-	+	
1000	3	7,81	0,31	+	+	-	+	
1250	3	7,81	0,17	+	+	-	+	
1600	3	7,81	0,46	+	+	-	+	
2000	3	7,81	0,38	+	+	-	+	
2500	3	7,81	0,52	+	+	-	+	
4000	3	7,81	1,4	+	+	-	+	
5000	3	7,81	2,41	+	+	-	+	
8000	3	7,81	4,57	+	+	-	+	
10000	3	7,81	6,25	+	+	-	+	

### 8 Results of the comparison

### 8.1 Degree of equivalence between the participants

In order to compare the individual reults of the participating laboratories of this comparison with one another the DoE of pairs of results with respect to a certain frequency were calculated. This DoE are each a pair of values of the difference  $\underline{D}_{ij}$  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:

$$D_{ij} = x_i - x_j \tag{8}$$

$$U_{ij} = k \cdot \sqrt{u^2(x_i) + u^2(x_j)}$$
(9)

with a coverage factor of k = 2.

#### 8.1.1 DoE for magnitude of sensitivity of the SE transducer

Table 18: DoE for magnitude of sensiti	vity between the participants of CCAUV.V-K1.1 for the SE
transducer	

		NIM		NPLI		INMETRO	
		D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>
		in 104 p	C/(m/s²)	in 10⁴ p	C/(m/s²)	in 10 <sup>4</sup> pC/(m/s <sup>2</sup> )	
10,0 Hz	PTB	-2,2	6,7	-2,6	13,2	-2,4	4,7
	NIM			-0,4	14,6	-0,2	8,0
	NPLI					0,2	13,8
12,5 Hz	PTB	-3,2	6,7			-2,7	4,7
	NIM					0,4	8,0
	NPLI						
16,0 Hz	PTB	-2,6	6,7			-2,2	4,7
	NIM					0,4	8,0
	NPLI						
20,0 Hz	PTB	-2,5	6,7	-2,4	9,3	-2,3	4,7
	NIM			0,1	11,3	0,2	8,0
	NPLI					0,1	10,2
25,0 Hz	PTB	-1,7	6,7			-1,9	3,5
	NIM					-0,2	7,3
	NPLI						
31,5 Hz	PTB	-2,7	6,7			-2,4	3,5
	NIM					0,2	7,3
	NPLI						

		NIM		NPLI		INMETRO	
		D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	$U_{ij}$
		in 10⁴ p	C/(m/s²)	in 104 p	C/(m/s²)	in 104 p	C/(m/s²)
40,0 Hz	PTB	-2,3	6,7	-2,3	9,3	-1,8	3,5
	NIM			0,0	11,3	0,4	7,3
	NPLI					0,4	9,7
50,0 Hz	PTB	-2,3	6,7			-1,4	3,5
	NIM					0,8	7,3
	NPLI						
63,0 Hz	PTB	-2,3	6,7			-1,9	3,5
	NIM					0,3	7,3
	NPLI						
80,0 Hz	PTB	-2,3	6,7	-3,3	9,3	-2,0	3,5
	NIM			-1,0	11,3	0,3	7,3
	NPLI					1,3	9,7
100,0 Hz	PTB	-1,8	6,7	-3,2	9,3	-2,0	3,5
	NIM			-1,4	11,3	-0,2	7,3
	NPLI					1,2	9,7
125,0 Hz	PTB	-1,9	6,7			-1,9	3,5
	NIM					0,0	7,3
	NPLI						
160,0 Hz	PTB	-1,8	3,0	-3,7	9,3	-1,1	3,5
	NIM			-1,9	9,6	0,7	4,2
	NPLI					2,6	9,7
200,0 Hz	PTB	-2,1	6,7	-1,8	9,3	-1,4	3,5
	NIM			0,3	11,3	0,6	7,3
	NPLI					0,3	9,7
250,0 Hz	PTB	-2,5	6,7			-1,4	3,5
	NIM					1,1	7,3
	NPLI						
315,0 Hz	PTB	0,5	6,7			1,3	3,5
	NIM					0,8	7,3
	NPLI						
400,0 Hz	PTB	-1,4	6,7			-1,0	3,5
	NIM					0,3	7,3

		NIM		NPLI		INMETRO	
		D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>
		in 10⁴ p	C/(m/s²)	in 10⁴ p	C/(m/s²)	in 10 <sup>4</sup> pC/(m/s <sup>2</sup> )	
	NPLI						
500,0 Hz	PTB	-1,8	6,7	-0,1	9,3	-0,8	3,5
	NIM			1,7	11,3	1,0	7,3
	NPLI					-0,7	9,7
630,0 Hz	PTB	-2,5	6,7			-1,6	3,5
	NIM					0,9	7,3
	NPLI						
800,0 Hz	PTB	-1,8	6,7	-1,0	9,3	-1,6	3,5
	NIM			0,8	11,3	0,2	7,3
	NPLI					-0,6	9,7
1000,0 Hz	PTB	-1,9	6,7	-0,4	9,3	-1,9	3,5
	NIM			1,5	11,3	0,0	7,3
	NPLI					-1,5	9,7
1250,0 Hz	PTB	-1,8	6,7			-1,6	4,7
	NIM					0,2	8,0
	NPLI						
1600,0 Hz	PTB	-1,2	6,7			-1,6	4,7
	NIM					-0,4	8,0
	NPLI						
2000,0 Hz	PTB	-0,5	6,7	5,9	9,3	-1,3	4,8
	NIM			6,4	11,3	-0,8	8,0
	NPLI					-7,2	10,2
2500,0 Hz	PTB	-2,2	6,7			-1,8	6,8
	NIM					0,4	9,4
	NPLI						
3150,0 Hz	PTB	-2,2	6,8			-1,5	6,8
	NIM					0,7	9,4
	NPLI						
4000,0 Hz	PTB	-0,2	6,8	23,6	13,1	-2,2	6,9
	NIM			23,7	14,7	-2,0	9,5
	NPLI					-25,7	14,7
5000,0 Hz	PTB	0,2	6,9	29,9	13,2	-2,0	13,5

Degree of equivalence between the participants

		NIM		NPLI		INMETRO	
		D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>
		in 10⁴ p	C/(m/s²)	in 10⁴ p	C/(m/s²)	in 10 <sup>4</sup> pC/(m/s <sup>2</sup> )	
	NIM			29,7	14,8	-2,2	15,1
	NPLI					-31,9	18,8
6300,0 Hz	PTB	1,0	14,3			1,9	20,9
	NIM					1,0	24,6
	NPLI						
8000,0 Hz	PTB	-2,6	14,7			8,3	21,4
	NIM					10,8	25,2
	NPLI						
10000,0 Hz	PTB	3,9	15,3			0,4	22,4
	NIM					-3,5	26,4
	NPLI						

		N	IM	INMETRO		
		Dii	U <sub>ii</sub>	Dii	U <sub>ii</sub>	
		in	1°	in 1°		
10,0 Hz	PTB	-0,1	0,5	-0,1	0,5	
	NIM			-0,0	0,7	
12,5 Hz	РТВ	0,1	0,5	0,0	0,5	
	NIM			-0,0	0,7	
16,0 Hz	РТВ	-0,0	0,5	-0,1	0,5	
	NIM			-0,0	0,7	
20,0 Hz	РТВ	0,2	0,5	0,1	0,5	
	NIM			-0,1	0,7	
25,0 Hz	PTB	0,1	0,5	0,0	0,5	
	NIM			-0,0	0,7	
31,5 Hz	PTB	0,0	0,5	-0,0	0,5	
	NIM			-0,0	0,7	
40,0 Hz	РТВ	-0,1	0,5	-0,1	0,5	
	NIM			-0,0	0,7	
50,0 Hz	PTB	0,3	0,5	0,2	0,5	

		NIM		INMETRO		
	NIM			-0,1	0,7	
63,0 Hz	РТВ	0,1	0,5	-0,0	0,5	
	NIM			-0,1	0,7	
80,0 Hz	РТВ	0,1	0,5	-0,0	0,5	
	NIM			-0,1	0,7	
100,0 Hz	РТВ	0,0	0,5	-0,0	0,5	
	NIM			-0,1	0,7	
125,0 Hz	РТВ	0,0	0,5	-0,0	0,5	
	NIM			-0,1	0,7	
160,0 Hz	РТВ	0,0	0,3	0,0	0,5	
	NIM			-0,0	0,5	
200,0 Hz	РТВ	0,0	0,5	-0,1	0,5	
	NIM			-0,1	0,7	
250,0 Hz	РТВ	-0,0	0,5	-0,0	0,5	
	NIM			0,0	0,7	
315,0 Hz	РТВ	0,0	0,5	-0,1	0,5	
	NIM			-0,1	0,7	
400,0 Hz	РТВ	0,0	0,5	-0,0	0,5	
	NIM			-0,1	0,7	
500,0 Hz	РТВ	0,0	0,5	-0,1	0,5	
	NIM			-0,1	0,7	
630,0 Hz	РТВ	0,1	0,5	-0,1	0,5	
	NIM			-0,2	0,7	
800,0 Hz	РТВ	0,1	0,5	-0,1	0,5	
	NIM			-0,2	0,7	
1000,0 Hz	РТВ	0,1	0,5	-0,1	0,5	
	NIM			-0,2	0,7	
1250,0 Hz	РТВ	0,1	0,9	-0,1	1,1	
	NIM			-0,2	1,2	
1600,0 Hz	РТВ	0,1	0,9	-0,2	1,1	
	NIM			-0,3	1,2	
2000,0 Hz	PTB	0,2	0,9	-0,2	1,1	
	NIM			-0,3	1,2	
2500,0 Hz	PTB	0,1	0,9	-0,4	1,1	

Degree of equivalence between the participants

		NIM		INMETRO	
	NIM			-0,4	1,2
3150,0 Hz	PTB	0,3	0,9	-0,3	1,1
	NIM			-0,5	1,2
4000,0 Hz	PTB	0,2	0,9	-0,4	1,1
	NIM			-0,6	1,2
5000,0 Hz	PTB	0,3	0,9	-0,4	1,1
	NIM			-0,7	1,2
6300,0 Hz	PTB	0,4	1,1	-0,5	1,6
	NIM			-1,0	1,8
8000,0 Hz	PTB	0,5	1,1	-0,5	1,6
	NIM			-1,0	1,8
10000,0 Hz	PTB	0,4	1,1	-1,1	1,6
	NIM			-1,5	1,8

## 8.1.2 DoE for phase shift of sensitivity of the SE transducer

# Table 19: DoE for phase shift of sensitivity between the participants of CCAUV.V-K1.1 for the SE transducer

		NIM		INMETRO	
		Dii	U <sub>ii</sub>	Dii	U <sub>ii</sub>
		in 1°		in 1°	
10,0 Hz	РТВ	-0,1	0,5	-0,1	0,5
	NIM			-0,0	0,7
12,5 Hz	РТВ	0,1	0,5	0,0	0,5
	NIM			-0,0	0,7
16,0 Hz	РТВ	-0,0	0,5	-0,1	0,5
	NIM			-0,0	0,7
20,0 Hz	РТВ	0,2	0,5	0,1	0,5
	NIM			-0,1	0,7
25,0 Hz	РТВ	0,1	0,5	0,0	0,5
	NIM			-0,0	0,7
31,5 Hz	РТВ	0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
40,0 Hz	PTB	-0,1	0,5	-0,1	0,5
	NIM			-0,0	0,7
50,0 Hz	PTB	0,3	0,5	0,2	0,5

		NIM		INMETRO	
	NIM			-0,1	0,7
63,0 Hz	РТВ	0,1	0,5	-0,0	0,5
	NIM			-0,1	0,7
80,0 Hz	РТВ	0,1	0,5	-0,0	0,5
	NIM			-0,1	0,7
100,0 Hz	РТВ	0,0	0,5	-0,0	0,5
	NIM			-0,1	0,7
125,0 Hz	РТВ	0,0	0,5	-0,0	0,5
	NIM			-0,1	0,7
160,0 Hz	РТВ	0,0	0,3	0,0	0,5
	NIM			-0,0	0,5
200,0 Hz	PTB	0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
250,0 Hz	PTB	-0,0	0,5	-0,0	0,5
	NIM			0,0	0,7
315,0 Hz	РТВ	0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
400,0 Hz	РТВ	0,0	0,5	-0,0	0,5
	NIM			-0,1	0,7
500,0 Hz	РТВ	0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
630,0 Hz	РТВ	0,1	0,5	-0,1	0,5
	NIM			-0,2	0,7
800,0 Hz	РТВ	0,1	0,5	-0,1	0,5
	NIM			-0,2	0,7
1000,0 Hz	РТВ	0,1	0,5	-0,1	0,5
	NIM			-0,2	0,7
1250,0 Hz	РТВ	0,1	0,9	-0,1	1,1
	NIM			-0,2	1,2
1600,0 Hz	PTB	0,1	0,9	-0,2	1,1
	NIM			-0,3	1,2
2000,0 Hz	PTB	0,2	0,9	-0,2	1,1
	NIM			-0,3	1,2
2500,0 Hz	PTB	0,1	0,9	-0,4	1,1

Degree of equivalence between the participants

		NIM		INMETRO	
	NIM			-0,4	1,2
3150,0 Hz	PTB	0,3	0,9	-0,3	1,1
	NIM			-0,5	1,2
4000,0 Hz	PTB	0,2	0,9	-0,4	1,1
	NIM			-0,6	1,2
5000,0 Hz	PTB	0,3	0,9	-0,4	1,1
	NIM			-0,7	1,2
6300,0 Hz	РТВ	0,4	1,1	-0,5	1,6
	NIM			-1,0	1,8
8000,0 Hz	PTB	0,5	1,1	-0,5	1,6
	NIM			-1,0	1,8
10000,0 Hz	PTB	0,4	1,1	-1,1	1,6
	NIM			-1,5	1,8

#### 8.1.3 DoE for magnitude of sensitivity the B2B transducer

Table 20: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 for the B2B transducer

		NIM		NPLI		INMETRO	
		D"	U"	D <sub>ii</sub>	Uii	D"	U <sub>ii</sub>
		in 10 <sup>4</sup> pC/(m/s <sup>2</sup> )		in 10 <sup>4</sup> pC/(m/s <sup>2</sup> )		in 10 <sup>4</sup> pC/(m/s²)	
10,0 Hz	PTB	1,7	6,4	-1,4	12,7	0,2	4,5
	NIM			-3,1	14,1	-1,5	7,6
	NPLI					1,6	13,3
12,5 Hz	PTB	2,4	6,4			1,2	4,5
	NIM					-1,2	7,6
	NPLI						
16,0 Hz	PTB	0,3	6,4			-0,1	4,5
	NIM					-0,4	7,6
	NPLI						
20,0 Hz	PTB	0,7	6,4	-0,9	8,9	0,0	4,5
	NIM			-1,6	10,8	-0,7	7,6
	NPLI					0,9	9,8
25,0 Hz	PTB	1,1	6,4			0,7	3,3
## Degree of equivalence between the participants

		N	IIM	N	PLI	INME	TRO
		Dii	U	Dii	U <sub>ii</sub>	Dii	U <sub>ii</sub>
		in 10⁴ p	oC/(m/s²)	in 10⁴ p	oC/(m/s²)	in 10⁴ pC/(m/s²)	
	NIM					-0,4	7,0
	NPLI						
31,5 Hz	PTB	0,2	6,4			0,2	3,3
	NIM					0,0	7,0
	NPLI						
40,0 Hz	PTB	-0,3	6,4	-1,2	8,9	0,0	3,3
	NIM			-0,9	10,8	0,3	7,0
	NPLI					1,2	9,3
50,0 Hz	PTB	2,4	6,4			-1,0	3,3
	NIM					-3,4	7,0
	NPLI						
63,0 Hz	PTB	1,4	6,4			-0,1	3,3
	NIM					-1,5	7,0
	NPLI						
80,0 Hz	PTB	0,6	6,4	-2,0	8,9	0,0	3,3
	NIM			-2,6	10,8	-0,6	7,0
	NPLI					2,0	9,3
100,0 Hz	PTB	-0,2	6,4	-2,3	8,9	-0,4	3,3
	NIM			-2,1	10,9	-0,2	7,0
	NPLI					1,9	9,3
125,0 Hz	PTB	0,1	6,4			0,0	3,3
	NIM					-0,1	7,0
	NPLI						
160,0 Hz	PTB	0,2	2,8	-2,4	8,9	0,3	3,3
	NIM			-2,6	9,2	0,1	3,9
	NPLI					2,7	9,3
200,0 Hz	PTB	1,1	6,4	0,7	8,9	1,3	3,3
	NIM			-0,4	10,8	0,2	7,0
	NPLI					0,6	9,3
250,0 Hz	PTB	0,0	6,4			-0,2	3,3
	NIM					-0,2	7,0
	NPLI						

## Degree of equivalence between the participants

		N	IM	N	PLI	INME	TRO
		D"	U <sub>"</sub>	Dii	U <sub>ii</sub>	D <sub>ii</sub>	U <sub>ii</sub>
		in 10⁴ p	C/(m/s²)	in 10⁴ p	oC/(m/s²)	in 10⁴ p	C/(m/s²)
315,0 Hz	PTB	1,0	6,4			1,4	3,3
	NIM					0,4	7,0
	NPLI						
400,0 Hz	PTB	-0,1	6,4			0,1	3,3
	NIM					0,2	7,0
	NPLI						
500,0 Hz	PTB	-0,7	6,4	0,6	8,9	-0,6	3,3
	NIM			1,3	10,8	0,1	7,0
	NPLI					-1,2	9,3
630,0 Hz	PTB	-1,6	6,4			-0,6	3,3
	NIM					1,0	7,0
	NPLI						
800,0 Hz	PTB	-0,8	6,4	1,4	8,9	-0,2	3,3
	NIM			2,2	10,8	0,6	7,0
	NPLI					-1,6	9,3
1000,0 Hz	PTB	0,5	6,4	3,0	8,9	0,6	3,3
	NIM			2,5	10,8	0,1	7,0
	NPLI					-2,4	9,3
1250,0 Hz	PTB	1,1	6,4			1,6	4,5
	NIM					0,5	7,6
	NPLI						
1600,0 Hz	PTB	2,1	6,4			1,5	4,5
	NIM					-0,6	7,6
	NPLI						
2000,0 Hz	PTB	2,7	6,5	12,0	8,9	2,1	4,5
	NIM			9,3	10,8	-0,6	7,7
	NPLI					-9,9	9,8
2500,0 Hz	PTB	2,9	6,5			2,6	6,5
	NIM					-0,3	9,0
	NPLI						
3150,0 Hz	PTB	1,6	6,5			2,0	6,5
	NIM					0,4	9,0

## Degree of equivalence between the participants

		N	IM	NF	PLI	INME	TRO
		D"	U <sub>ii</sub>	Dii	U <sub>ii</sub>	Dii	U <sub>ii</sub>
		in 10⁴ p	C/(m/s²)	in 10⁴ p	C/(m/s²)	in 10⁴ p	C/(m/s²)
	NPLI						
4000,0 Hz	PTB	3,5	6,5	20,4	12,7	2,0	6,5
	NIM			16,9	14,1	-1,5	9,0
	NPLI					-18,4	14,1
5000,0 Hz	PTB	3,3	6,6	50,4	12,4	2,7	12,9
	NIM			47,1	13,9	-0,6	14,4
	NPLI					-47,7	17,8
6300,0 Hz	PTB	4,7	13,6			0,6	19,9
	NIM					-4,1	23,4
	NPLI						
8000,0 Hz	PTB	0,2	13,9			2,4	20,3
	NIM					2,2	23,9
	NPLI						
10000,0 Hz	PTB	-1,8	14,3			1,5	20,9
	NIM					3,3	24,7
	NPLI						

#### 8.1.4 DoE for phase shift of sensitivity of the B2B transducer

		N	IM	INME	TRO
		Dii	U <sub>ii</sub>	Dii	U,
		in	1°	in	1°
10,0 Hz	PTB	0,0	0,5	0,0	0,5
	NIM			0,0	0,7
12,5 Hz	PTB	0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
16,0 Hz	PTB	-0,0	0,5	-0,0	0,5
	NIM			0,0	0,7
20,0 Hz	PTB	0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
25,0 Hz	PTB	-0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
31,5 Hz	PTB	-0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
40,0 Hz	РТВ	-0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
50,0 Hz	РТВ	-0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
63,0 Hz	PTB	0,0	0,5	-0,0	0,5
	NIM			-0,1	0,7
80,0 Hz	PTB	-0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
100,0 Hz	PTB	0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
125,0 Hz	PTB	-0,0	0,5	-0,0	0,5
	NIM			-0,0	0,7
160,0 Hz	РТВ	-0,1	0,3	-0,1	0,5
	NIM			-0,0	0,5
200,0 Hz	PTB	-0,1	0,5	-0,1	0,5
	NIM			-0,1	0,7
250,0 Hz	PTB	0,0	0,5	-0,0	0,5

# Table 21: DoE for phase shift of sensitivity between the participants of CCAUV.V-K1.1 for the B2B transducer

		N	IM	INME	ETRO
		D"	U <sub>ii</sub>	D <sub>ii</sub>	U <sub>ii</sub>
		in	1°	in	1°
	NIM			-0,0	0,7
315,0 Hz	PTB	0,1	0,5	0,0	0,5
	NIM			-0,1	0,7
400,0 Hz	PTB	0,1	0,5	0,0	0,5
	NIM			-0,1	0,7
500,0 Hz	PTB	0,0	0,5	-0,1	0,5
	NIM			-0,1	0,7
630,0 Hz	PTB	0,1	0,5	-0,0	0,5
	NIM			-0,1	0,7
800,0 Hz	PTB	0,1	0,5	-0,1	0,5
	NIM			-0,2	0,7
1000,0 Hz	PTB	0,1	0,5	-0,1	0,5
	NIM			-0,2	0,7
1250,0 Hz	PTB	0,1	0,9	-0,1	1,1
	NIM			-0,2	1,2
1600,0 Hz	PTB	0,3	0,9	0,0	1,1
	NIM			-0,3	1,2
2000,0 Hz	PTB	0,2	0,9	-0,1	1,1
	NIM			-0,4	1,2
2500,0 Hz	PTB	0,2	0,9	-0,2	1,1
	NIM			-0,4	1,2
3150,0 Hz	PTB	0,3	0,9	-0,2	1,1
	NIM			-0,6	1,2
4000,0 Hz	PTB	0,4	0,9	-0,3	1,1
	NIM			-0,7	1,2
5000,0 Hz	PTB	0,6	0,9	-0,3	1,1
	NIM			-0,9	1,2
6300,0 Hz	PTB	0,6	1,1	-0,5	1,6
	NIM			-1,0	1,8
8000,0 Hz	PTB	1,1	1,1	-0,5	1,6
	NIM			-1,6	1,8
10000,0 Hz	PTB	1,2	1,1	-0,8	1,6

	N	IM	INMETRO		
	D:: U::		D#	U"	
	in	1°	in	1°	
NIM			-2,0	1,8	

### 8.2 Degree of equivalence relative to the KCRV of CCAUV.V-K1

#### 8.2.1 The Linking

In order to keep up the consistency of procedure and thus the comparability between the different KC in the field of vibration performed so far, the linking was calculated according to the same scheme, already applied for APMP.AUV.V-K1 and EUROMET.AUV.V-K1. The calculation procedure is described in [5] and [6] in more detail.

To put it simple, the linking transforms the results ( $x_i$ ,  $u(x_i)$ ) of the participants of CCAUV.V-K1.1 to scaled values  $z_i$  and their respective uncertainty  $u(z_i)$ , which are directly comparable to the results of CCAUV.V-K1 in absolute terms. The scaling is done with the so called linking factor R. This factor is calculated from the results of the linking laboratories in this subsequent KC and the KCRV on CIPM-level.

A specific characteristic for this subsequent comparison documented in this report is, that only one single linking laboratory, namely PTB, is responsible to calculate the estimate r of the linking factor R and it's corresponding uncertainty u(r). Therefore the linking coefficient in this particular case is simply the ratio of the CIPM-KCRV and the results of the linking laboratory (PTB) in CCAUV.V-K1.1.

Since the linked results of the pilot are of no importance in the process (PTB already took part in CCAUV.V-K1 and EUROMET.AUV.V-K1), this section will concentrate on the linked results of the other three participants and their Degree of Equivalence (DoE) with the participants of CCAUV.V-K1 and with its reference value.

#### 8.2.2 DoE relative to the KCRV of CCAUV.V-K1 for the SE transducer

In order to perform a comparison of the participants with the reference value of CCAUV.V-K1 the difference of the linked results  $z_i$  and its uncertainty is calculated. This gives the DoE relative to the KCRV. The following tables document this for the two transducers used in this comparison.

	NIM		NF	PLI	INMETRO					
	D <sub>i</sub>	Ui	D <sub>i</sub>	Ui	D <sub>i</sub>	Ui				
Frequency in Hz	in 10⁴ p	C/(m/s²)	in 10⁴ pC/(m/s²)		in 10 <sup>4</sup> pC/(m/s <sup>2</sup> )		in 10 <sup>4</sup> pC/(m/s <sup>2</sup> )		in 10⁴ pC/(m/s²)	
40,0	2,2	6,6	2,2	9,1	1,8	3,5				
80,0	2,3	6,6	3,3	9,1	1,9	3,5				
160,0	1,8	2,9	3,7	9,2	1,1	3,5				
800,0	1,8	6,6	1,0	9,1	1,6	3,5				
2000,0	0,5	6,6	-5,8	9,1	1,3	4,7				

Table 22: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and the KC	RV
of CCAUV.V-K1 for the SE transducer	

#### 8.2.3 DoE to the KCRV of CCAUV.V-K1 for the B2B transducer

Table 23: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and the KCRV of CCAUV.V-K1 for the B2B transducer

	N	IM	NF	PLI	INME	TRO
	D <sub>i</sub>	Ui	D <sub>i</sub>	Ui	$D_i$	Ui
Frequency in Hz	in 10⁴ p	10 <sup>4</sup> pC/(m/s <sup>2</sup> ) in 10 <sup>4</sup> pC/(m/s <sup>2</sup> ) in 10 <sup>4</sup> pC/(m/s <sup>2</sup> )		in 10 <sup>4</sup> pC/(m/s²)		C/(m/s²)
40,0	0,3	6,5	1,2	9,0	0,0	3,3
80,0	-0,6	6,5	2,0	9,0	0,0	3,3
160,0	-0,2	2,8	2,4	9,0	-0,3	3,3
800,0	0,8	6,5	-1,4	9,0	0,2	3,3
2000,0	-2,7	6,5	-12,0	8,9	-2,1	4,5
5000,0	-3,3	6,6	-50,6	12,5	-2,7	13,0

## 8.3 Degree of equivalence relative to the participants of CCAUV.V-K1

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

	N	IM	NPLI		INMETRO			
	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>		
CCAUV.V-K1	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>		
PTB	-1,9	6,7	-1,9	9,2	-1,5	3,6		
BNM-CESTA	-1,1	9,2	-1,1	11,1	-0,7	7,3		
CSIRO-NML	-1,1	8,3	-1,1	10,5	-0,7	6,2		
CMI	-4,6	8,8	-4,6	10,8	-4,2	6,8		
CSIR-NML	3,9	11,2	3,9	12,8	4,3	9,7		
CENAM	-2,8	9,2	-2,8	11,1	-2,4	7,3		
NRC	-4,5	7,6	-4,5	9,9	-4,1	5,1		
KRISS	-4,9	8,0	-4,9	10,2	-4,5	5,7		
NMIJ	-6,8	8,5	-6,8	10,6	-6,4	6,4		
VNIIM	-8,9	8,3	-8,9	10,4	-8,5	6,1		
NIST	3,9	7,6	3,9	9,9	4,3	5,1		
NMI-VSL	-1,6	13,5	-1,6	15,0	-1,2	12,3		

# Table 24: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the SE transducer at 40 Hz

	N	IM	NF	PLI	INMETRO	
	$D_{ij}$	U <sub>ij</sub>	Dij	U <sub>ij</sub>	Dij	U <sub>ij</sub>
CCAUV.V-K1	in pC/(m/s <sup>2</sup> ) · 10 <sup>4</sup>		in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m/s <sup>2</sup> ) 10 <sup>4</sup>	
PTB	-2,0	6,7	-3,0	9,2	-1,6	3,6
BNM-CESTA	0,9	9,2	-0,1	11,2	1,3	7,3
CSIRO-NML	-3,1	7,6	-4,1	9,9	-2,7	5,1
CMI	-3,6	8,8	-4,6	10,9	-3,2	6,8
CSIR-NML	-0,1	11,2	-1,1	12,8	0,3	9,6
CENAM	-2,6	9,2	-3,6	11,1	-2,2	7,3
NRC	1,6	7,6	0,6	9,9	2,0	5,1
KRISS	-4,8	8,0	-5,8	10,2	-4,4	5,7
NMIJ	-4,3	9,0	-5,3	11,0	-3,9	7,0
VNIIM	-6,3	8,3	-7,3	10,4	-5,9	6,1
NIST	-2,1	7,6	-3,1	9,9	-1,7	5,1
NMI-VSL	-4,0	7,2	-5,0	9,6	-3,6	4,6

Table 25: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the SE transducer at 80 Hz

Table 26: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the SE transducer at 160 Hz

	N	IM	NF	NPLI		INMETRO	
	$D_{ij}$	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>	
CCAUV.V-K1	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m/s <sup>2</sup> ) · 10 <sup>4</sup>		
PTB	-1,5	3,1	-3,4	9,2	-0,8	3,6	
BNM-CESTA	1,3	7,0	-0,6	11,2	2,0	7,3	
CSIRO-NML	-2,7	4,8	-4,6	9,9	-2,0	5,1	
CMI	-1,7	6,6	-3,6	10,9	-1,0	6,8	
CSIR-NML	-4,7	7,0	-6,6	11,1	-4,0	7,3	
CENAM	-3,1	7,0	-5,0	11,1	-2,4	7,3	
NRC	-0,3	4,8	-2,2	9,9	0,4	5,1	
KRISS	-3,7	5,4	-5,6	10,2	-3,0	5,7	
NMIJ	-3,9	6,3	-5,8	10,7	-3,2	6,6	
VNIIM	-3,5	5,9	-5,4	10,5	-2,8	6,1	
NIST	-0,7	4,8	-2,6	9,9	0,0	5,1	
NMI-VSL	-2,2	5,2	-4,1	10,1	-1,5	5,5	

	N	IM	NF	PLI	INME	TRO
	D <sub>ij</sub>	Uij	D <sub>ij</sub>	Uij	D <sub>ij</sub>	U <sub>ij</sub>
CCAUV.V-K1	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>
PTB	-2,1	6,7	-1,3	9,2	-1,9	3,6
BNM-CESTA	1,3	9,2	2,1	11,2	1,5	7,3
CSIRO-NML	-2,7	7,6	-1,9	9,9	-2,5	5,1
CMI	0,3	10,8	1,1	12,5	0,5	9,2
CSIR-NML	2,3	10,2	3,1	12,0	2,5	8,5
CENAM	-1,4	9,2	-0,6	11,2	-1,2	7,3
NRC	0,7	8,7	1,5	10,7	0,9	6,6
KRISS	-3,7	8,0	-2,9	10,2	-3,5	5,7
NMIJ	-4,7	10,9	-3,9	12,6	-4,5	9,4
VNIIM	-6,5	8,6	-5,7	10,7	-6,3	6,6
NIST	0,3	12,9	1,1	14,4	0,5	11,6
NMI-VSL	4,4	8,5	5,2	10,6	4,6	6,4

Table 27: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the SE transducer at 800 Hz

Table 28: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the SE transducer at 2000 Hz

	N	IM	NF	PLI	INME	TRO
	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>
CCAUV.V-K1	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10⁴	in pC/(m	/s²) · 10 <sup>4</sup>
PTB	-0,5	6,7	5,8	9,2	-1,3	4,8
BNM-CESTA	-0,3	9,2	6,0	11,2	-1,1	8,0
CSIRO-NML	-1,3	7,6	5,0	9,9	-2,1	6,0
CMI	1,2	10,4	7,5	12,2	0,4	9,3
CSIR-NML	3,7	10,2	10,0	12,0	2,9	9,1
CENAM	0,2	12,3	6,5	13,8	-0,6	11,4
NRC	-3,6	10,8	2,7	12,5	-4,4	9,7
KRISS	-4,5	9,0	1,8	11,0	-5,3	7,7
NMIJ	10,8	9,3	17,1	11,2	10,0	8,0
VNIIM	-8,1	8,7	-1,8	10,7	-8,9	7,3
NIST	-2,3	11,0	4,0	12,7	-3,1	9,9
NMI-VSL	4,8	14,4	11,1	15,7	4,0	13,6

#### 8.3.2 DoE to the participants of CCAUV.V-K1 of CCAUV.V-K1 for the B2B transducer

	N	IM	NF	PLI	INME	ETRO
	Dij	Uij	D <sub>ij</sub>	Uij	D <sub>ij</sub>	U <sub>ij</sub>
CCAUV.V-K1	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>
PTB	0,3	6,5	-0,6	9,0	0,6	3,4
BNM-CESTA	0,8	9,0	-0,1	10,9	1,1	7,1
CSIRO-NML	0,8	8,1	-0,1	10,2	1,1	6,0
CMI	-1,3	8,6	-2,2	10,6	-1,0	6,6
CSIR-NML	8,8	13,1	7,9	14,5	9,1	11,9
CENAM	-2,1	9,0	-3,0	10,9	-1,8	7,1
NRC	-1,5	7,4	-2,4	9,7	-1,2	4,9
KRISS	-1,5	7,8	-2,4	10,0	-1,2	5,5
NMIJ	-3,3	8,3	-4,2	10,4	-3,0	6,2
VNIIM	-5,8	8,1	-6,7	10,2	-5,5	5,9
NIST	0,8	7,4	-0,1	9,7	1,1	4,9
NMI-VSL	-1,2	7,2	-2,1	9,5	-0,9	4,5

Table 29: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the B2B transducer at 40 Hz

# Table 30: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the B2B transducer at 80 Hz

	N	IM	NF	PLI	INME	TRO
	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	Uij	D <sub>ij</sub>	U <sub>ij</sub>
CCAUV.V-K1	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>
PTB	1,0	6,5	-1,6	9,0	0,4	3,4
BNM-CESTA	2,8	9,0	0,2	10,9	2,2	7,1
CSIRO-NML	0,8	7,4	-1,8	9,7	0,2	4,9
CMI	0,8	8,5	-1,8	10,5	0,2	6,4
CSIR-NML	-4,2	10,9	-6,8	12,5	-4,8	9,4
CENAM	-0,5	9,0	-3,1	10,9	-1,1	7,1
NRC	4,5	7,4	1,9	9,7	3,9	4,9
KRISS	-0,5	7,8	-3,1	10,0	-1,1	5,5
NMIJ	0,4	8,8	-2,2	10,8	-0,2	6,8
VNIIM	-4,0	8,1	-6,6	10,2	-4,6	5,9
NIST	-0,2	7,4	-2,8	9,7	-0,8	4,9
NMI-VSL	-1,1	7,0	-3,7	9,3	-1,7	4,2

	N	IM	NF	PLI	INME	TRO
	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	Uij	D <sub>ij</sub>	U <sub>ij</sub>
CCAUV.V-K1	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>
PTB	0,3	2,9	-2,3	9,0	0,4	3,4
BNM-CESTA	0,9	6,9	-1,7	10,9	1,0	7,1
CSIRO-NML	-0,1	4,6	-2,7	9,7	0,0	4,9
CMI	-0,1	6,4	-2,7	10,6	0,0	6,6
CSIR-NML	-0,1	6,9	-2,7	10,9	0,0	7,1
CENAM	-0,1	6,9	-2,7	10,9	0,0	7,1
NRC	1,4	4,6	-1,2	9,7	1,5	4,9
KRISS	-1,2	5,3	-3,8	10,0	-1,1	5,5
NMIJ	-0,1	6,2	-2,7	10,5	0,0	6,4
VNIIM	2,1	5,7	-0,5	10,3	2,2	6,0
NIST	-1,1	4,6	-3,7	9,7	-1,0	4,9
NMI-VSL	-0,1	5,1	-2,7	9,9	0,0	5,3

Table 31: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the B2B transducer at 160 Hz

Table 32: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the B2B transducer at 800 Hz

	N	IM	NF	PLI	INME	TRO
	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>
CCAUV.V-K1	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>
PTB	-1,2	6,5	1,0	9,0	-0,6	3,4
BNM-CESTA	1,9	9,0	4,1	10,9	2,5	7,1
CSIRO-NML	-1,1	7,4	1,1	9,7	-0,5	4,9
CMI	-1,1	9,4	1,1	11,2	-0,5	7,5
CSIR-NML	0,9	9,0	3,1	10,9	1,5	7,1
CENAM	-1,4	9,0	0,8	10,9	-0,8	7,1
NRC	0,6	8,5	2,8	10,5	1,2	6,4
KRISS	-1,6	7,8	0,6	10,0	-1,0	5,5
NMIJ	-2,0	9,2	0,2	11,1	-1,4	7,3
VNIIM	2,7	8,5	4,9	10,5	3,3	6,4
NIST	-4,1	12,6	-1,9	14,0	-3,5	11,3
NMI-VSL	4,0	9,0	6,2	10,9	4,6	7,1

	N	IM	NF	PLI	INME	TRO
	D <sub>ij</sub>	Uij	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>
CCAUV.V-K1	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>
PTB	3,0	6,5	12,3	8,9	2,4	4,6
BNM-CESTA	4,4	9,0	13,7	10,9	3,8	7,7
CSIRO-NML	2,4	7,4	11,7	9,6	1,8	5,8
CMI	2,0	8,8	11,3	10,7	1,4	7,5
CSIR-NML	2,4	9,9	11,7	11,7	1,8	8,8
CENAM	3,5	12,0	12,8	13,5	2,9	11,1
NRC	3,4	10,6	12,7	12,2	2,8	9,5
KRISS	1,6	8,0	10,9	10,1	1,0	6,5
NMIJ	1,6	8,7	10,9	10,6	1,0	7,3
VNIIM	20,4	8,5	29,7	10,5	19,8	7,2
NIST	-1,6	10,7	7,7	12,3	-2,2	9,7
NMI-VSL	0,6	8,3	9,9	10,3	0,0	6,9

Table 33: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the B2B transducer at 2000 Hz

Table 34: DoE for magnitude of sensitivity between the participants of CCAUV.V-K1.1 and those of CCAUV.V-K1 for the B2B transducer at 5000 Hz

	N	IM	NF	PLI	INME	TRO
	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>	D <sub>ij</sub>	U <sub>ij</sub>
CCAUV.V-K1	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>	in pC/(m	/s²) · 10 <sup>4</sup>
PTB	3,1	7,0	50,4	12,7	2,5	13,2
BNM-CESTA						
CSIRO-NML	4,7	8,3	52,0	13,5	4,1	13,9
CMI	3,2	10,1	50,5	14,7	2,6	15,1
CSIR-NML	1,7	11,1	49,0	15,4	1,1	15,8
CENAM	2,8	12,2	50,1	16,2	2,2	16,6
NRC	2,7	15,4	50,0	18,7	2,1	19,0
KRISS	4,3	8,6	51,6	13,7	3,7	14,1
NMIJ	2,8	18,3	50,1	21,1	2,2	21,4
VNIIM	17,1	11,0	64,4	15,3	16,5	15,7
NIST	1,7	16,8	49,0	19,9	1,1	20,2
NMI-VSL	2,6	49,3	49,9	50,4	2,0	50,6

# 9 Conclusion

During the CCAUV.V-K1.1 comparison four laboratories of different countries measured the (complex) charge sensitivities of two artefacts, a single ended and a back-to-back accelerometer in a frequency range between 10 Hz and 10 kHz. Three of the laboratories included in their results the full frequency range with magnitude and phase shift, while one laboratory limited the results to the scope given by the previous CCAUV.V-K1 comparison [3], I.e. magnitude from 40 Hz to 5 kHz.

One laboratory (PTB) was acting as pilot and linking laboratory, as it had taken part in the CCAUV.V-K1, too. The other three participants were linked to the results of this former comparison via the pilot laboratory.

For the purpose of comparison over the wider scope the degrees of equivalence were calculated between the participants of CCAUV.V-K1.1 over the full frequency range for magnitude and phase shift. While the DoE with respect to CCAUV.V-K1 were only calculated where applicable.

A major complication during the reported comparison proved to be the instability of one of the two artefacts. This problem, however, could be solved based on the model of a linear drift combined with the appropriate correction and a supplementary uncertainty component related to this correction.

With only very few exceptions the results of the participants proved to be consistent with each other as well as with those of the participants of CCAUV.V-K1 within the limits of the reported measurement uncertainties.

# Bibliography

- [1]: H.-J. v. Martens et al., Linking the results of the regional key comparison APM-P.AUV.V-K1 ..., Metrologia (2004), IOP, www.bipm.org/utils/common/pdf/final\_reports/AUV/V-K1/CCAUV.V-K1\_APMP.AUV.V-K1.pdf
- [2]: H.-J. v. Martens et al., *Final Report of Key Comparison EUROMET.AUV.V-K1*, Metrologia (2006), IOP, <u>www.bipm.org/utils/common/pdf/final\_reports/AUV/V-K1/EUR-</u> <u>OMET.AUV.V-K1.pdf</u>
- [3]: H.-J. v. Martens et al., *Report on Key Comparison CCAUV.V-K1*, Metrologia (2002), IOP, <u>www.bipm.org/pdf/final\_reports/AUV/V-K1/CCAUV.V-K1.pdf</u>
- [4]: T. J. Quinn, *Guidelines for CIPM key comparisons*, (2003), BIPM, <u>http://www.bipm.org/utils/en/pdf/guidelines.pdf</u>
- [5]: Ignacio Lira, *Evaluating the Measurement Uncertainty: fundamentals and practical guidance*, (2002), IOP,
- [6]: M. G. Cox, *The evaluation of Key Comparison Data*, Metrologia (2002), IOP, www.iop.org/EJ/article/0026-1394/39/6/10/me2610.pdf

# **Appendix A: Technical Protocol**

# Technical Protocol of the Comparison in Vibration between NIM (China) NPL (India) INMETRO (Brazil) and PTB (Germany)

## 1 Task and purpose of the comparison

In the field of vibration and shock, this regional comparison is organized in order to compare measurements of sinusoidal linear accelerations in the frequency range from 40 Hz 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 charge

sensitivity of two accelerometer standards (back-to-back and single ended in design) at different frequencies with acceleration amplitudes as specified in section 2.

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 reference surface is defined as the transfer surface of the accelerometer.

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 2.

A calibrated charge amplifier is to be used to measure the output charge and phase shift of the accelerometer standards, applying appropriate electrical calibration methods. For the calibration of the accelerometer standards, laser interferometry in compliance with method 3 of the international standard ISO 16063-11:1999 has to be applied, in order to cover the entire frequency range. Supplementary measurement results of the participants might be considered in the report if appropriate.

# 2 Conditions of measurement

The measurements have to comply with the following conditions:

• mandatory vibration frequencies:

40 Hz, 80 Hz, 160 Hz, 800 Hz, 2000 Hz, 5000 Hz

(Optionally the lab can measure at other frequencies provided they are included in the third-oktave frequency series between 10 Hz and 10 kHz, results at additional frequencies between 10 Hz and 10 kHz will be reported).

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

# 3 Transfer standard

As transfer standards, two types of piezoelectric accelerometers are to be used: standard accelerometer (back-to-back) type 8305 (Accelerometer A) and standard accelerometer (single-ended) type 8305 WH2335 (Accelerometer B) (manufacturer Brüel & Kjaer):

- Accelerometer A: Bruel & Kjaer model 8305 serial number: 748737 nominal charge sensitivity (magnitude): 0.13 pC/(m/s<sup>2</sup>)
- Accelerometer B: Bruel & Kjaer model 8305 WH2335 serial number: 1610168 nominal charge sensitivity (magnitude): 0,13 pC/(m/s<sup>2</sup>)

# 4 Circulation type and transportation

- The comparison has three participants.
- The transfer standard will be transported in a closed box, hand-carried by representatives of NIM or PTB.

# **5** Measurement instructions

The participating laboratories have to observe the following instructions:

- The charge amplifier used in the laboratory is to be calibrated using a standard capacitor and standard voltmeter, both traceable to national standards. The calibration of the charge amplifier has to be carried out shortly before the calibration, using values of the electric quantities similar to those expected in the accelerometer calibration.
- In order to suppress the effect of any non-rectilinear motion, the displacement has to be measured at least at four different points. These points should be equally spaced on the top surface of the back-to-back accelerometer.
- **Primary calibration of BB accelerometer (A) by laser interferometry:** The motion is to be sensed at the top surface (polished) without any dummy mass; no reflector (e.g. corner cube) must be attached to the top surface. The reflectivity of the polished

top surface will be 80 % or higher, and the flatness over the top surface in the order of 1  $\mu m.$ 

- Primary calibration of SE accelerometer (B) by laser interferometry: The reference surface for acceleration measurement is by definition the base or mounting surface of the accelerometer. If this surface is covered during the calibration, the motion is to be sensed on the moving part close to the accelerometer. Alternatively, the motion can be sensed at the mounting surface of the accelerometer via longitudinal holes in the moving part of the vibration exciter. ISO 16063-11 is to be observed.
- The mounting surface of the accelerometer and the moving part of the vibration exciter must be slightly lubricated before mounting.

Complete measurement series shall be carried out on different days under nominally the same conditions, except that the accelerometer is re-mounted and the cable refixed. The (mean) result of the all the measurement series is to be given as the final measurement result.

# 6 Communication of the results to the pilot laboratory

The participants will submit the calibration report to the PTB including descriptions of:

- the calibration equipment
- the calibration methods used
- the ambient conditions
- the mounting technique
- the calibration results
- the uncertainty of measurement (k = 2) for each measurement result

In each case, the uncertainties have to be evaluated in accordance with the Guide to the expression of uncertainty in measurement (GUM), which has been adapted to the calibration of vibration and shock transducers as stated in ISO 16063-1:1998, Annex A.

Appendix B: Uncertainty Budgets of the participants

### PTB:

Measurement uncertainties applicable for the fringe counting method used in CCAUV.V-K1.1 from 10 Hz to 800 Hz for magnitude of complex sensitivity:

DUT	B&K 8305 or 8305-001	+ B&K 2650				
acceleration:	100 m/s <sup>2</sup>					
Voltage	typic. 1V				std. un	cert.
Disturbing Component	comment	typical width	distribution	factor	TO Hz to 40 Hz	to 800Hz
nominal Frequency	Generator accuracy	5,00E-05	rectangular	1,73	2,89E-05	2,89E-05
Accelerometer Voltage	DVM calibration (200mV to 900 mV)	0 5,00E-05	rectangular	1,73	2,89E-05	2,89E-05
Acceleration Amol. bv FC	optical misalignment, Heydeman correction, Wavelnoth	1.00E-04	rectangular	1.73	5.77E-05	5.77E-05
harmonic distortion on Voltage measurement	estimated < 6e-5 max at 63 Hz		single point		3 00F-05	3 00F-05
Humm	50 Hz. ~0.7mV RMS	1,23E-05	single point	2.00	6,13E-06	3,83E-07
Noise	1,7mV RMS	0,00007225	single point	5	3,61E-05	2,26E-06
Transverse motion	1 % transv. Sensitivity @ 4% transv. Excitation		complex		1,14E-04	1,14E-04
Base Strain sensitivity	S = 0,005m/s² / μ€ € < 0,1 μm/m	depending on acc. Level	rectangular	1,73	2,89E-05	5,77E-06
Mounting torque	S = 6e-4/Nm; dM = 0,2 Nm	0,00012	rectangular	1,73	6,93E-05	6,93E-05
temperature sensitivity	S=2,5e-4 /K dT = 0,3 K	0,000075	rectangular	1,73	4,33E-05	4,33E-05
magnetic sensitivity	S=1/a *(m/s²)/T B < 0,03mT	depending on acc. Level	rectangular	1,73	1,73E-06	3,46E-07
airborne sound	S=0,008 m/s <sup>2</sup> at 154 dB max sound level 88 dB	8,00E-08	rectangular	1,73	4,62E-08	4,62E-08
quantization	suppressed by known phase-disturbance	1,00E-05	U-type	1,41	7,07E-06	7,07E-06
phase disturbance	Depending on ratio of stoch. Veloc. to stat. Veloc.	Stoch. Veloc. RMS 30µm/s	Steiner	-	1,78E-08	1,78E-08
trigger hysteresis	set hysteresis value 20 mV system. Dev. Corrected	est. remaining dev. < 1e-6		-	1,00E-06	1,00E-06
Low pass of photo detector voltage	f_c (-3db) 3 MHz	1,00E-07	rectangular	1,73	5,77E-08	5,77E-08
foto electric noise	RMS 2,5mV		Steiner	-	1,30E-05	2,00E-05
	Phase. Only 1st harmonic				10 107 0	
harmonical distortion	essential, ampl. ratio 0,0012	1,33E-04	U-type	1,41	9,43E-05	9,43E-05
humm (50 Hz)	humm acc. 0,08m/s <sup>2</sup>	1,77E-05	rectangular	1,73	1,02E-05	1,60E-04
asynchronous measurement	voltage/acceleration/voltage	1,00E-04	rectangular	1,73	5,77E-05	5,77E-05
residual influences		1,00E-04	normal	1,41	7,07E-05	7,07E-05
exp. std. deviation		1,70E-04	normal	1,41	1,20E-04	1,20E-04
Charge Amplifier calibration		4,24E-04	normal	0	2,12E-04	2,12E-04
rel. std. uncertainty	n %				0,0324	0,0358
rel. comb. exp. Uncertainty (K=2)	in %				0,0647	0,0716
stated rel. comb. exp. Uncertainty	in %				0,1000	0,1000

DUT	B&K 8305 or 8305-001	+ B&K 2650				
acceleration: Voltage	100 m/s <sup>2</sup> typic. 1V					
Sample rate	10 MS/s	@ 12 Bit				
					std. un	cert.
Disturbing Component	comment	95% value	distribution	factor	combined frequences 500 Hz to 5 kHz	Lency ranges to 10 kHz
	deviation of sample clock					
frequency of SAM	from generator clock	1,00E-04	rectangular	1,73	5,77E-05	5,77E-05
Accelerometer Voltage	sampling of HP3458A	5,00E-04	rectangular	1,73	2,89E-04	2,89E-04
Velocity amolitude	wave length, optical adjustment,	1 16E-05	normal	00 0	5 80F-06	5 80F-06
harmon. Distortion	mainly 1st harmonic		Steiner	1,00	7,84E-06	7,84E-06
Humm on Voltage	typical 1mV	5,00E-07	Steiner	1,00	5,00E-07	5,00E-07
Noise on Voltage	MC on influence to SAM duration 20ms, Un=1,0mV	6,60E-06	normal	1,00	3,30E-06	3,30E-06
Transverse Motion	S(transv) = 0,7% a(transv) < 4%		u-type	1,41	1,98E-04	1,98E-04
	S = 0,005m/s² / μ€					
Base strain sensitivity	€ < 0,1 μm/m	5,00E-06	rectangular	1,73	2,89E-06	2,89E-06
mounting	S = 6e-4/Nm; dM = 0,2 Nm	1,20E-04	rectangular	1,73	6,93E-05	6,93E-05
Temperature	S=2,5e-4 /K dT = 0,3 K	7,50E-05	rectangular	1,73	4,33E-05	4,33E-05
Magnetic field	S=1/a *(m/s²)/T B < 0,03mT	3.00E-07	rectangular	1.73	1,73E-07	1,73E-07
Airborne acoustics	S=0,008 m/s <sup>2</sup> at 154 dB max sound level 88 dB	8,00E-08	rectangular	1,73	4,62E-08	4,62E-08
Noise on Interferom.	noise level equiv. of 2 nm after demodulation, Monte Carlo		normal	1.00	1.10E-04	3.00E-04
a-synchronous Mageurament		1 00E-04	ractandular	1 73	5 77E_05	5 77E_05
charge ampl. calibration		4.24E-04	normal	2.00	2.12E-04	2.12E-04
resid. influences		1,00E-04	normal	1,41	7,07E-05	7,07E-05
exp. std. dev					2,30E-05	1,60E-04
rel. std. uncertainty	in %				0,0446	0,0549
rel. comb. exp. Uncertainty (k=2)	in %				0,0891	0,1098
stated rel. comb. exp. Uncertainty	in %				0,1000	0,3000

Measurement uncertainties applicable for the sine approximation method method used in CCAUV.V-K1.1 from 1 kHz to 10 kHz for magnitude of complex sensitivity:

DUT	B&K 8305 or 8305-001	+ B&K 2650				
acceleration:	100 m/s <sup>2</sup>					
Voltage	typic. 1V					
Sample rate	10 MS/s	@ 12 Bit		_		
					combined frequ	ency ranges
Disturbing Component	comment	95% value	distribution	factor	10 Hz to 1 kHz	to 10 kHz
Channel a-synchronisity	all frequencies	< 10 ns	normal	2	1,80E-03	1,80E-02
	Monte Carlo,	-				
	multiples of 20ms	equivalent		T		
Humm (50 HZ)	are evaluated	alsplacement amp. 4 µm	normai	_	8,UUE-U3	1,00E-U3
Noise on accelerometer						
Voltage output	Monte Carlo, SNR=500	< 2mV @ 1V	normal	1	4,00E-04	4,00E-04
	1 % transv. Sensitivity					
Transverse/Rocking motion	@ 10% transv. Excitation	rel. Phase 0 2pi	U-type (by MC)	1	7,00E-04	7,00E-04
delay of Laser Vibrom.	absolut correction	uncert. of correction				
+ Mixer + Filter	1,54µs applied	100 ns	rectang.	1,73	2,08E-02	2,08E-01
	including Stability,					
Calibration Charge Amplifier	reproducibility,					
B&K 2650	methode (black box)	<0,02°	normal	2	2,00E-02	2,00E-02
	noise level equiv. of 2 nm					
Noise on heterodyne	after demodulation,					
interferometer channel	Monte Carlo	< 2nm	normal	-	1,43E-04	1,43E-02
	drift, relative motion					
	evaluation as velocity					
Motion disturbance	and period by period	estimated < 0,02°	normal	2	1,00E-02	1,00E-02
exp. Std. deviation		typical < 0,02°	normal	2	5,00E-02	1,20E-01
std. uncertainty	in 1°				0,059	0,242
exp. Uncertainty (k=2)	in 1°				0,118	0,484
stated exp. Uncertainty	in 1 °				0,200	0,500

Measurement uncertainties applicable for the sine approximation method method used in CCAUV.V-K1.1 from 10 Hz to 10 Hz for phase of complex sensitivity:

### INMETRO:

<b>Normal Contraction Contraction Normal Contractio</b>	erianty budi erianty budi CHARTGI CHARTGI Standard anotaeria anot	99 - Tabloute Interferometric calibration of a backting 90 - Tabloute AS AS 90 - Tabloute AS AS 50 - Tabloute A	<ul> <li>chack standard acceletometer (load acceletometer (load acceletometer and acceletometer accelotometer accelotometer accelotometer acceletometer acceleto</li></ul>	ling mass = 10 der Prodefing relandund model relandund (+c-1) retangular retangular retangular retangular retangular normal (sc) normal (sc) retangular normal (sc) normal (sc)	9)	Relative exp requently (1) 0,10 0,10 0,000 0,00 0,00 0,00 0,000 0	The second sec	14411111111111111111111111111111111111	2000 0000 0000 0000 0000 0000 0000 000	Image         Image <th< th=""><th>Component         Component           31.5         0.05           0.000         0.000           0.000         0.000           0.000         0.000           0.000         0.000           0.000         0.000</th><th>Addition         Addition         Addition</th><th>80 90 90 90 90 90 90 90 90 90 9</th><th>6 6 6 6 6 6 6 6 6 6 6 6 6 6</th><th>80         90&lt;</th><th>0.000 0.0000 0.00000 0.00000 0.0000 0.0000</th><th>0.0002 0.00000 0.00000000</th><th>10000000000000000000000000000000000000</th><th>2000 200 2000 2</th><th>250 250 0.005 00000000</th><th></th></th<>	Component         Component           31.5         0.05           0.000         0.000           0.000         0.000           0.000         0.000           0.000         0.000           0.000         0.000	Addition         Addition	80 90 90 90 90 90 90 90 90 90 9	6 6 6 6 6 6 6 6 6 6 6 6 6 6	80         90<	0.000 0.0000 0.00000 0.00000 0.0000 0.0000	0.0002 0.00000 0.00000000	10000000000000000000000000000000000000	2000 200 2000 2	250 250 0.005 00000000	
11 16	$u(e_{T,A})$ $u(e_{L,f,A})$	different amonition settings) definerent amonitions extings) deviation from constant amplitude-frequency characteristic of reference amplifier	gain setting gain setting Not applicable. Amplifier calibrated at all frequencies			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,0	0 0
18	$\frac{u(e_{1,j,p})}{u(e_{1,j,p})}$	deviation from constant amplitude-frequency characteristic of reference accelerometer	Not applicable. Results reported with the input acceleration Estimated to be less than (amplitude	retangular	0.58	00'00	00'0	00'00	00'0	00'00	00'00	0,00	00'00	00'0	00'0	00'00	0,00	00'0	0,00	8	
19 20	$u(e_{1,a,h})$ $u(e_{1,a,p})$	amplitude effect on gain of reference amplifier amplitude effect on sensitivity (magnitude) of reference accelerometer	range up to 100 m/s <sup>2</sup> ) Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular retangular	0,58	0,02 0,02	0,02 0,02	0,02 0,02	0,02 0,02	0,02 0,02	0,02 0,02	0,02 0,02	0,02 0,02	0,02 0,02	0,02 0,02	0,02 0,02	0,02 0,02	0,02 0,02	0,02 0,02	0,0	N N
21	$u\left(e_{\mathrm{LP}}\right)$	instability of reference amplifier gain, and effect of source impedance on gain instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than Estimated to be less than	retangular retangular	0,58 0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,0	
23	$u\left(e_{\mathrm{E,A}}\right)$	environmental effects on gain of reference amplifier	Estimated to be less than $(dT =+/-1 \text{ oC})$ during one complete calibration	retangular	0,58	0,06	0,05	0,05	0,04	0,04	0,04	0,03	0,03	0,03	0,03	0'03	0,03	0,02	0,02	8 8	
25	$u(e_{EP})$ $u(S_{SF})$	environmental erects on sensitivity (magnitude) of reference accelerometer safety factor	during calibration, St = 0.02%/°C) Estimated to be less than	retangular	0,58 0.58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,0	~ ~
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T									(v/) (/v)									_	-	-
						frequency	(ZH)													
	Standard			Prohability																
i	component u(x1)	Source of uncertainty	description	distribution model	Factor $x_i$	10	12,5	16	20	25	31,5	40	50	63	30	100	125 1	160 21	00 28	3
-	$u(\hat{u}_v)$	accelerometer output voltage measurement ( ADC resolution + DAQ range linearity ).	results of different calibrations measured against hp3458A	retangular	0,58	£0'0	0'03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	6	0 80'0	0 80'0	,03 0,	0 80	0 0
N	$u(\hat{u}_{\rm F})$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	10	01	0,01	,01 0,	0, 0,	0,
m	$u(\hat{u}_D)$	effect of voltage disturbance on accelerometer output voltage measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	-	0,10	0,10	0,10	0,10	0,05	0,05	0,05	0,05	0,05 0	05	0,05	0,05	,05 0,	05 0,	0 0
4	$u(\hat{u}_T)$	effect of transverse, rocking and bending acceleration on accelerometer voltage measurement (transverse sensitivity )	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,58	00'0	00'0	0,01	0,01	0,01	0,01	0,02	0,04	0	8	10	0	10, 0,	°	ہ ح
ω	и(Ф <sub>М 0</sub> )	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. distes, voltage amplitude deviation, deviation from 90° nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in $i = 3$			00'0	00'0	00'0	00'0	00'0	00'0	00'0	000	00'0	8	00'0	00'0	0	°	o g
ø	$u(\Phi_{\rm M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation )	No analog filtering applied.	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	10	10,0	0,01	,0 0	0	
~	$u(\Phi_{\mathrm{M,VD}})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	6	0,02	0,02	,02 0,	0, 0,	o N
80	$u(\Phi_{\mathrm{M,MD}})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0'03	0,03	0,03	0,03	0,03	0,03	0,03	8	000	0,03	,03 0,	0 8	ő
6	$u(\varPhi_{\mathrm{M,PD}})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	03	03 03	0 80'0	,03 0,	0	3 0,
6	$u(\Phi_{\mathrm{M,RE}})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,30	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	8	0,02	0,02	,02 0,	02	° 5
Ξ	$u(f_{FG})$	vibration frequency measurement (frequency generator and indicator )	Estimated to be less than (standard limit)	normal (k=2)	0,5	00'0	00'0	00'0	00'0	0,00	00'0	0,00	00'0	0,00	8	0,00	0,00	'o 00'i	°	o,
12	$u (S_{\text{RE}})$	residual effects on sensitivity measurement ( e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	measured (for N=6, std dev of the mean)	normal (sqrt(N))	0,41	0,03	0,03	0,02	0,01	0,01	0,00	0,00	0,00	0,00	6	0,00	0 00'0	'0 00'	ð 8	ő
5	$u(\lambda cal)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,5	00'0	00'0	0,00	0,00	0,00	00'0	0,00	00'0	0,00,0	8	0,00	0,00,0	,0 ,00	°	ó
14	$u(\lambda_{\rm E})$	environmental effects on laser wavelength . Estimated to be less than $(dT =+t^{-} 3 \text{ C}, dP =+t^{-} 70 \text{ hPa}, dU =+t^{-} 20 \%)$	Estimated to be less than (Temp range from 21 to 25 degrees)	retangular	0,58	00'0	00'0	00'0	00'0	00'0	0,00	00'0	00'0	00'0	0	00'0	0 00'0	'0 00'1	0 0	o g
15	u(A cal)	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,05	0,05	0,05	0,05	0,05	0,04	0,04	0,03	0,03	03	03	0,03	,03 0,	0	0 0
16	$u(e_{T,\Lambda})$	reference amplifiers tracking (deviations in gain for different amplification settings)	Not applicable. Amplifier used at a fixed gain setting			00'0	00'0	00'0	00'0	00'0	00'0	0'00	00'0	00'00	0	00'00	0,00,0	0	0 0	°
17	$u(e_{1,f,A})$	deviation from constant amplitude-frequency characteristic of reference amplifier	Not applicable. Amplifier calibrated at all frequencies			0,00	0,00	0,00	0,00	0,00	0,00	0,00	00'0	0,00	8	0,00	00,00	,00 00,1	° 8	ő
18	$u(e_{\mathrm{L},f,\mathrm{P}})$	deviation from constant amplitude-frequency characteristic of reference accelerometer	Not applicable. Results reported with the input acceleration			0,00	0,00	0,00	0,00	0,00	0,00	0,00	00'00	0,00 C	00	00 00	00 00	,00 0,	00 0,	0,0
6	u (e 1.a)	amplitude effect on gain of reference amplifier	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	10,	10,0	0,01	,01 0,	0	-0 0
20	$u(e_{1,a,p})$	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	10	10,0	0,01	,01 0,	0	5 0
21	$u(e_{1,0})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	,02 0	0,02	0,02	1,02 0,	02 0,	0, 22
22	$u(e_{\rm LP})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	10,	10,0	0,01	,01 0,	0	10 0
23	u (e <sub>E,A</sub> )	environmental effects on gain of reference amplifier	Estimated to be less than (dT =+/- 1 oC during one complete calibration)	retangular	0,58	0,04	0'03	0,03	0,03	0,02	0,02	0,02	0,02	0,02	,02	0,02	0,01 0	,01 0,	01 0,	0,
24	$u(e_{EP})$	environmental effects on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (dT =+/- 1 °C during calibration. St = 0.02%/°C)	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	10,	,01 0,	0,01 0	,01 0,	0 10	0, 10
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,58	00'0	00'0	00'0	00'0	0,00	00'0	0,00	00'0	0,00	00	00'00	0 00'0	'0 00'i	° 0	0
	$u_{rd}(S_2)$	Estimated Uncertainty fi	for acelerometer sensitivity (k=1)			0,14	0,13	0,13	0,13	0,10	0,09	0,09	0,10	0 60'0	0 60	0 60'0	0 60'(	,09 0,	° 60	,0 ,0
	$u_{rel}(S_2)$	Estimated Uncertainty f	for acelerometer sensitivity (k=2)			0,28	0,27	0,27	0,26	0,19	0,19	0,19	0,19 0	0,18 C	,18 0	0,17 0	0,17 0	,17 0,	17 0,	17 0,
-		_	_	-			_	-	-	-	-	-	-	-	-	-		-	-	-

<mark>SO IS</mark>	ertainty bud 16063-11:19	get - Absolute Interferometric calibration of a back-to 999 - Table A.3 & A.5	o-back standard accelerometer (load	ding mass = 0																	
	CHARGI	E SENSITIVITY - MAGNITUDE																			
										-											
	Standard uncertainty component u(x,	) Source of uncertainty	description	Probability distribution model	400	500	630	08	1000	1250	1600	2000	5200	2500	0000	3150	3500	3800	4000	1200	5000
-	$u\left(\hat{u}_{V}\right)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
N	$u\left(\hat{u}_{\rm F}\right)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
ы	$u\left(\hat{u}_{\mathrm{D}}\right)$	effect of voltage disturbance on accelerometer output voltage measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	$u\left(\hat{u}_{\mathrm{T}}\right)$	effect of transverse, rocking and bending acceleration on accelerometer voltage measurement (transverse sensitivity ) - dev% from fit	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	60'0	0,04	0,05	0,04	0,06	0,06	60'0	0,06	0,02	0,06	0,03	0,01	0,01	0,02	0 50,0	0,10	0,12
ŝ	$u(\varPhi_{\mathrm{M},\mathbb{Q}})$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. dists, voltage amplitude deviation, deviation from 90° nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in <i>i</i> = 3		00'0	00'0	0,00	0,00	0.0	00'0	00.0	8.0	800	0,0	0.0	00.0	0.0	0,0	00'0	8	00'0
9	$u(\varPhi_{\rm M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
~	$u(\varPhi_{\mathrm{M,VD}})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0'03	0'03	50,03	0,03
80	$u\left(\varPhi_{\mathrm{M,MD}}\right)$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
თ	$u(\varPhi_{\rm M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\varPhi_{\rm M, RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N)	0,05	0'05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0'02	0,05	0,05	0,05
÷	$u\left(f_{\mathrm{FG}}\right)$	vibration frequency measurement (frequency generator and indicator )	Estimated to be less than (standard limit)	normal (k=2)	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001 0	,0001	,0001	0001 0	0,0001	0,0001 0	,0001 0,	0001	1000
12	$u\left(S_{RE} ight)$	residual effects on sensitivity measurement ( e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	measured (for N=6, std dev of the mean)	normal (sqrt(N)	0,04	0,01	0,01	0,01	0,01	0,01	0,02	0,03	0,04	0,03	0,05	0,08	0,06	0,08	0,07	0,12	0,06
13	$u(\lambda \operatorname{cal})$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002 0	,0002	,0002 0	,0002 0	0,0002	0,0002 0	,0002 0,	0002	,0002
14	$u(\lambda_{\rm E})$	environmental effects on laser wavelength . Estimated to be less than $(dT =+t^{-}. 3 \text{ C}, dP =+t^{-}. 70 \text{ hPa}, dU =+t^{-}. 20 \%)$	Estimated to be less than (Temp range from 21 to 25 degrees)	retangular	0,0007	0,0007	0,0007	0'0002	2000'0	0,0007	0,0007	0,0007	0,0007 0	0001	0001	0 2000'	0,0007 0	0 2000,0	,0007 0,	0007 0	2000,
15	u(A  cal)	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05 (	0,05	0,05
16	$u\left(e_{\mathrm{T},\mathrm{A}}\right)$	reference amplifiers tracking (deviations in gain for different amplification settings)	Not applicable. Amplifier used at a fixed gain setting		0,00	00'0	0,00	0,00	00'00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	00'0	0,00
17	$u\left(e_{1,f,\Lambda}\right)$	deviation from constant amplitude-frequency characteristic of reference amplifier	Not applicable. Amplifier calibrated at all frequencies		00'0	00'0	0,00	00'0	00'00	00'0	0,00	00'0	0,00	0,00	0,00	0,00	0,00	0,00	0'00	00'0	0,00
18	$u(e_{1,f,\mathbf{p}})$	deviation from constant amplitude-frequency characteristic of reference accelerometer	Not applicable. Results reported with the input acceleration		0,00	0,00	00'0	0,00	00,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	00'0	0,00
6	$u\left(e_{1,a,\Lambda}\right)$	amplitude effect on gain of reference amplifier	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
20	$u\left(e_{1,a,p}\right)$	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
21	$u\left(e_{\mathrm{LA}}\right)$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0'03	50,03	0,03
52	$u\left(e_{\rm LP}\right)$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
23	$u \; (e \mathrel{_{\mathrm{E},\mathrm{A}}})$	environmental effects on gain of reference amplifier	Estimated to be less than (dT =+/- 1 oC during one complete calibration)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
24	$u \left( e_{\mathrm{EP}} \right)$	environmental effects on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (dT =+/- 1 °C during calibration, St = 0.02%/°C)	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,00	00'0	00'00	00'0	00'0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0'00	00'0	0'00
									-	+	+			-				-	-	-	+

Unce ISO 1	rtainty bud 6063-11:199	get - Absolute Interferometric calibration of a back-t 99 - Table A.3 & A.5	o-back standard accelerometer (load	ding mass = 0	(B																
	CHARGE	E SENSITIVITY - MAGNITUDE																	-		
						Relative e:	xpanded un	certainty or	ounds of es	timated erri	or compone	nts (%)									Π
						frequency	(Hz)		-	-	-	-	-	-	-	-	-	-	-	-	
;	Standard uncertainty component u(x,)	) Source of uncertainty	description	Probability distribution model	Factor x <sub>i</sub>	10	12,5	16	50	25	31,5	6	20	8	80	100	125	160	500	20	315
-	$u\left( \hat{u}_{V}\right)$	accelerometer output voltage measurement ( ADC resolution + DAQ range linearity )	results of different calibrations measured against hp3458A	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05 0	05 0	,05	0,05
2	$u\left(\hat{u}_{\rm F}\right)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	02	0,02
т	$u\left(\hat{u}_{\text{D}}\right)$	effect of voltage disturbance on accelerometer output voltage measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	۰	0,10	0,10	0,10	0,10	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05 0	05 0	,05	0,05
4	$u(\hat{u}_{\rm T})$	effect of transverse, rocking and bending acceleration on accelerometer voltage measurement (transverse sensitivity ) - dev% from fit	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,58	00'0	0,00	0,01	0,02	0,01	0,01	0,04	0,07	0,04	0,03	0,02	0,02	0,01	000	6	0,01
5	$u(\varPhi_{\mathrm{M},\varrho})$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. distast, voltage amplitude deviation, deviation from 90° nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in $i = 3$			00'0	00'0	00'0	00'0	00'0	00'0	0,00	0,00	00'0	0,00	00'0	00'0	0'00	0 00'	00	00,0
9	$u(\varPhi_{\rm M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation )	No analog filtering applied.	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	02 0	05	0,02
7	$u(\varPhi_{\mathrm{M,VD}})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03 0	0	.0	0,03
8	$u(\varPhi_{\mathrm{M},\mathrm{MD}})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05 0	,05 0	,05	0,05
6	$u(\varPhi_{\mathrm{M,PD}})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05 0	0,05 0	,05	0,05
6	$u(\varPhi_{\rm M, RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,30	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	05	,05 	0,05
Ξ	$u\left(f_{\mathrm{FG}}\right)$	vibration frequency measurement (frequency generator and indicator )	Estimated to be less than (standard limit)	normal (k=2)	0,5	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	,0001	0001	0001 0,	,0001 0	,0001 0,	0,0	001	0001
12	$u\left(S_{RE}\right)$	residual effects on sensitivity measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	measured (for N=6, std dev of the mean)	normal (sqrt(N))	0,41	0,08	0,06	0,04	0,03	0,02	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	01 0	01	00'0
13	$u(\lambda cal)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,5	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	,0002 0	0002	0002 0,	,0002 0.	,0002 0,	0002 0,0	0,002	0002
14	$u(\lambda_{\rm E})$	environmental effects on laser wavelength . Estimated to be less than (dT =+/- 3 C, dP = +/- 70 hPa, dU = +/- 20 %).	Estimated to be less than (Temp range from 21 to 25 degrees)	retangular	0,58	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007 0	0007	0007 0	0007 0,	,0007 0,	,0007 0,	0007 0,0	0, 2007	0007
15	u(A  cal)	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,10	0,10	0,10	0,10	0,09	0,08	0,07	0,06	0,05	0,05	0,05	0,05	0,05 0	,05 0	,05	0,05
16	$u\left(e_{\mathrm{T,A}}\right)$	reference amplifiers tracking (deviations in gain for different amplification settings)	Not applicable. Amplifier used at a fixed gain setting			00'0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	00,00	0,00	0,00 0	00'00'0	,00	00'0
17	$u\left(e_{1,f,\Lambda}\right)$	deviation from constant amplitude-frequency characteristic of reference amplifier	Not applicable. Amplifier calibrated at all frequencies			00'0	0,00	0,00	0,00	0,00	0'00	0,00	0,00	0,00	00'00	00'0	0,00	0,00	00,00	0	00'0
18	$u(e_{\mathrm{L},f,\mathrm{P}})$	deviation from constant amplitude-frequency characteristic of reference accelerometer	Not applicable. Results reported with the input acceleration			00'0	0,00	00'0	0,00	0,00	0,00	0,00	0,00	0,00	00'0	00'0	0,00	0,00	0 00'0	0,	00'0
6	$u(e_{1,a,A})$	amplitude effect on gain of reference amplifier	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0	8	0,02
20	$u\left(e_{1,a,p}\right)$	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	02 0	02	0,02
21	$u\left(e_{\mathrm{LA}}\right)$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03 0	,03 0	,03	0,03
53	$u\left(e_{\mathrm{LP}}\right)$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	02	05	0,02
23	$u(e_{\rm E,A})$	environmental effects on gain of reference amplifier	Estimated to be less than (dT =+/- 1 oC during one complete calibration)	retangular	0,58	0,06	0,05	0,05	0,04	0,04	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,02	0,02	,02	0,02
24	$u\left(e_{\mathrm{EP}}\right)$	environmental effects on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (dT =+/- 1 °C during calibration, St = 0.02%/°C)	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	02 0	05	0,02
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,58	0,00	0,00	00'0	0'00	0,00	00'0	0'00	00'0	0'00	00'0	00'0	0,00	0'00	0,00	0	00'0

Photo	artainty bud	김명et - Absolute Interferometric calibration of a back-t. 200 - T-아니스 시 3 은 시 도	o-back standard accelerometer (load	ting mass = 0			$\left  \right $	╞	$\left  \right $	╞	$\left  \right $	$\left  \right $		╞	$\left  \right $						H
8																					
	CHARG	<b>TE SENSITIVITY - MAGNITUDE</b>																			
								-	-	•			-	-		-	-	-		-	-
	Standard uncertainty component u(x <sub>i</sub> ,	<ul> <li>Source of uncertainty</li> </ul>	description	Probability distribution model	6500	2000	7500	8000	8500	000	500	11	000 120	00	500 130	140	000	000	00 170	00 180	8
-	$u\left(\hat{u}_{V}\right)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,05	0,05	0,05	0,05	0,05 0	,05 0	),05 (	05 0	10 0,0	0	10 0,	10 0,	10	10	0,1	0,1	
N	$u\left(\hat{u}_{\mathrm{F}}\right)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,02	0,02	0,02	0,02	0,02	1,02	,02	1,02	02 0,0	32 0,1	02 0,(	02	02	0,0	22 0,0	0'0	Q
т	$n\left( \hat{n}_{\mathrm{D}} ight)$	effect of voltage disturbance on accelerometer output voltage measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	0,05	0,05	0,05	0,05	0,05 C	),05 C	),06	0 0	06 0,0	);0 9(	06 0,0	0 90	0 90'	,06 0,0	0,0	6 0,0	g
4	$u(\hat{u}_T)$	effect of transverse, rocking and bending acceleration on accelerometer voltage measurement (transverse sensitivity ) - dev% from fit	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,04	0,00	0,03	0,05	0,12	132	05	,12 0	0 02	1	13	16 0,	14	31	0,2	4	5
ŝ	$u(\varPhi_{\mathrm{M},\mathbb{Q}})$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. distest, vultage amplitude deviation, deviation from 90° nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in <i>i</i> = 3		00'0	00'0	00'0	00.0	000	8	8	0	8	00 00	00	8	0	8	0.0	0.0	
٥	$u(\varPhi_{\rm M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation )	No analog filtering applied.	retangular	0,02	0,02	0,02	0,02	0,02	1,02	,02	\02 0	0,0	0°	0,0	0 0 0	05	6	0,0	0,0	~
7	$u(\varPhi_{\rm M,  VD})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0	03	0 80%	03 0,0	о, б	03 0,0	03 0,	03	0,0	0'0	0,0	
80	$u(\varPhi_{\rm M,MD})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05 C	),05	,05	0 0	05 0,0	35 0,1	05 0,(	05 0,	05 0	05 0,	5 0,0	5 0,0	<u>ں</u>
6	$u(\varPhi_{\mathrm{M,PD}})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	),05 C	,05	,05 0	05 0,0	35 0,1	05 0,0	05 0,	05 0	,05 0,0	5 0,0	5 0,0	<u>ں</u>
10	$u(\varPhi_{\rm M,RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,05	0,05	0,05	0,05	0,05 C	),05 C	),05 G	1,05 O	05 0,0	35 0,1	05 0,(	05 0,	05 0	,05 0,0	0,0	5	Q
Ξ	$u\left(f_{\mathrm{FG}} ight)$	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,0001	0,0001	0,0001	0,0001	0,0001 0,0	001 0,	0001 0,	0,0	1001 0,00	0,0	001 0,00	0,0	0,0	0,0	001 0,00	0,00	5
12	$u(S_{RE})$	residual effects on sensitivity measurement ( e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	measured (for N=6, std dev of the mean) r	normal (sqrt(N))	0,17	0,15	0,12	0,15	0,21	125	,45 0	,36 ,36	49 0,1	o So	0; 52	37 0;	39	38	27 0,3	2 0,5	<u>n</u>
5	$u(\lambda cal)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,0002	0,0002	0,0002	0,0002 0	0'0005 0'r	0,002	0002 0,	0002 0,0	1002 0,00	0,0	002 0,0(	002 0,0	0,0	0,002 0,00	00'0	02 0,00	8
14	$u(\lambda_{\rm E})$	environmental effects on laser wavelength . Estimated to be less than (dT =+/- 3 C, dP = +/- 70 hPa, dU = +/- 20 %)	Estimated to be less than (Temp range from 21 to 25 degrees)	retangular	0,0007	0,0007	0,0007	0,0007 0	1000 <sup>1</sup> 0	0 2000	0 2000	0'0 2006	1007 0,00	0,0	0'0 200	007 0,0	0'0 200	007 0,01	00'0 200	0) 0,00	07
15	u(A  cal)	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,05	0,05	0,05	0,05	0,05 C	),05 C	),05 C	1,05 0	05 0,0	35 0,	05 0,(	05 0,	,05 0	,05 0,1	0'0 0'0	5 0,0	Q Q
16	$u\left(e_{\mathrm{T,A}}\right)$	reference amplifiers tracking (deviations in gain for different amplification settings)	Not applicable. Amplifier used at a fixed gain setting		00'0	0,00	00'0	00'0	0,00	00'	00'	000	00	0 0	0,0	°0 00	0	00'	0'0	0'0	0
17	$u\left(e_{1,f,A}\right)$	deviation from constant amplitude-frequency characteristic of reference amplifier	Not applicable. Amplifier calibrated at all frequencies		00'0	00'0	00'0	00'00	0'00 C	00'00'	00'0	0 00'0	00 00'	00	00 0'(	00	0 00	00	0'0	0'0	0
18	$u\left(e_{\mathrm{L},f,\mathrm{p}}\right)$	deviation from constant amplitude-frequency characteristic of reference accelerometer	Not applicable. Results reported with the input acceleration		0,00	0,00	0,00	0,00	0,00	00'0	00'(	0 00'	00 00'	0 0	00 0'(	°0 00	0 00'	00,	0,0 0,0	0'0	0
19	$u\left(e_{1,a,A}\right)$	amplitude effect on gain of reference amplifier	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,02	0,02	0,02	0,02	0,02 C	,02 0	,02	1,02 0	02 0,0	32 0,	02 0,(	02 0,	02 0	,02 0,	2 0,0	2 0,0	8
20	$u(e_{1,a,p})$	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,02	0,02	0,02	0,02	0,02 C	,02	,02 6	02 0	02 0,0	32 0,	02 0'(	02 0,	02 0	02 0,	20,0	0,0	N
21	$u\left(e_{1,A}\right)$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03 C	,03 (	03 50'0	0 80'0	03 0'(	33 0,	03 0'(	03 0,	03 0	,03 0,	33 0,0	3 0,0	0
52	$u \left( e_{1,\mathrm{P}} \right)$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02 C	02 0	,02 0	02 0	02 0,0	22	02 0'(	02 0,	02 0	,02 0,1	0,0	2 0'0	8
53	$u\left(e_{\mathrm{E},\Lambda}\right)$	environmental effects on gain of reference amplifier	Estimated to be less than (dT =+/- 1 oC during one complete calibration)	retangular	0,02	0,02	0,02	0,02	0,02	,02	,02	02 0	02 0,0	75 01	0,0	02 0,	02	0,0	20,0	0,0	N
24	$u\left(e_{\mathrm{E,P}}\right)$	environmental effects on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (dT =+/- 1 °C during calibration, St = 0.02%/°C)	retangular	0,02	0,02	0,02	0,02	0,02 C	,02 (	,02 6	02 0	02 0,0	32 0,	02 0,(	02 0,	02 0	02 0,	20,0	2 0'0	Q
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,00	0,00	0,00	0,00	0,00	00'0	00'0	00'00	00 <sup>.</sup>	o 8	00	0 0	0	00	0'0	0'0	0
t					T	t	+	+	+	+	+	+	+	+	+		_	_		_	†

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modeline																-					-
Ommer:         Operation contained         Operatind         Operation c	_	Standard uncertainty			Probability																
1         1	-	component w(x1)	Source of uncertainty	description	distribution model	6500	2000	7500	8000	8500	0006	9500	10000	11000	12000	2500	13000	14000	15000 1	5000	7000
international conditional conditinal conditional conditional conditional conditional condit		$u(\hat{u}_V)$	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0'03	0'03	0,03	0'03	0,03	0,03	0,03	0,03	90'0	0,06	0,06	0,06	0,06	0'08	000	90
international statement and stateme		$u(\hat{u}_{\rm F})$	voltage filtering effect on accelerometer output amplitude neasurement	No analog filtering applied	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	6
Image: state interface		$u(\hat{u}_D)$	effect of voltage disturbance on accelerometer output 6 voltage measurement in	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,06	90,0	90,0	0,06	0,06	0,06	0,06	90'0	90'0	90
$ = \frac{1}{12} = \frac{1}{1$		$u(\hat{u}_T)$	effect of transverse, rocking and bending acceleration on accelerometer voltage measurement (transverse sensitivity e to	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,02	00'0	0,02	6,03	0,07	0,18	0,03	0,07	0,03	9,06	0,08	60'0	80'0	0,18	8	4
		$u(\Phi_{\mathrm{M},0})$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. t forsts, voltage amplitude deviation, deviation from 90° nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in <i>i</i> = 3		0,0	00 <sup>.0</sup>	00'0	00'0	0,0	00'0	0,0	00,0	8,0	0,0	0,0	0,0	00'0	0,0	8	8
		$u(\Phi_{\mathrm{M,F}})$	interferometer signal filtering effect on phase amplitude neasurement (frequency band limitation)	No analog filtering applied.	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	10,0	10
		$u(\Phi_{\mathrm{M,VD}})$	effect of voltage disturbance on phase amplitude teasurement	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	02
		$u(\Phi_{\mathrm{M,MD}})$	effect of motion disturbance on phase amplitude t measurement	Estimated to be less than	retangular	60'0	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0	8
1 $0 + 0^{-1}$ Restandment effection of the ment effective of the ment effectint of the ment effective of the ment effective of the ment eff		$u(\Phi_{\mathrm{M,PD}})$	effect of phase disturbance on phase amplitude terment	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0'03	50	8
	0	$u(\Phi_{\mathrm{M,RE}})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	05
	-	$u(f_{FG})$	vibration frequency measurement (frequency generator E and indicator)	Estimated to be less than (standard limit)	normal (k=2)	00'0	00'0	00'0	0,00	0,00	00'0	0,00	0,00	0,00	0,00	0,00	0,00	00'0	0,00	8	8
	2	$u(S_{RE})$	residual effects on sensitivity measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	measured (for N=6, std dev of the mean)	normal (sqrt(N))	0,07	90'0	0,05	0,06	60'0	0,21	0,18	0,15	0,20	0,20	0,21	0,15	0,16	0,16	0,11	<u></u>
4 ( $u$ ( $j$ )         evolution (functional effection function effection function effection (functional effectional effec		$u(\lambda cal)$	aser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,00	00'0	0,00	0,00	0,00	00'0	0,00	0,00	00'0	0,00	0,00	0,00	00'0	0,00	0	8
Image: form (1)         Image: fo	4	$u(\lambda_{\rm E})$	environmental effects on laser wavelength . Estimated to the less than (dT =+/- 3 C, dP = +/- 70 hPa, dU = +/- 20 %) fr	Estimated to be less than (Temp range from 21 to 25 degrees)	retangular	00'0	00'0	00'0	00'0	00'0	0,00	00'0	00'0	0,00	0,00	0,00	00'0	0,00	0,00	000	00
	ы	u(A  cal)	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	8
$ \frac{1}{1 \cdot (x_1, y_1)} $ (deviation contain multicule frequency characteristic for approx currant or motion. Consider the monoment of the mon	6	$u(e_{T,\Lambda})$	reference amplifiers tracking (deviations in gain for different amplification settings) 9	Not applicable. Amplifier used at a fixed gain setting		00'0	00'0	00'0	00'0	00'0	00'0	0,00	00'0	0,0	0,00	0,00	0,00	00'0	00'0	00'00	00
Image: constraint for the constraint many constraint for the constraint for the constraint for the constraint many constraint for the c	~	$u(e_{1,f,\Lambda})$	deviation from constant amplitude-frequency characteristic   of reference amplifier	Not applicable. Amplifier calibrated at all frequencies		0,00	0,00	00'0	0,00	0,00	00'0	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0	8
	æ	$u(e_{\mathrm{L},f,\mathrm{P}})$	deviation from constant amplitude-frequency characteristic 1 of reference accelerometer	Not applicable. Results reported with the input acceleration		0,00	00'0	0,00	0,00	00'0	00'0	0,00	0,00	00'0	0,00	0,00	0,00	0,00	0,00	00,00	00
	თ	u (e 1.a)	amplitude effect on gain of reference amplifier	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	10,0	6
	0	$u(e_{1,a,p})$	amplitude effect on sensitivity (magnitude) of reference	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	10,0	6
	-	$u(e_{1,0})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	05
	N	$u(e_{\rm LP})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	10
4 $(v_{(x_j)})$ fereno momenta effects on entitivity (magnitude) of entitomenta effects on entitivity (magnitude) of entitients observed.         Entitients observed.         Entitient	0	u (e <sub>E,A</sub> )	tenvironmental effects on gain of reference amplifier a	Estimated to be less than (dT =+/- 1 oC during one complete calibration)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01 0	101
5 $u(S_3)$ safety factor         Estimated to be less than $ueadate$ $0,00$ $0,0$	4	$u \left( e_{\text{ EP}} \right)$	environmental effects on sensitivity (magnitude) of [1] reference accelerometer d	Estimated to be less than (dT =+/- 1 °C during calibration, St = 0.02%/°C)	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	- 10'	5
$ u_{m}(5_2) = \begin{tabular}{lllllllllllllllllllllllllllllllllll$	ŝ	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	00'0	00'0	00'0	00'0	0,00	00'0	00'00	0,00	00'0	0,00	0,00	0,00	0,00	0'00	00'0	00
w <sub>m</sub> (5 <sub>2</sub> ) Estimated Uncertainty for applicamenter sensitivity (k=2) 0.23 0.21 0.20 0.22 0.28 0.41 0.28 0.44 0.47 0.49 0.41 0.42 0.54 0.52 0.52 0.55		$u_{rel}(S_2)$	Estimated Uncertainty fc	or acelerometer sensitivity (k=1)		0,11	0,11	0,10	0,11	0,14	0,29	0,21	0,19	0,23	0,24	0,25	0,21	0,21	0,26 (	0,18 0	,22
	-	$u_{rol}(S_2)$	Estimated Uncertainty fc	or acelerometer sensitivity (k=2)		0,23	0,21	0,20	0,22	0,28	0,59	0,41	0,38	0,46	0,47	0,49	0,41	0,42	0,52	0,36 0	,44

Unce ISO 1	rtainty bud 6063-11:19	get - Absolute Interferometric calibration of a single 199 - Table A.3 & A.5	s-ended standard accelerometer					$\left  \right $		$\left  \right $	$\left  \right $	$\left  \right $		$\left  \right $							
	CHARGE	E SENSITIVITY - MAGNITUDE									-			-							
						Relative exp	anded unc.	ertainty or bc	ounds of estin	nated error	componer	nts (%)									
					Τ	requency (h	- [7	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Standard uncertainty component u(x,)	) Source of uncertainty	description	Probability distribution model	Factor x <sub>i</sub>	10	12,5	16	30	25	31,5	40	20	8	80	100	125	160	200	250	315
-	$u\left( \eta \; v \right)$	accelerometer output voltage measurement ( ADC resolution + DAQ range linearity )	results of different calibrations measured against hp3458A	retangular	0,58	0,05	0,05	0,05	0,05 C	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
~	$u\left(\hat{u}_{\mathrm{F}}\right)$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
т	$u\left( \hat{u}_{\text{D}}\right)$	effect of voltage disturbance on accelerometer output voltage measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	-	0,10	0,10	0,10	0,10 0	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	$u\left(\hat{u}_{\mathrm{T}}\right)$	effect of transverse, rocking and bending acceleration on accelerometer voltage measurement (transverse sensitivity)	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,58	0,00	0,01	0,02	0,01	5,01	0,02	0,01	0,04	0,01	0,00	0,00	0,01	0,03	0,01	0,02	0,01
5	$u(\varPhi_{\mathrm{M},\varrho})$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offses, voltage amplitude deviation, deviation from 90° nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in $i = 3$			00'0	0,00	00'0	0'00	00'C	0,00	00'0	00'0	00'0	00'0	00'0	0,00	00'0	00'0	00'0	0,00
9	$u(\varPhi_{\mathrm{M,F}})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No analog filtering applied.	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
7	$u(\varPhi_{\mathrm{M,VD}})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03 0	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
80	$u(\varPhi_{\mathrm{M,MD}})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
6	$u(\varPhi_{\mathrm{M,PD}})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05 C	9,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\varPhi_{\rm M,RE})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0;30	0,05	0,05	0,05	0,05 C	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Ξ	$u\left(f_{\mathrm{FG}}\right)$	vibration frequency measurement (frequency generator and indicator )	Estimated to be less than (standard limit)	normal (k=2)	0,5	0,0001	0,0001	0,0001	0,0001 0,	0001	1000	0,0001	0001	0001	,0001	0001	0,0001	0,0001	0,0001	0001	,0001
12	$u\left(S_{RE}\right)$	residual effects on sensitivity measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	measured (for N=6, std dev of the mean)	normal (sqrt(N))	0,41	0,02	0,02	0,01	0,01 6	9,01	0,01	0,01	0,01	0,01	0,01	0,01	0,02	0,01	0,02	0,01	0,02
5	$u(\lambda cal)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,5	0,0002	0,0002	0,0002	0,0002 0,	0002	0002	2,0002 C	0002 0	0002 0	,0002 0,	,0002 0	0,0002	0,0002	0,0002 0.	0002 0	,0002
14	$u(\lambda_{\rm E})$	environmental effects on laser wavelength . Estimated to be less than (dT =+/- 3 C, dP = +/- 70 hPa, dU = +/- 20 %)	Estimated to be less than (Temp range from 21 to 25 degrees)	retangular	0,58	0,0007	0,0007	0,0007	0 2000,0	0007 0	0007	0007 0	0 2000	0 2000	0 2000	0007 0	0,0007	0,0007	0 2000,0	0007 0	2000)
15	$u\left(A \text{ cal}\right)$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,10	0,10	0,10	0,10 (	60'0	0,08	0,07	0,06	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
16	$u  (e_{\mathrm{T,A}})$	reference amplifiers tracking (deviations in gain for different amplification settings)	Not applicable. Amplifier used at a fixed gain setting			0,00	00'0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	00'0	0,00
17	$u\left(e_{1,f,\Lambda}\right)$	deviation from constant amplitude-frequency characteristic	Not applicable. Amplifier calibrated at all frequencies			00'0	00'0	00'00	0'00	00'0	0,00	00'0	0,00	00'00	00'0	0,00	0,00	00'0	0,00	00'0	0,00
8	$u\left(e_{\mathrm{L},f,\mathrm{P}}\right)$	deviation from constant amplitude-frequency characteristic of reference accelerometer	Not applicable. Results reported with the input acceleration			0,00	00'0	0,00	0,00	0,00	0,00	0,00	0'00	0,00	0,00	0,00	0,00	00'0	0,00	00'0	0,00
6	$u\left(e_{\mathrm{L},a,A}\right)$	amplitude effect on gain of reference amplifier	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
20	$u\left(e_{1,a,p}\right)$	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
21	$u\left(e_{\mathrm{LA}}\right)$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03 0	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
22	$u\left(e_{\mathrm{LP}}\right)$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02 C	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
53	$u(e_{\rm E,A})$	environmental effects on gain of reference amplifier	Estimated to be less than (dT =+/- 1 oC during one complete calibration)	retangular	0,58	0,06	0,05	0,05	0,04 0	0,04	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,02	0,02	0,02	0,02
24	$u\left(e_{\mathrm{EP}}\right)$	environmental effects on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (dT =+/- 1 °C during calibration, St = 0.02%/°C)	retangular	0,58	0,02	0,02	0,02	0,02 (	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,58	00'0	00'0	0,00	0,00	0,00	0,00	00'0	0,00	00'00	0'00	0,00	0,00	00'0	0,00	0,00	0,00

					Ľ	elative uncer	tainty contrib	ution <i>u</i> relu(y)	(%)											
					-	equency (Hz)														
į	Standard uncertainty component <i>u</i> ( <i>x</i> ,	Source of uncertainty	description	Probability distribution model	Factor x <sub>i</sub>	10	12,5	9	0 25	31,5	40	20	63	80	100	125	160	200	250	315
-	$u(\hat{u}_v)$	accelerometer output voltage measurement (ADC i resolution + DAQ range linearity)	results of different calibrations measured against hp3458A	retangular	0,58	0,03	0,03	8	0,03	0,03	0'0	0,03	0'03	0,03	0'03	0'03	0,03	0,03	0,03	0,03
N	$u(\hat{u}_{\rm F})$	voltage filtering effect on accelerometer output amplitude measurement	No analog filtering applied	retangular	0,58	0,01	0,01 0	01 0,	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
ю	$u(\hat{u}_D)$	effect of voltage disturbance on accelerometer output i voltage measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	-	0,10	0,10 0	10 0,	10 0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	$u\left(\hat{u}_{\mathrm{T}}\right)$	effect of transverse, rocking and bending acceleration on accelerometer voltage measurement (transverse sensitivity t )	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,58	0,00	0,01 0	01 0,	0,01	0,01	0,01	0,02	0,01	0,00	0,00	0,01	0,02	0,01	0,01	0,01
ى د	$u(\Phi_{\rm M, Q})$	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90° hommal angle difference)	Ellipse fit correction implemented. Residual effect already included in <i>i</i> = 3			00'0	0 00'0	io 00	00'0	00'0	00'0	00'0	00'0	00'0	00'0	0,00	00'0	00'0	00'0	0,00
9	$u(\boldsymbol{\Phi}_{\mathrm{M,F}})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation )	No analog filtering applied.	retangular	0,58	0,01	0,01 0	01 0,	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
~	$u(\varPhi_{\mathrm{M,VD}})$	effect of voltage disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,02	0,02	05	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
80	$u(\Phi_{\mathrm{M,MD}})$	effect of motion disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03 0	03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
თ	$u(\varPhi_{M,PD})$	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03 0	03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
10	$u(\Phi_{\mathrm{M,RE}})$	residual interferometric effects on phase amplitude measurement	Estimated to be less than	normal (sqrt(N))	0,30	0,02	0,02 0	02 01	22 0,02	0'05	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
÷	$u(f_{FG})$	vibration frequency measurement (frequency generator and indicator )	Estimated to be less than (standard limit)	normal (k=2)	0,5	00'0	00'0	6 8	00'0	0,0	0,0	0,00	0'0	0,00	00'0	00'0	0,00	0,00	0,0	00'0
12	$u(S_{\text{RE}})$	residual effects on sensitivity measurement ( e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	measured (for N=6, std dev of the mean)	normal (sqrt(N))	0,41	0,01	0,01 0	01 0,	0,00	0,00	00'0	0,00	0,00	0,00	0,01	0,01	00'0	0,01	0,01	0,01
13	$u(\lambda cal)$	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,5	0,00	0,00	00	00'0 00	0,00	00'0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14	$u(\lambda_{\rm E})$	environmental effects on laser wavelength . Estimated to the less than (dT =+/- 3 C, dP = +/- 70 hPa, dU = +/- 20 %)	Estimated to be less than (Temp range from 21 to 25 degrees)	retangular	0,58	0,00	0,00	00	00'0	0'00	00'0	00'0	00'0	0,00	00'0	0,00	00'0	0'00	00'0	0,00
15	u(A  cal)	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,05	0,05 0	02	0,05	0,04	0,04	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
16	$u(e_{T,A})$	reference amplifiers tracking (deviations in gain for different amplification settings)	Not applicable. Amplifier used at a fixed gain setting			00'0	0,00	0	00'0	0,00	00'0	00'0	00'0	00'0	00'0	0,00	00'0	0,00	0,00	0,00
17	$u(e_{1,f,\Lambda})$	deviation from constant amplitude-frequency characteristic in of reference amplifier	Not applicable. Amplifier calibrated at all requencies			0,00	0 00'0	00	00'0 00	0,00	00'0	0,00	0,00	0,00	00'0	00'0	0,00	0,00	0,00	0,00
18	$u(e_{1,f,P})$	deviation from constant amplitude-frequency characteristic i of reference accelerometer i	Not applicable. Results reported with the input acceleration			00'0	0 00'0	10 00	00'0 00	00'0	00'0	00'0	00'0	00'0	00'0	00'0	00'0	0,00	0,00	00'0
19	$u(e_{1,a,\Lambda})$	amplitude effect on gain of reference amplifier	Estimated to be less than (amplitude ange up to 100 m/s <sup>2</sup> )	retangular	0,58	0,01	0,01 0	01 0,	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
20	$u(e_{1,a,p})$	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude ange up to 100 m/s <sup>2</sup> )	retangular	0,58	0,01	0,01 0	01 0,	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
21	$u(e_{1,A})$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,58	0,02	0,02 0	05	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
22	$u(e_{\rm LP})$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,58	0,01	0,01 0	01 0,	0,0 10	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
23	$u\left(e_{\mathrm{E},\Lambda}\right)$	environmental effects on gain of reference amplifier	Estimated to be less than (dT =+/- 1 oC during one complete calibration)	retangular	0,58	0,04	0,03 0	03 01	33 0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,01	0,01	0,01	0,01	0,01
24	$u(e_{EP})$	environmental effects on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (dT =+/- 1 °C during calibration, St = 0.02%/°C)	retangular	0,58	0,01	0,01 0	01 0,	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
25	$u(S_{SF})$	safety factor	Estimated to be less than	retangular	0,58	00'0	0'00	00	00'0	00'0	00'0	00'0	00'0	00'0	0,00	0,00	00'0	0,00	00'0	00'0
	$u_{rol}(S_2)$	Estimated Uncertainty for	or acelerometer sensitivity (k=1)			0,13	0,13 0	13 0,	13 0,10	60'0	60'0	60'0	60'0	60'0	60'0	60'0	0'0	60'0	0,09	60'0
	$u_{rol}(S_2)$	Estimated Uncertainty for	or acelerometer sensitivity (k=2)	-		0,27	0,27 0	27 0,	26 0,19	0,19	0,18	0,18	0,17	0,17	0,17	0,17	0,18	0,17	0,17	0,17
				T	+	-	+	+	+	+	_	_	_			T	T	Ť	Ť	T

				5000	0,05	0,02	0,05	60'0	00'0	0,02	0,03	0,05	0,05	0,05	0.0001	0,20	0,0002	2000,0	0,05	00'0	00'0	0,00	0,02	0,02	0,03	0,02	0,02	0,02	0,00	
				4500	0,05	0,02	0,05	0,08	00'0	0,02	0,03	0,05	0,05	0,05	0.0001	0,21	0,0002	0,0007	0,05	0,00	00'0	0,00	0,02	0,02	0,03	0,02	0,02	0,02	00'0	
				4000	0,05	0,02	0,05	0,08	0,00	0,02	0,03	0,05	0,05	0,05	0.0001	0,17	0,0002	0,0007	0,05	0,00	00'0	00'0	0,02	0,02	0,03	0,02	0,02	0,02	0,00	
				3800	0,05	0,02	0,05	6,03	0,00	0,02	0,03	0,05	0,05	0,05	0.0001	0,10	0,0002	0,0007	0,05	0,00	00'0	00'0	0,02	0,02	0,03	0,02	0,02	0,02	0,00	
			-	3500	0,05	0,02	0,05	0,02	0,00	0,02	0,03	0,05	0,05	0,05	0.0001	0,11	0,0002	0,0007	0,05	0,00	00'0	00'0	0,02	0,02	0,03	0,02	0,02	0,02	0,00	
			-	3150	0,05	0,02	0,05	0,00	0,00	0,02	0,03	0,05	0,05	0,05	0.0001	0,10	0,0002	0,0007	0,05	0,00	00'0	00'0	0,02	0,02	0,03	0,02	0,02	0,02	0,00	
			-	3000	0,05	0,02	0,05	0,01	0,00	0,02	0,03	0,05	0,05	0,05	0.0001	0,09	0,0002	0,0007	0,05	0,00	00'0	00'0	0,02	0,02	0,03	0,02	0,02	0,02	0,00	
				2500	0,05	0,02	0,05	0,02	00'0	0,02	0,03	0,05	0,05	0,05	0.0001	0,07	0,0002	0,0007	0,05	0,00	00'0	0,0	0,02	0,02	0,03	0,02	0,02	0,02	0,00	
				2200	0,05	0,02	0,05	0,01	0,0	0,02	0,03	0,05	0,05	0,05	0.0001	0,07	0,0002	0,0007	0,05	0,00	00'0	00'0	0,02	0,02	0,03	0,02	0,02	0,02	0,00	
			-	2000	0,05	0,02	0,05	0,03	0,0	0,02	0,03	0,05	0,05	0,05	0,0001	0,04	0,0002	2000,0	0,05	0,00	00'0	0,00	0,02	0,02	0,03	0,02	0,02	0,02	0,00	_
			-	1600	0,05	0,02	0,05	0,04	00'0	0,02	0,03	0,05	0,05	0,05	0,0001	0,02	0,0002	0,0007	0,05	0,00	00'0	0,00	0,02	0,02	0,03	0,02	0,02	0,02	00'0	
				1250	0.05	0,02	0,05	0,02	0,00	0,02	0,03	0,05	0,05	0,05	0,0001	0,03	0,0002	0,0007	0,05	0,00	00'0	0,00	0,02	0,02	0,03	0,02	0,02	0,02	00'0	
				1000	0.05	0,02	0,05	0,02	0,00	0,02	0,03	0,05	0,05	0,05	0,0001	0,02	0,0002	0,0007	0,05	0,00	00'0	0,00	0,02	0,02	0,03	0,02	0,02	0,02	00'0	
				800	0,05	0,02	0,05	0,01	0,00	0,02	0,03	0,05	0,05	0,05	0,0001	0,02	0,0002	0,0007	0,05	0,00	00'0	00'0	0,02	0,02	0,03	0,02	0,02	0,02	00'0	
				630	0,05	0,02	0,05	0,01	00'0	0,02	0,03	0,05	0,05	0,05	0.0001	0,01	0,0002	0,0007	0,05	00'0	00'0	00'0	0,02	0,02	0,03	0,02	0,02	0,02	0,00	
				500	0,05	0,02	0,05	£0'0	00'0	0,02	0,03	0,05	0,05	0,05	0.0001	0,11	0,0002	0,0007	0,05	00'0	00'0	00'0	0,02	0,02	0,03	0,02	0,02	0,02	0,00	
				400	0,05	0,02	0,05	0,02	00'0	0,02	0,03	0,05	0,05	0,05	0.0001	0,03	0,0002	0,0007	0,05	00'0	00'0	0,0	0,02	0,02	0,03	0,02	0,02	0,02	0,00	
				Probability tribution model	retangular	etangular	ormal (k=1)	etangular		retangular	retangular	retangular	retangular	mal (sqrt(N))	ormal (k=2)	irmal (sqrt(N))	ormal (k=2)	retangular	ormal (k=2)				retangular	retangular	retangular	retangular	retangular	retangular	retangular	
ended standard accelerometer				description	results of different calibrations measured against hp3458A	No analog filtering applied	effect on sensitivity by simulated noise on riterferometer and accel channels	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	Ellipse fit correction implemented. Residual effect already included in <i>i</i> = 3	No analog filtering applied.	Estimated to be less than	Estimated to be less than	Estimated to be less than	Estimated to be less than no	Estimated to be less than (standard limit)	n measured (for N=6, std dev of the mean)	calibration of laser + bandwidth (1200 n	Estimated to be less than (Temp range from 21 to 25 degrees)	calibration of amplifier BK 2650 with constant charge input	Not applicable. Amplifier used at a fixed gain setting	Not applicable. Amplifier calibrated at all frequencies	Not applicable. Results reported with the input acceleration	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	Estimated to be less than	Estimated to be less than	Estimated to be less than (dT =+/- 1 oC during one complete calibration)	Estimated to be less than (dT =+/- 1 °C during calibration. St = 0.02%/°C)	Estimated to be less than	
et - Absolute Interferometric calibration of a single 9 - Table A.3 & A.5		SENSITIVITY - MAGNITUDE		Source of uncertainty	accelerometer output voltage measurement (ADC resolution + DAQ range linearity)	voltage filtering effect on accelerometer output amplitude measurement	effect of voltage disturbance on accelerometer output	effect of transverse, rocking and bending acceleration on laccelerometer voltage measurement (transverse sensitivity )	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	effect of voltage disturbance on phase amplitude measurement	effect of motion disturbance on phase amplitude measurement	leffect of phase disturbance on phase amplitude measurement	residual interferometric effects on phase amplitude measurement	vibration frequency measurement (frequency generator and indicator)	residual effects on sensitivity measurement ( e.g. random leffect in repeat measurements; experimental standard deviation of arithmetic mean )	laser wavelength calibration	environmental effects on laser wavelength . Estimated to be less than (dT =+/- 3 C, dP = +/- 70 hPa, dU = +/- 20 %)	amplifier gain calibration	reference amplifiers tracking (deviations in gain for different amplification settings)	deviation from constant amplitude-frequency characteristic of reference amplifier	deviation from constant amplitude-frequency characteristic of reference accelerometer	amplitude effect on gain of reference amplifier	amplitude effect on sensitivity (magnitude) of reference accelerometer	instability of reference amplifier gain, and effect of source impedance on gain	instability of sensitivity (magnitude) of reference accelerometer	environmental effects on gain of reference amplifier	environmental effects on sensitivity (magnitude) of reference accelerometer	safety factor	
tainty budg 063-11:1999		CHARGE		Standard uncertainty mponent u(x,)	$u(\hat{u}_V)$	$u(\hat{u}_{\rm F})$	$u\left(\hat{u}_{\text{D}}\right)$	$u\left(\hat{u}_{\mathrm{T}}\right)$	$u(\varPhi_{\mathrm{M},\mathbb{Q}})$	$u(\varPhi_{\rm M,F})$	$u(\varPhi_{\mathrm{M,VD}})$	$u(\varPhi_{\mathrm{M,MD}})$	$u(\varPhi_{\mathrm{M,PD}})$	$u(\varPhi_{\mathrm{M,RE}})$	$u(f_{\rm FG})$	$u(S_{RE})$	$u(\lambda cal)$	$u(\lambda_{\rm E})$	u(A cal)	$u\left(e_{\mathrm{T},\mathrm{A}}\right)$	$u\left(e_{1,f,A}\right)$	$u\left(e_{1,f,\mathrm{P}}\right)$	$u\left(e_{1,a,h}\right)$	$u(e_{\mathrm{L},a,\mathrm{P}})$	$u (e_{1A})$	$u\left(e_{1,\mathrm{P}}\right)$	$u\left(e_{\mathrm{E,A}}\right)$	$u(e_{EP})$	$u(S_{SF})$	
Uncer ISO 16	H			i co	-	N	e	4	ŝ	9	7	8	6	9	=	12	₽ ₽	4	15	16	17	8	19	20	21	53	23	24	25	-

_	-	0 4500	0,03	1 0,01	5 0,05	5 0,05	0,0	1 0,01	2 0,02	0 <sup>03</sup>	0,03	2 0,02	00'0 0	60'0	00'0	00'0	G 0,03	00'0	0,00	00'0 0	1 0,01	1 0,01	2 0,02	0,01	1 0,01	1 0,01	0,00	0 13	21'n 7	a dia
-	-	00 400	0,0	0,0	5 0,0	0,0	00	0,0	0,0	0,0	0,0	0,0	0'0	4 0,0	0,0	0'0	3 0,0	0,0	0'0	0'0	1 0,0	0,0	0'0	0,0	1 0,0	0,0	0'0	c		5
-	-	380	0'0	0,0	)5 0,0	0,0	00	0,0	0,0	0,0	0'0	0,0	0'0 0'0	0,0	0,0	0,0	33 0,0	0,0	0,0	0'0 00	0,0	0,0	20 0,0	0,0	0,0	0,0	0'0 00	0		5
-	-	35	0,0	0,0	0°0	0,0	0,0	0,0	0,0	0'0	0,0	0'0	0,0	0,0	0'0	0,0	0,0	0,0	0,0	0'0	0,0	0,0	0,0	0,0	0,0	0,0	0'0	0	50	5
-	-	00 31	0'0	01 0,0	05 0,(	0,0	8	0,0	0,0	0,0	0,0	0,0	00 00	0,0	00	0,0	03 0,0	00 0'	0'0	00 00	01 0,0	0,0	0,0	0,0	01 0,0	0,0	0'0	00	10	5
-	-	30	0 0	0,0	0,0	0 <sup>0</sup>	8	0,0	0,0 0,0	0,0	о о́	0,0	°	0 0	0,0	0,0	0,0	0'0	0,0	0,0	01 0,0	0,0	0,0	0,0	01 0,0	0,0	0'0 0	00	το 10 10	5 0
-	-	55 25	8	01 0,	00	0	8	0	00	0 8	8	00	°0 00	о о	0 00	00 00	03	0 0	0 0	°0 00	01 0,	01 0,	00	01	01 0,	0	°0 00	0		5 2
-	-	52	o B	01 0,	05 0,	o S	ő 8	01 0	0 0	0 8	o B	0	° 00	o B	°	°	03 0,	° 0	° 8	° 0	01 0,	01 0,	0000	01 0,	01 0,	01 0,	° 8	0	18 19 0	5
	-	500	0 80,	.01 0	,05	o S	6	10, 0	,02 0	0	8	02	o 00'	10, 0	0	00,	,03	0	,0 0	0 00'	,01	0,	,02 0	10, 0	,01 0	10, 0	0	g	ο 1 α 1	5 0
	-	250	0	01	,05	0	0	10	0	0	8	0	0	0	0	00	,03	0	0	0 00	01 0	01	02	01	01 0	10,	0	0	2 0	, ,
	-	000 11	0	01	,05	0	0	0	0	0	8	0	0	0	0	00	,03	0	0	0 00	01 0	01	02	01	01 0	10,	0	0	2 0	, ,
	-	- 00	0	01	02	6	8	10	0	0	8	0	0	<u>6</u>	0	0	,03	0	8	0	01 0	01	02	01	01	10,	0	0	12	
	-	2 230	0	0,01	0,05	0,01	8	10,0	0,02	0	0,00	0,02	00'00	0	0,00	00'0	0,03 0	00 0	0 00'0	00'00	0,01 0	0,01	0,02	0,01	0,01 0	0,01	0,00	0	212	,
	-	000	0	010	0,05 0	0,02	8	10,0	0,02	0	0,00	0,02	00'00	0,05	0,00	00'0	0,03 0	00 0	0 00'0	00'00	0,01 C	0,01	0,02	0,01	0,01 0	0,01	0,00	10		2
	-	60 10	0	0100	0,05 0	0,01	8	0,01	0,02	0	0,03	0,02	00'00	10,0	0,00	00'0	0,03 0	00 0	0 00'0	00'00	0,01 C	0,01	0,02	0,01	0,01 0	0,01	0,00	0	2 1 2	
	[	ability on model	gular	gular	I (k=1) C	gular	0	gular	gular	gular	gular	(sqrt(N))	I (k=2) C	(sqrt(N))	I (k=2) C	gular C	I (k=2) C	0	0	0	gular C	gular C	gular	gular	gular	gular	gular C			
		Prob distributi	red retan	retan	e on norma	cetan Sh is	n	retan	retan	retan	retan	normal	mit) norma	an) normal (	norma	e	norma	8	all	the	retan	retan	retan	retan	C	C	retan			
		description	s of different calibrations measur st hp3458A	alog filtering applied	on sensitivity by simulated noise ometer and accel channels	sidual effect on sensitivity is ted by the error to a LS fit, whic ass than	fit correction implemented. al effect already included in <i>i</i> =	alog filtering applied.	nated to be less than	nated to be less than	ated to be less than	ated to be less than	ted to be less than (standard lir	ured (for N=6, std dev of the me	ation of laser + bandwidth (1200	ated to be less than (Temp rang 21 to 25 degrees)	ation of amplifier BK 2650 with ant charge input	pplicable. Amplifier used at a fixe setting	applicable. Amplifier calibrated at sencies	applicable. Results reported with t t acceleration	mated to be less than (amplitude je up to 100 m/s <sup>2</sup> )	imated to be less than (amplitude ge up to 100 m/s <sup>2</sup> )	timated to be less than	timated to be less than	timated to be less than (dT =+/- 1 o ring one complete calibration)	timated to be less than $(dT = +/-1^{\circ})$ ring calibration. St = 0.02%/°C)	stimated to be less than	acataromatar sansitivity (k-1)	acelerolinerer sensitivity (n=1) seelerometer sensitivity (k=2)	מספומו חוויםיםי שמושוות וא לא-אל
			result again	No an	effect o	The re estima to be lo	Ellipse Residu	No ani	Estim	Estir	Estim	Estima	Estima	meas	calibr: MHz)	Estim from :	consta	Not a gain	Not a	Not inpu	Esti	Est ran	ш	ů	8 원	шə	Шŭ	i i	5 2	5
		Source of uncertainty	accelerometer output voltage measurement ( ADC result resolution + DAQ range linearity ) again	voltage filtering effect on accelerometer output amplitude No an measurement	effect of voltage disturbance on accelerometer output effect ( voltage measurement	effect of transverse, rocking and bending acceleration on The re accelerometer voltage measurement (transverse sensitivity estima )	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. Ellipse offest, voltage amplitude deviation, deviation from 90° Residu nominal angle difference)	interferometer signal filtering effect on phase amplitude No ani measurement (frequency band limitation)	effect of voltage disturbance on phase amplitude Estimmeasurement	effect of motion disturbance on phase amplitude Estir measurement	effect of phase disturbance on phase amplitude Estim measurement	residual interferometric effects on phase amplitude Estima measurement	vibration frequency measurement (frequency generator Estima and indicator)	residual effects on sensitivity measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	calibr laser wavelength calibration	environmental effects on laser wavelength . Estimated to Estimate to be less than (dT =+/- 3 C, dP = +/- 70 hPa, dU = +/- 20 %)	calibra amplifier gain calibration	reference amplifiers tracking (deviations in gain for Not a different amplification settings)	deviation from constant amplitude-frequency characteristic Not: of reference amplifier	deviation from constant amplitude-frequency characteristic Not of reference accelerometer inpu	Estin amplitude effect on gain of reference amplifier rang	amplitude effect on sensitivity (magnitude) of reference Est accelerometer ran	instability of reference amplifier gain, and effect of source impedance on gain	instability of sensitivity (magnitude) of reference accelerometer	Es environmental effects on gain of reference amplifier du	environmental effects on sensitivity (magnitude) of Es reference accelerometer du	safety factor Es	Estimated Hovertainty for	Estimated Undertainty for	
		Standard uncordinity amporent <i>a</i> ( <i>x</i> , ) Source of uncertainty	accelerometer output voltage measurement ( ADC result $u(\hat{a}_v)$ resolution + DAQ range linearity ) again	voltage filtering effect on accelerometer output amplitude $N_{\rm O}$ an measurement	effect of voltage disturbance on accelerometer output effect ( $u\left(\hat{n}_{\rm D}\right)$ voltage measurement	effect of transverse, rocking and bending acceleration on The re- accelerometer voltage measurement (transverse sensitivity lestima $u(\hat{u}, \gamma)$ )	effect of interferometer quadrature output signal effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. Ellipse offsets, voltage amplitude deviation, deviation from 90° Residu $u (\phi_{A,A,D})$ hominal angle differences	interferometer signal filtering effect on phase amplitude No and $u(\Phi_{\rm M,F})$ measurement (frequency band limitation )	effect of voltage disturbance on phase amplitude Estimmed u ( $\varPhi_{\rm M,VD}$ ) measurement	effect of motion disturbance on phase amplitude Estimation $u\left(\Phi_{\mathrm{M,MD}}\right)$ measurement	effect of phase disturbance on phase amplitude Estimmed ( $\varPhi_{M_{1},\mathrm{PD}}$ ) measurement	residual interferometric effects on phase amplitude Estimu $u\left( \varphi_{\mathrm{M},\mathrm{RE}} \right)$ measurement	vibration frequency measurement ( frequency generator Estima $u(f_{\rm FG})$ and indicator )	residual effects on sensitivity measurement ( e.g. random effect in repeat measurements; experimental standard meas u (S RE) deviation of arithmetic mean )	$u(\lambda cal)$ [aser wavelength calibration] MHz)	$\lim_{u(\cdot,\lambda_{\pm})} \lim_{b \in \text{less than }(dT=*+^{\prime}-3,c,dP=*+^{\prime}.7\text{hFa}, dU=*+^{\prime}.22\%)} \inf_{from}$	calibre u (A cal) amplifier gain calibration consta	reference amplifiers tracking (deviations in gain for Not a $u(e_{T,\Lambda})$ different amplification settings) gain	deviation from constant amplitude-frequency characteristic Not: $u(e_{1,f,\Lambda})$ of reference amplifier [frequ	deviation from constant amplitude-frequency characteristic Not $u(e_{L,f,p})$ of reference accelerometer	$u(e_{1,a,.,b})$ amplitude effect on gain of reference amplifier range (	amplitude effect on sensitivity (magnitude) of reference $\mathbb{E}$ t $u(e_{L_{a,p}})$ accelerometer ran	instability of reference amplifier gain, and effect of source $u(e_{1,\lambda})$ impedance on gain Es	instability of sensitivity (magnitude) of reference $u(e_{\rm LP})$ accelerometer Es	$u(e_{E,\lambda})$ environmental effects on gain of reference amplifier du	$ \begin{array}{c c} & \text{environmental effects on sensitivity (magnitude) of} & \text{E}e \\ & u \ (e \ {}_{EP}) & \text{reference accelerometer} \end{array} $	u (S <sub>SF</sub> ) safety factor	Letimated Horartainty for a	"rativ 2) Estimated Undertainty for Estimated Undertainty for	

		18000	0.10	0,02	0,06	0,64	00'0	0,02	0'03	0,05	0,05	0,05	0.0001	1,39	0,0002	2000'0	0,05	00'0	00'0	00'0	0,02	0,02	0,03	0,02	0,02	0.02	00'0
		17000	0.10	0,02	0,06	0,14	00'0	0,02	0,03	0,05	0,05	0,05	0.0001	1,91	0,0002	0,0007	0,05	00'0	00'0	00'0	0,02	0,02	0,03	0,02	0,02	0,02	0'00
		16000	0.10	0,02	0,06	0,02	0,00	0,02	0,03	0,05	0,05	0,05	0.001	1,23	0,0002	0,0007	0,05	00'0	0'0	00'0	0,02	0,02	0,03	0,02	0,02	0.02	00'0
		15000	0.10	0,02	0,06	0,22	00'0	0,02	0,03	0,05	0,05	0,05	0.0001	1,17	0,0002	0,0007	0,05	0,00	0'0	0,0	0,02	0,02	0,03	0,02	0,02	0.02	0,00
		14000	0.10	0,02	0,06	0,06	0,00	0,02	0,03	0,05	0,05	0,05	0.001	1,09	0,0002	0,0007	0,05	00'0	00'0	00'0	0,02	0,02	0,03	0,02	0,02	0.02	0,00
		00061	0.10	0,02	0,06	0,16	0,00	0,02	0,03	0,05	0,05	0,05	0.001	0,78	0,0002	0,0007	0,05	00'0	00'0	0,0	0,02	0,02	0,03	0,02	0,02	0.02	00'0
		12500	0.10	0,02	0,06	0,0	00'0	0,02	0,03	0,05	0,05	0,05	0.0001	0,77	0,0002	0,0007	0,05	0,0	0'0	0,0	0,02	0,02	0,03	0,02	0,02	0.02	0,00
		12000	0.10	0,02	0,06	0,11	0,0	0,02	0,03	0,05	0,05	0,05	0.0001	1,13	0,0002	0,0007	0,05	00'0	00'0	00'0	0,02	0,02	0,03	0,02	0,02	0.02	0,00
		11000	0.10	0,02	90,0	0,34	8,0	0,02	0,03	0,05	0,05	0,05	0.0001	1,03	0,0002	0,0007	0,05	0,0	0,0	8,0	0,02	0,02	0,03	0,02	0,02	0.02	00'0
		10000	0.05	0,02	90,0	0,40	8,0	0,02	0,03	0,05	0,05	0,05	0.0001	1,18	0,0002	0,0007	0,05	0,0	0°'0	8,0	0,02	0,02	0,03	0,02	0,02	0.02	00'0
		9500	0.05	0,02	90,06	65,0	0,0	0,02	0,03	0,05	0,05	0,05	0.0001	0,47	0,0002	0,0007	0,05	00,0	0,0	0,0	0,02	0,02	0,03	0,02	0,02	0.02	00'0
		000	0.05	0,02	0,05	0,12	00'0	0,02	0,03	0,05	0,05	0,05	0.0001	0,36	0,0002	0,0007	0,05	00'0	00'0	00'0	0,02	0,02	0,03	0,02	0,02	0.02	00'0
	1	8500	0.05	0,02	0,05	0,07	0,0	0,02	0,03	0,05	0,05	0,05	0.0001	0,28	0,0002	0,0007	0,05	00'0	00'0	0,0	0,02	0,02	0,03	0,02	0,02	0.02	00'0
			0.05	0,02	0,05	0,38	00'0	0,02	0,03	0,05	0,05	0,05	0.00	0,37	0,0002	2000,0	0,05	0,00	0'00	0,00	0,02	0,02	0,03	0,02	0,02	0.02	00'0
	1	7500	0.05	0,02	0,05	0,31	00'0	0,02	0,03	0,05	0,05	0,05	0.0001	0,66	0,0002	0,0007	0,05	0,0	00'0	0,0	0,02	0,02	0,03	0,02	0,02	0.02	00'0
	1	2000	0.05	0,02	0,05	0,01	0,0	0,02	0,03	0,05	0,05	0,05	0.00	0,49	0,0002	2000,0	0,05	00'0	00'0	0,0	0,02	0,02	0,03	0,02	0,02	0.02	00'0
	1	6500	0.05	0,02	0,05	0,12	00'0	0,02	0,03	0,05	0,05	0,05	0.001	0,55	0,0002	0,0007	0,05	0,0	0'0	0,0	0,02	0,02	0,03	0,02	0,02	0.02	00'0
		robability bution model	tangular	tangular	mal (k=1)	tangular		etangular	stangular	etangular	tangular	al (sqrt(N))	mal (k=2)	nal (sqrt(N))	mal (k=2)	tangular	mal (k=2)				tangular	stangular	etangular	stangular	etangular	stangular	etangular
-ended standard accelerometer		description	results of different calibrations measured	No analog filtering applied	effect on sensitivity by simulated noise on ni interferometer and accel channels	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	Ellipse fit correction implemented. Residual effect already included in <i>i</i> = 3	No analog filtering applied.	Estimated to be less than	Estimated to be less than	Estimated to be less than	Estimated to be less than nor	Estimated to be less than (standard limit) no	nc measured (for N=6, std dev of the mean)	calibration of laser + bandwidth (1200 nt MHz)	Estimated to be less than (Temp range from 21 to 25 degrees)	calibration of amplifier BK 2650 with nt constant charge input	Not applicable. Amplifier used at a fixed gain setting	Not applicable. Amplifier calibrated at all frequencies	Not applicable. Results reported with the input acceleration	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	Estimated to be less than	Estimated to be less than	Estimated to be less than (dT =+/- 1 oC during one complete calibration)	Estimated to be less than $(dT =+/-1 °C)$	Estimated to be less than
et - Absolute Interferometric calibration of a single 9 - Table A.3 & A.5	SENSITIVITY - MAGNITUDE	Source of incredianty	accelerometer output voltage measurement ( ADC resolution + DAQ range linearity )	voltage filtering effect on accelerometer output amplitude measurement	effect of voltage disturbance on accelerometer output voltage measurement	effect of transverse, rocking and bending acceleration on accelerometer voltage measurement (transverse sensitivity)	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	effect of voltage disturbance on phase amplitude measurement	effect of motion disturbance on phase amplitude measurement	effect of phase disturbance on phase amplitude measurement	residual interferometric effects on phase amplitude measurement	vibration frequency measurement (frequency generator and indicator)	residual effects on sensitivity measurement (e.g. random reffect in repeat measurements; experimental standard deviation of arithmetic mean )	laser wavelength calibration	environmental effects on laser wavelength . Estimated to be less than (dT =+/- 3 C, dP = +/- 70 hPa, dU = +/- 20 %)	amplifier gain calibration	reference amplifiers tracking (deviations in gain for different amplification settings)	deviation from constant amplitude-frequency characteristic of reference amplifier	deviation from constant amplitude-frequency characteristic of reference accelerometer	amplitude effect on gain of reference amplifier	amplitude effect on sensitivity (magnitude) of reference accelerometer	instability of reference amplifier gain, and effect of source impedance on gain	instability of sensitivity (magnitude) of reference accelerometer	environmental effects on gain of reference amplifier	environmental effects on sensitivity (magnitude) of reference accelerometer	safety factor
tainty budg 3063-11:199	HARGE	Standard uncertainty	u (û v)	$u\left(\hat{u}_{\rm F}\right)$	$u\left(\hat{u}_{\mathrm{D}}\right)$	$u(\hat{u}_{T})$	$u(\varPhi_{\mathrm{M},\mathbb{Q}})$	$u(\varPhi_{\rm M,F})$	$u(\varPhi_{\mathrm{M,VD}})$	$u(\varPhi_{\mathrm{M,MD}})$	$u(\varPhi_{\mathrm{M, PD}})$	$u(\varPhi_{\mathrm{M,RE}})$	$u(f_{\rm FG})$	$u(S_{RE})$	$u(\lambda cal)$	$u(\lambda_{\rm E})$	u(A  cal)	$u\left(e_{\mathrm{T,A}}\right)$	$u\left(e_{1,f,\lambda}\right)$	$u\left(e_{\mathrm{L},f,\mathrm{P}}\right)$	$u\left(e_{\mathrm{L},a,\mathrm{A}}\right)$	$u(e_{1,a,p})$	$u \left( e_{\perp \Lambda} \right)$	$u \left( e_{1,\mathrm{P}} \right)$	$u\left(e_{\mathrm{E,A}}\right)$	$u(e_{\rm EP})$	$u(S_{SF})$
Uncer ISO 16			-	~	m	4	ŝ	9	7	80	<b>б</b>	9	=	5	₽ ₽	4	15	16	17	8	19	20	5	53	23	24	25

### Appendix B: Uncertainty Budgets of the participants

F	1		-	-	-	I		-	<u> </u>			-	-	L	-					-	<u> </u>		-				$\vdash$		+	-
		18000	0'0	0,01	0,06	0,37	00'o	0,01	0,02	0'03	0,03	0,02	0,00	0,57	0,00	00'0	0,03	00'0	00'0	00'0	0,01	0,01	0,02	0,01	0,01	0,01	00'0	0.60	A0'0	1,37
		17000	0'0	0,01	0,06	0,08	0,0	0,01	0,02	0'03	0,03	0,02	00'0	0,78	00'0	0,00	0,03	00'0	00'0	00'0	0,01	0,01	0,02	0,01	0,01	0,01	00'0	0.70	n'/a	1,59
		16000	0,06	0,01	0,06	0,01	00'0	0,01	0,02	0,03	0,03	0,02	0,00	0,50	0,00	0,00	0,03	00'0	0,00	00'0	0,01	0,01	0,02	0,01	0,01	0,01	00'0	0.61	10'0	1,03
		15000	0,06	0,01	0,06	0,13	0,0	0,01	0,02	0,03	0,03	0,02	0,00	0,48	0,00	0,00	0,03	00'0	0,00	00'0	0,01	0,01	0,02	0,01	0,01	0,01	0,00	0.61	10'0	1,01
		14000	0,06	0,01	0,06	0,03	0,0	0,01	0,02	0,03	0,03	0,02	00'0	0,44	0,00	0,00	0,03	00'0	00'0	00'0	0,01	0,01	0,02	0,01	0,01	0,01	00'0	0.4E	0,40	0,91
		13000	0,06	0,01	0,06	0,09	0,0	0,01	0,02	0,03	0,03	0,02	00'0	0,32	00'0	0,00	0,03	00'0	00'0	00'0	0,01	0,01	0,02	0,01	0,01	0,01	0,00	0.35	0010	0,70
		12500	0,06	0,01	0,06	0,0	0,0	0,01	0,02	0,03	0,03	0,02	0,00	0,32	0,00	00'0	0,03	0,00	0,00	0,00	0,01	0,01	0,02	0,01	0,01	0,01	0,00	1 33	55,0	0,67
		12000	0,06	0,01	0,06	0,0	8	0,01	0,02	0,03	0,03	0,02	0,0	0,46	0,00	0,00	0,03	00'0	0,00	0,00	0,01	0,01	0,02	0,01	0,01	0,01	0,00	0.48	0,40	0 <sup>,96</sup>
		11000	90'0	0,01	0,06	0,20	8,0	0,01	0,02	0,03	0,03	0,02	0,00	0,42	0,0	0,00	0,03	00'0	0,00	00'0	0,01	0,01	0,02	0,01	0,01	0,01	0,00	87.0	0,40	0,95
		10000	0,03	0,01	0,06	0,23	8,0	0,01	0,02	0,03	0,03	0,02	0,00	0,48	0,0	0,00	0,03	00'0	0,00	00'0	0,01	0,01	0,02	0,01	0,01	0,01	0,00	0.54	t 0,04	1,08
		9500	0,03	0,01	0,06	0,23	8,0	0,01	0,02	0,03	0,03	0,02	0,00	0,19	0,0	00'0	0,03	00'0	0,00	00'0	0,01	0,01	0,02	0,01	0,01	0,01	0,00	100	10,0	0,62
		0006	0,03	0,01	0,05	0,07	8,0	0,0	0,02	0,03	0,03	0,02	0,00	0,15	0,00	0,00	0,03	00'0	0,00	0,00	0,0	0,01	0,02	0,0	0,01	0,01	0,00	0.18	0,10	0,36
		8500	0,03	0,01	0,05	0,04	8,0	0,01	0,02	0'03	0,03	0,02	0,00	0,12	0,00	00'0	0,03	00'0	00'0	00'0	0,0	0,01	0,02	0,01	0,01	0,01	0,00	0.15	0,10	0'30
-		8000	0,03	0,01	0,05	0,22	80	0,01	0,02	0,03	0,03	0,02	0,00	0,15	0,00	00'0	0,03	00'0	0,00	00'0	0,01	0,01	0,02	0,01	0,01	0,01	00'0	80 0	07'0	0,56
		7500	0,03	0,01	0,05	0,18	0,0	0,01	0,02	0,03	0,03	0,02	0,0	0,27	0,0	00'0	0,03	00'0	0,00	00'0	0,01	0,01	0,02	0,01	0,01	0,01	00'0	0.33	50'D	0,67
		7000	0,03	0,01	0,05	0,01	0,0	0,01	0,02	0,03	0,03	0,02	0,0	0,20	0,0	00'0	0,03	00'0	0,00	00'0	0,01	0,01	0,02	0,01	0,01	0,01	00'0	0.00	0,42	0,43
		6500	0,03	0,01	0,05	0,07	0,0	0,01	0,02	0,03	0,03	0,02	0,0	0,23	0,0	00'0	0,03	00'0	0,00	00'0	0,01	0,01	0,02	0,01	0,01	0,01	00'0	0.05	0,43	0'20
		robability bution model	atangular	stangular	rmal (k=1)	stangular		etangular	atangular	etangular	etangular	nal (sqrt(N))	rmal (k=2)	nal (sqrt(N))	rmal (k=2)	etangular	rmal (k=2)				atangular	etangular	etangular	etangular	etangular	etangular	stangular			
		P	inred	2	se on no	ich is	۳ ۱	2	2	2	2	nom	limit) no	ean) norr	0	age	ē.	xeq	at all	n the			2	2	20	ء د	2	_		
		description	results of different calibrations meas against hp3458A	No analog filtering applied	effect on sensitivity by simulated noi interferometer and accel channels	The residual effect on sensitivity is estimated by the error to a LS fit, wh to be less than	Ellipse fit correction implemented. Residual effect already included in <i>i</i>	No analog filtering applied.	Estimated to be less than	Estimated to be less than	Estimated to be less than	Estimated to be less than	Estimated to be less than (standard	measured (for N=6, std dev of the m	calibration of laser + bandwidth (120 MHz)	Estimated to be less than (Temp rar from 21 to 25 degrees)	calibration of amplifier BK 2650 with constant charge input	Not applicable. Amplifier used at a fi gain setting	Not applicable. Amplifier calibrated a frequencies	Not applicable. Results reported with input acceleration	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	Estimated to be less than	Estimated to be less than	Estimated to be less than (dT =+/- 1 during one complete calibration)	Estimated to be less than (dT =+/- 1 during calibration, St = 0.02%/°C)	Estimated to be less than	ins and sometar sansitivity (k=1)	Of acelerometer sensitivity (n=1)	or acelerometer sensitivity (k=2)
		Source of uncertainty	accelerometer output voltage measurement ( ADC n resolution + DAQ range linearity ) a	voltage filtering effect on accelerometer output amplitude heasurement	effect of voltage disturbance on accelerometer output e voltage measurement in	effect of transverse, rocking and bending acceleration on a accelerometer voltage measurement (transverse sensitivity e )	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. E disturbance on phase amplitude deviation, deviation from 90° fi nominal angle difference	interferometer signal filtering effect on phase amplitude heasurement (frequency band limitation)	effect of voltage disturbance on phase amplitude E measurement	effect of motion disturbance on phase amplitude E measurement	effect of phase disturbance on phase amplitude E measurement	residual interferometric effects on phase amplitude E measurement	vibration frequency measurement (frequency generator E and indicator)	residual effects on sensitivity measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	c laser wavelength calibration M	environmental effects on laser wavelength . Estimated to be less than (dT =+/- 3 C, dP = +/- 70 hPa, dU = +/- 20 %) fr	amplifier gain calibration	reference amplifiers tracking (deviations in gain for 6 different amplification settings) g	deviation from constant amplitude-frequency characteristic h of reference amplifier	deviation from constant amplitude-frequency characteristic h of reference accelerometer	E amplitude effect on gain of reference amplifier	amplitude effect on sensitivity (magnitude) of reference <sup>E</sup> accelerometer	instability of reference amplifier gain, and effect of source E impedance on gain	instability of sensitivity (magnitude) of reference accelerometer	E environmental effects on gain of reference amplifier d	environmental effects on sensitivity (magnitude) of E reference accelerometer	safety factor E	Estimated I Incertainty for		Estimated Uncertainty to
		Standard uncertainty omponent u(x,	$u(\hat{u}_V)$	$u(\hat{l}_{\rm F})$	$u(\hat{u}_D)$	$u(\hat{u}_T)$	$u(\Phi_{\mathrm{M},0})$	$u(\boldsymbol{\phi}_{\mathrm{M,F}})$	$u(\Phi_{\mathrm{M,VD}})$	$u(\Phi_{\mathrm{M,MD}})$	$u({\pmb{\phi}}_{\mathrm{M,PD}})$	$u(\Phi_{\mathrm{M,RE}})$	$u(f_{EG})$	u (S <sub>RE</sub> )	u( & cal)	$u(\lambda_{\rm E})$	u(A cal)	$u(e_{T,\Lambda})$	$u(e_{1,f,\Lambda})$	$u(e_{1,f,p})$	$u(e_{1,a,A})$	$u(e_{L,a,p})$	$u(e_{1,h})$	$u(e_{\rm LP})$	$u (e_{E,\Lambda})$	$u(e_{EP})$	$u(S_{SF})$	(-3)	(2 C) In H	u rd (5 2)
F		ن 	-	N	m	4	ۍ	9	~	8	6	9	=	12	13	4	15	16	17	18	19	20	5	8	53	24	25	+	+	+

	rtainty bud	det - Absolute Interferometric calibration of a back-to	-hack standard accelerometer (loading n	1925 - 0 d)				, OSI	16063-11:	1999 - Tak	A 4 8 1	9					
								2				2					
	CHARGI	E SENSITIVITY - PHASE SHIFT				Expanded	uncertaint	y or bound	ds of estim	ated error	compone	nts (°)					
						frequency	(Hz)	-	-	-	-	-	-	-	-	-	
	Standard uncertainty component			Probability distribution	Factor												
i	$u(x_i)$	Source of uncertainty	description	model	x <sub>i</sub>	10	12,5	16	20	25	31,5	40	50	63	80	100	125
-	$u\left( \Phi_{u,V}\right)$	accelerometer output phase measurement	results of different calibrations measured against hp3458A	normal (k=1)	ł	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
2	$u\left( \Phi_{u,F}\right)$	voltage filtering effect on accelerometer output phase measurement	No analog filtering applied. Special digital filter has negligible effect.	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
ю	$u(\Phi_{u,D})$	effect of voltage disturbance on output phase measurement (e.g hum and noise)	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	۰.	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	$u(\varPhi_{u,T})$	effect of transverse, rocking and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,58	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
ى س	$u(\Phi_{s,Q})$	effect of interferometer quadrature output signal effect of interferometer quadrature output signal effects, voltage amplitude deviation deviation from 90 degrees nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in <i>i</i> = 3														
9	$u(\Phi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation)	No analog filtering applied.	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
~	$u(\Phi_{s,VD})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
œ	$u(\Phi_{s,MD})$	effect of motion disturbance on displacement phase masurement (e.g. drift; relative motion between accelerometer reference surface and the spot sensed by the interferometer)	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
6	$u(\varPhi_{s,PD})$	effect of phase disturbance on displacement phase measurement (e.g. phase noise of the interferometer signals)	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\Phi_{s,RE})$	residual interferometric effects on displacement phase measurement	Estimated to be less than	normal (sqrt(N))	0,30	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
÷	$u\left(\Delta \Phi_{RE} ight)$	residual effects on phase shift measurement (e.g. random effect in repeat measurements, experimental standard deviation of arithmetic mean )	Measured (for N=5, std dev of the mean)	normal (sqrt(N))	0,45	0,03	0,01	0,01	0,04	0,01	0,01	00'0	0,00	0,00	00'0	0,01	0,01
12	$u\left(\Delta \Phi_{A,cal}\right)$	amplifier phase shift calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
13	$u \left( e_{\mathrm{T,A}} \right)$	reference amplifier tracking (deviations in phase for different amplification settings)	Not applicable. A single calibrated setting is used.	retangular	0,58	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	,0002	,0002 0	,0002 0	,0002
14	$u\left(e_{\mathrm{T,f,A}}\right)$	deviations from linear phase-frequency characteristic of reference amplifier	Not applicable. A single calibrated setting is used.	retangular	0,58	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007 0	0 2000,	,0007 0	0 2000,	,0007
15	$u(\lambda cal)$	deviations from linear phase-frequency characteristic of reference accelerometer	Effect included in the standard deviation of the mean	normal (k=2)	0,5	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
16	$u(e_{1,a,A})$	amplitude effect on phase shift of reference amplifier	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,01	0,01	0,01	0,01	0,01
17	$u(e_{L,a,p})$	amplitude effect on phase shift of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
18	$u \left( e_{1,\mathrm{A}} \right)$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
19	u(e,)	instability of reference accelerometer phase shift	Estimated to be less than	retangular	0.58	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

T.			10	2	•	2	ى ى	0	-	0	0	e	N	5	-	•	0			-	~	-
			125	0°0	0'0	0,0	0,06	0,0	0,01	0,02	0,0	0'0	0,0	1 0,000	0,0	0,0	0,0	0,0	0,0	0'0	0,0	
			10	0,05	00'0	0,05	0,06	0,0	0,01	0,02	0,03	0,03	0,02	.000'0	0,0	0,0	00'0	0,03	0,01	0,01	0,02	6
			80	0,05	0,00	0,05	0,06	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,00	0,0	00'0	0,03	0,01	0,01	0,02	0
			8	0,05	0,00	0,05	0,06	0,00	0,01	0,02	0,03	0'03	0,02	0,0001	0,00	00'0	00'0	0,03	0,01	0,01	0,02	00
			50	0,05	0,00	0,05	0,06	00'0	0,01	0,02	0,03	0,03	0,02	0,0001	0,00	0,00	0,00	0,03	0,01	0,01	0,02	0.01
			40	0,05	00'0	0,05	0,06	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,00	0,00	00'0	0,03	0,01	0,01	0,02	50
			31,5	0,05	0,00	0,05	0,06	00'0	0,01	0,02	0,03	0,03	0,02	0,0001	0,00	0,0	00'0	0,03	0,01	0,01	0,02	5
			55	0,05	0,00	0,05	0,06	00'0	0,01	0,02	0,03	0,03	0,02	0,0001	0,00	00'0	0,00	0,03	0,01	0,01	0,02	2
	(_)		50	0,05	0,00	0,05	0,06	0,0	0,01	0,02	0,03	0,03	0,02	0,0001	0,02	0,0	00'0	0,03	0,01	0,01	0,02	
	n u rei,i(y)		<u>ب</u>	0,05	00'0	0,05	0,06	00'0	0,01	0,02	0,03	0,03	0,02	0,0001	0,00	0,00	00'0	0,03	0,01	0,01	0,02	
	contributic	(zł	12,5	0,05	0,00	0,05	0,06	0,00	0,01	0,02	0,03	0,03	0,02	,0001	0,01	0,00	00'0	0,03	0,01	0,01	0,02	
	certainty	quency (F	9	0,05	0,00	0,05	0,06	0,00	0,01	0,02	0,03	0,03	0,02	,0001	0,01	0,00	0,00	0,03	0,01	0,01	0,02	
	5	fre	actor x;	0,58	0,58	-	0,58		0,58	0,58	0,58	0,58	0,30	0,5	0,45	0,5	0,58	0,5	0,58	0,58	0,58	0,58
-			ution F	ular	ar	k=1)	ar		ar	ar	ar	lar	ц(N))	(=2)	ц(N))	(=2)	lar	k=2)	lar	ar	ы ы	
			1 4 7 7			I =	3		13	3	5	<b>D</b>	σ	LĚ –	Q.	LE I			131		1 1 1	1 3
			Proba distrib moo	retangu	retangu	normal (	retangu		retangul	retangu	retangu	retangu	normal (sq	normal (k	normal (sq	normal (k	retangu	normal (	retangu	retangul	retangul	
			Proba distrib description mo	results of different calibrations measured retang against hp3458A	No filtering applied	effect on sensitivity by simulated noise on normal ( interferometer and accel channels	The residual effect on sensitivity is estimated retangu by the error to a LS fit, which is to be less than	atready included in $i = 3$	No filtering applied	retangu Estimated to be less than	Estimated to be less than	Estimated to be less than	Estimated to be less than	Estimated to be less than (standard limit) normal (k	Estimated to be less than (for N=5, std dev of normal (sq the mean at a single point measurement)	calibration of laser + bandwidth (1200 MHz) normal (k	Estimated to be less than (Temp range from 21 to 25 degrees)	calibration of amplifier BK 2650 with constant normal () charge input	Estimated to be less than retangu	Estimated to be less than (amplitude range up to 100 $m/s^2$ ) retangul	Estimated to be less than retangul	
			Proba distrib ource of uncertainty description mo	ccelerometer output phase measurement (ADC results of different calibrations measured retang. solution) against hp3458A	Itlege filtering effect on accelerometer output phase No filtering applied easurement	fiest of voltage disturbance on accelerometer output leffect on sensitivity by simulated noise on normal (i hase measurement	The residual effect or transverse, rocking and bending acceleration on The residual effect on sensitivity is estimated retangu celerometer output phase measurement (transverse by the error to a LS fit, which is to be less than the error to a LS fit, which is to be less than the error to a LS fit, which is to be less than the error to a LS fit.	flect of interferometer quadrature output signal isturbance on phase amplitude measurement (e.g. fsets, voltage amplitude deviation, deviation from 900 minal angle difference)	terferometer signal filtering effect on phase amplitude No filtering applied easurement ( frequency band limitation )	flect of voltage disturbance or displacement phase teacurement (e.g. andom noise in the photoelectric easuing chained to be less than easuing chained and the photoelectric teaching chained and teaching chained and teaching chained and the photoelectric teaching chained and the photoelectric teaching chained and the photoelectric teaching chained and teaching chained and tea	field of motion disturbance on diaplacementphase Estimated to be less than easurement	ffect of phase disturbance on phase amplitude Estimated to be less than easurement	isidual interferometric effects on phase amplitude Estimated to be less than easurement	bration frequency measurement (frequency generator Estimated to be less than (standard limit) normal (k 1d indicator)	sidual effects on sensitivity measurement (e.g. random festimated to be less than (for N=5, std dev of hormal (sa watchon of anthmetic man).	calibration of laser + bandwidth (1200 MHz) normal (k	wricommental effects on laser wavelength. Estimated to less than (dT =+/-30, dP =+/-70 hPa, dU = +/-20 21 to 25 degrees)	calibration of amplifier BK 2850 with constant normal ( charge input	mplitude effect on gain of reference amplifier Estimated to be less than retangu	mplitude effect on sensitivity (magnitude) of reference Estimated to be less than (amplitude range up coelerometer to 100 m/s <sup>5</sup> ) to 100 m/s <sup>2</sup> )	stability of reference amplifier gain, and effect of source Estimated to be less than retangul	stability of sensitivity (magnitude) of reference
			Standard Leonard Leonarainy description mou	accelerometer output phase measurement ( ADC results of different calibrations measured retangue $u(\hat{u}_v)$ resolution ) against hp3458A	voltage filtering effect on accelerometer output phase No filtering applied retargu $u(\hat{u}_D)$ measurement	effect of voltage disturbance on accelerometer output effect on sensitivity by simulated noise on normal (( $u(\hat{u}_{T})$ phase measurement	effect of transverse, rocking and bending acceleration on The residual effect on sensitivity is estimated retangu accelerometer output phase measurement (transverse by the error to a LS fit, which is to be less have.) than the error to a LS fit, which is to be less the effect.	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. affects, voltage amplitude deviation, deviation from 90o (*e).	Interferometer signal filtering effect on phase amplitude No filtering applied retangul (sp.) measurement (frequency band limitation )	effect of voltage disturbance on displacement phase transmission of the photoelectric measurement (e.g. andom noise in the photoelectric Estimated to be less than $u(s_{VO})$ measuring chains with the photoelectric transmission of the photoele	effect of motion disturbance on diaplacementphase Estimated to be less than retangu $u(s_{\rm ND})$	effect of phase disturbance on phase amplitude $[u(s_{PD})]$ [Estimated to be less than retangu	residual interferometric effects on phase amplitude Estimated to be less than normal (sq. measurement	vibration frequency measurement ( frequency generator Estimated to be less than (standard limit) normal (k and indicator )	residual effects on sensitivity measurement (e.g. random terminated to be less than (for N=5, std dev of hormal (st deviation of arthinetic mean) and the mean at a single point measurement). $u(S_{RE})$ deviation of arthinetic mean)	<i>u</i> ( <i>G</i> ) laser wavelength calibration <i>u</i> ( <i>G</i> )	environmental effects on laser wavelength. Estimated to be less than (Temp range from be less than $(dT = +i - 3 C, dP = +i - 70 hPa, dU = +i - 20 (21 0.2)$	$(\lambda cal)$ amplifier BK 2850 with constant normal ( remark a calibration of amplifier BK 2850 with constant normal (	$\ell(e_{1,u,A})$ amplitude effect on gain of reference amplifier Estimated to be less than retangu	$ amplitude effect on sensitivity (magnitude) of reference Estimated to be less than (amplitude range up r(e_{1,a_1,b_1}) accelerometer to a construct the transmission of the sense that the sense of the sense o$	instability of reference amplifier gain, and effect of source Estimated to be less than retangul	instability of sensitivity (magnitude) of reference

Unce	ertainty bud	get - Absolute Interferometric calibration of a back-to	-back standard accelerometer (loading m	iass = 0 g)													
	CHARGE	E SENSITIVITY - DHASE SHIFT															
	Standard uncertainty			Probability													
<i>. .</i>	$u(x_i)$	Source of uncertainty	description	model	315	400	500	630	800	1000	1250	1600	2000	2200	2500	3000	3150
-	$u(\varPhi_{u,V})$	accelerometer output phase measurement	results of different calibrations measured against hp3458A	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
~	$u(\varPhi_{u,F})$	voltage filtering effect on accelerometer output phase measurement	No analog filtering applied. Special digital filter has negligible effect.	retangular	0,00	0,00	0,00	0,00	0,00	00'0	0,00	0,00	0,00	0,00	0,00	0,00	0,00
ო	$u(\Phi_{u,D})$	effect of voltage disturbance on output phase measurement (e.g hum and noise)	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	$u(\varPhi_{u,T})$	effect of transverse, rocking and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,20
ى س	$u(\Phi_{s,Q})$	effect of interferometer quadrature output signal exturbance on explorement phase measurement (e.g. offsets. voltage amplitude deviation, deviation from 90 degrees nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in $i = 3$														
9	$u(\Phi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation )	No analog filtering applied.	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
~	$u(\Phi_{s,VD})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
ω	$u(\Phi_{s,MD})$	effect of motion disturbance on displacement phase measurement (e.g. drift; relative motion between accelerometer reference surface and the spot sensed by the interferometer)	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
6	$u(\varPhi_{s,PD})$	effect of phase disturbance on displacement phase measurement (e.g. phase noise of the interferometer signals)	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\Phi_{s,RE})$	residual interferometric effects on displacement phase measurement	Estimated to be less than	ormal (sqrt(N))	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Ξ	$u\left(\Delta \Phi_{RE} ight)$	residual effects on phase shift measurement (e.g. random effect in repeat measurements, experimental standard deviation of arithmetic mean )	r Measured (for N=5, std dev of the mean)	ormal (sqrt(N))	0,00	0,02	0,02	0,01	0,01	00'0	0,00	0,01	0,01	0,02	0,02	0,02	0,02
12	$u\left(\Delta \Phi_{A, cal} ight)$	amplifier phase shift calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
13	и (е <sub>Т. А</sub> )	reference amplifier tracking (deviations in phase for different amplification settings)	Not applicable. A single calibrated setting is used.	retangular	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002
14	u (e <sub>T.f.A</sub> )	deviations from linear phase-frequency characteristic of reference amplifier	Not applicable. A single calibrated setting is used.	retangular	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007
15	$u(\lambda cal)$	deviations from linear phase-frequency characteristic of reference accelerometer	Effect included in the standard deviation of the mean	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
16	$u(e_{\mathrm{L},a,\mathrm{A}})$	amplitude effect on phase shift of reference amplifier	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
17	$u\left(e_{\mathrm{L},a,\mathrm{P}} ight)$	amplitude effect on phase shift of reference accelerometer	Estimated to be less than (amplitude range up to $100 \text{ m/s}^2$ )	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
18	$u\left(e_{\mathrm{LA}} ight)$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
19	n (e)	instability of reference accelerometer phase shift	Estimated to be less than	retangular	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

	Hainty hud	det - Absolute Interferometric celibration of a back-to	hack standard accelerometer (loading n	10 0 - 000				log FOS	6062-11-	de0 - Tah	0 A A 8. A	9					
				(R 0 - 000)				8				2					
	CHARGI	E SENSITIVITY - PHASE SHIFT				Expanded	uncertaint	/ or bound	ls of estim	ated error	componer	its (°)					
						frequency	(Hz) .	-	-	-	-	-	-	-	-	-	
	Standard uncertainty			Probability distribution	Factor												
i	$u(x_i)$	Source of uncertainty	description	model	x <sub>i</sub>	10	12,5	16	20	25	31,5	40	50	63	80	00	125
-	$u(\varPhi_{u,V})$	accelerometer output phase measurement	results of different calibrations measured against hp3458A	normal (k=1)	-	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05 (	,05 0	,05
2	$u\left( \Phi_{u,F}\right)$	voltage filtering effect on accelerometer output phase measurement	No analog filtering applied. Special digital filter has negligible effect.	retangular	0,58	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	00,0
<i>с</i>	$u(\Phi_{u,D})$	effect of voltage disturbance on output phase measurement (e.g hum and noise)	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)		0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	02	,05
4	$u(\varPhi_{u,T})$	effect of transverse, rocking and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,58	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	,10
ى س	$_{u}(\Phi_{s,Q})$	effect of interferometer quadrature output signal disturbance on displacement phase measurement (e.g. offsets, voltage amplitude deviation, deviation from 90 degrees nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in $i = 3$														
9	$u(\varPhi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation )	No analog filtering applied.	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	6
7	$u({\it \Phi}_{s,VD})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0000	6,03
ω	$u(\Phi_{s,MD})$	effect of motion disturbance on displacement phase masurement (e.g. drift; relative motion between accelerometer reference surface and the spot sensed by the interferometer)	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	,05 0	,05
6	$u(\varPhi_{s,PD})$	effect of phase disturbance on displacement phase measurement (e.g. phase noise of the interferometer signals)	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	02	02
10	$u(\Phi_{s,RE})$	residual interferometric effects on displacement phase measurement	Estimated to be less than	normal (sqrt(N))	0,30	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0 200	02
Ξ	$u\left(\Delta \Phi_{RE} ight)$	residual effects on phase shift measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	n Measured (for N=5, std dev of the mean)	hormal (sqrt(N))	0,45	0,03	0,01	0,01	0,04	0,01	0,01	0,0	0,0	00,00	00'0	10,	D.
12	$u\left(\Delta \Phi_{A, cal} ight)$	amplifier phase shift calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	,05	,05
13	$u \left( e_{\mathrm{T,A}} \right)$	reference amplifier tracking (deviations in phase for different amplification settings)	Not applicable. A single calibrated setting is used.	retangular	0,58	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002 0	,0002 0	0002	0002 0,	0002
4	$u\left(e_{\mathrm{T,f,A}} ight)$	deviations from linear phase-frequency characteristic of reference amplifier	Not applicable. A single calibrated setting is used.	retangular	0,58	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007 0	0 2000,	0 2000	0007 0,	2000
15	$u(\lambda cal)$	deviations from linear phase-frequency characteristic of reference accelerometer	Effect included in the standard deviation of the mean	normal (k=2)	0,5	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	,05	,05
16	$u\left(e_{1,a,A}\right)$	amplitude effect on phase shift of reference amplifier	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,01	0,01	0,01	,01	,01
17	$u(e_{L,a,p})$	amplitude effect on phase shift of reference accelerometer	Estimated to be less than (amplitude range up to $100 \text{ m/s}^2$ )	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	02 0	,02
18	$u \left( e_{1,\mathrm{A}} \right)$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	,03	,03
19	<i>u(e)</i>	instability of reference accelerometer phase shift	Estimated to be less than	retangular	0.58	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02		20
tainty budget - A	get - A	bsolute Interferometric calibration of a back-to	o-back standard accelerometer (loading n	nass = 0 g)													
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HARGE SENSITIVITY - PH	E SENSITIVITY - PH	ASE SHIFT															
							-	-				-	-		-	-	
Standard uncertainty component 	Source of uncertainty		decription	Probability distribution model	4500	5000	5500	6000	6300	6500	2000	7500		8500		0500	1000
$u(\Phi_{u,V})$ accelerometer output phase	accelerometer output phas	e measurement	results of different calibrations measured against hp3458A	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
$u\left(\varPhi_{u,F}\right)  \mbox{ woltage filtering effect on a measurement }$	voltage filtering effect on a measurement	ccelerometer output phase	No analog filtering applied. Special digital filter has negligible effect.	retangular	0,00	00'0	0,00	00'0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	00'0	0,00
$u(\Phi_{uD})$ effect of voltage disturbant $u(\Phi_{uD})$ measurement (e.g hum and	effect of voltage disturbant measurement (e.g hum an	ce on output phase d noise)	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	0,05	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
effect of transverse, rockir accelerometer output phas $u\left( \varPhi_{uT}  ight)$ sensitivity )	effect of transverse, rockir accelerometer output phas sensitivity )	ig and bending acceleration on se measurement (transverse	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,20	0,20	0,20	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,50	0,50	0,50
effect of interferometer quality disturbance on displacemolic disturbance on displacemolic distets, voltage amplitude $u\left( \phi_{s,Q}  ight)$ degrees nominal angle di	effect of interferometer q disturbance on displacerr offsets, voltage amplitude degrees nominal angle di	ladrature output signal tent phase measurement (e.g. t deviation, deviation from 90 fference)	Ellipse fit correction implemented. Residual effect already included in <i>i</i> = 3														
$u\left( \varPhi_{s,F}  ight)$ interferometer signal filt	interferometer signal filt measurement ( frequend	aring effect on displacement phase cy band limitation )	No analog filtering applied.	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
$\begin{array}{c} {\rm effect \ of \ voltage \ disturb} \\ {\rm measurement \ (e.g. \ ranc} \\ u\left( {{\varPhi _{{\rm S},VD}}} \right) \end{array} \end{array}$	effect of voltage disturb measurement (e.g. rand measuring chains)	ance on displacement phase dom noise in the photoelectric	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
effect of motion disturbs measurement (e.g. drift accelerometer reference $u ( \Phi_{s,MD} )$ the interferometer)	effect of motion disturbs measurement (e.g. drift accelerometer reference the interferometer)	ance on displacement phase relative motion between s surface and the spot sensed by	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
$\frac{\text{effect of phase disturbs}}{\text{measurement (e.g. phase)}} u(\Phi_{s,PD})  \text{signals})$	effect of phase disturb measurement (e.g. phe signals)	ance on displacement phase tse noise of the interferometer	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
$u\left( \varPhi_{s,RE}  ight)$ measurement	residual interferometric measurement	effects on displacement phase	Estimated to be less than	normal (sqrt(N))	0,05	0'05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
residual effects on pha effect in repeat measu $u\left(\Delta \varPhi_{RE} ight)$ deviation of arithmetic	residual effects on pha effect in repeat measu deviation of arithmetic	se shift measurement (e.g. random ements; experimental standard mean )	n Measured (for N=5, std dev of the mean)	normal (sqrt(N))	0,07	0,08	0,21	0,12	0,15	0,15	0,13	0,15	0,20	0,28	0,41	0,18	0,18
$_{u}(\Delta \Phi_{A,cal})$ amplifier phase shift ca	amplifier phase shift ca	alibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
$u(e_{T,A})$ different amplification s	reference amplifier tracl different amplification s	king (deviations in phase for ettings)	Not applicable. A single calibrated setting is used.	retangular	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002
$u\left(e_{\mathrm{T}\mathrm{f}\mathrm{A}} ight)$ reference amplifier	deviations from linear p reference amplifier	hase-frequency characteristic of	Not applicable. A single calibrated setting is used.	retangular	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007
deviations from linear p $u(\lambda cal)$ reference acceleromete	deviations from linear p reference acceleromete	hase-frequency characteristic of r	Effect included in the standard deviation of the mean	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
$u(e_{1-a,A})$ amplitude effect on pha	amplitude effect on pha	se shift of reference amplifier	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
$u(e_{1,a,p})$ amplitude effect on pha	amplitude effect on pha	se shift of reference accelerometer	Estimated to be less than (amplitude range up $\cdot$ to 100 m/s <sup>2</sup> )	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
$u(e_{1A})$ instability of reference source impedance on p	instability of reference source impedance on p	amplifier phase shift, and effect of phase shift	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
n (e) instability of reference a	instability of reference a	ccelerometer phase shift	Estimated to be less than	retangular	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

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		10000	0,05	00'0	0,10	0,29	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,08	00.0	0,00	0,03	0,01	0,01	0,02	0,01	
		9500	0,05	00'0	0,10	0,29	00'0	0,01	0,02	0,03	0,03	0,02	0,0001	0,08	00'0	00'0	0,03	0,01	0,01	0,02	0,01	
		0006	0,05	0,00	0,10	0,29	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,18	0,00	00'0	0,03	0,01	0,01	0,02	0,01	
		8500	0,05	00'0	0,10	0,23	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,12	0,00	0,00	0,03	0,01	0,01	0,02	0,01	Γ
		8000	0,05	00'0	0,10	0,23	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,09	0.00	00'0	0,03	0,01	0,01	0,02	0,01	
		7500	0,05	0,00	0,10	0,23	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,07	0,00	0,00	0,03	0,01	0,01	0,02	0,01	
		7000	0,05	00'0	0,10	0,23	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,06	0.0	00'0	0,03	0,01	0,01	0,02	0,01	
		6500	0,05	0,00	0,10	0,23	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,07	00.0	00,0	0,03	0,01	0,01	0,02	0,01	
		6300	0,05	00'0	0,10	0,23	0,0	0,01	0,02	0,03	0,03	0,02	0,0001	0,07	0.0	00'0	0,03	0,01	0,01	0,02	0,01	
		6000	0,05	0,00	0,10	0,23	00'0	0,01	0,02	0,03	0,03	0,02	0,0001	0,05	0,00	00'0	0,03	0,01	0,01	0,02	0,01	
		5500	0,05	00'0	0,10	0,12	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,09	00.0	00,0	0,03	0,01	0,01	0,02	0,01	
		5000	0,05	00'0	0,10	0,12	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,04	00.0	00,0	0,03	0,01	0,01	0,02	0,01	
		4500	0,05	00'0	0,05	0,12	00'0	0,01	0,02	0,03	0,03	0,02	0,0001	0,03	00,0	00,0	0,03	0,01	0,01	0,02	0,01	
		Probability distribution model	retangular	retangular	normal (k=1)	retangular		retangular	retangular	retangular	retangular	ormal (sqrt(N))	normal (k=2)	ormal (sqrt(N))	normal (k=2)	retangular	normal (k=2)	retangular	retangular	retangular	retangular	
		description	results of different calibrations measured against hp3458A	No filtering applied	effect on sensitivity by simulated noise on interferometer and accel channels	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	already included in $i = 3$	No filtering applied	Estimated to be less than	Estimated to be less than	Estimated to be less than	Estimated to be less than	Estimated to be less than (standard limit)	Estimated to be less than (for N=5, std dev of the mean at a single point measurement)	calibration of laser + bandwidth (1200 MHz)	Estimated to be less than (Temp range from 21 to 25 degrees)	calibration of amplifier BK 2650 with constant charge input	Estimated to be less than	Estimated to be less than (amplitude range up to 100 m/s $^2$ )	Estimated to be less than	Estimated to be less than	Estimated to be less than $(dT = +/- 1 \text{ oC})$
		ce of uncertainty	erometer output phase measurement (ADC ution )	ge filtering effect on accelerometer output phase surement	t of voltage disturbance on accelerometer output e measurement	ct of transverse, rocking and bending acceleration on lerometer output phase measurement (transverse aitivity)	ct of interferometer quadrature output signal urbance on phase amplitude measurement (e.g. s.voltage amplitude deviation, deviation from 900 linal angle difference)	rferometer signal filtering effect on phase amplitude surement (frequency band limitation )	ct of voltage disturbance on displacement phase surement (e.g. random noise in the photoelectric suring chains)	ct of motion disturbance on diaplacementphase surement	ct of phase disturbance on phase amplitude surement	ual interferometric effects on phase amplitude surement	ation frequency measurement (frequency generator indicator)	dual effects on sensitivity measurement (e.g. random ct in repeat measurements; experimental standard iation of arithmetic mean )	r wavelength calibration	ronmental effects on laser wavelength . Estimated to ess than $(dT = +/- 3 C, dP = +/- 70 hPa, dU = +/- 20$	lifier gain calibration	blitude effect on gain of reference amplifier	plitude effect on sensitivity (magnitude) of reference elerometer	ability of reference amplifier gain, and effect of source sdance on gain	ability of sensitivity (magnitude) of reference elerometer	
		Sour	accel	volta	effec	acce	offse distu	ntei	effe nea	affe	effe	resid	vibr.	esi affe fev	ase	envi be l	Ĕ	1 E		nsta mpe	acc acc	
		Standard uncertainty component u(x, ) Sour	u (û v) resolt	u (û <sub>D</sub> ) meas	$u(\hat{u}_T)$ phase	effec acce u (s <sub>0</sub> ) sens	effe disti offs	u (s <sub>F</sub> ) mea	effee mea u (svp) mea	u (s <sub>MD</sub> ) mea	u (spD) mea	u (s <sub>RE</sub> ) mea	u (SFG) and	effe u (S <sub>RE</sub> ) dev	u(G) lase	envi be l (G) %)	u( $\lambda$ cal) amp	и (е <sub>L. а. A</sub> ) атр	$u(e_{1,a,p})$ acc	$u (e_{1,A})$ impo	$u (e_{1,p})$ aco	

	Print Print	act. Abachita Interforemetric colibration of a cinale o	udad atandard accelerameter				-	l ca	COC2 11.	1000 Tob			-				
								8				3					
	CHARG	E SENSITIVITY - PHASE SHIFT				Expanded	uncertainty	/ or bound	ls of estim	ated error	componel	nts (°)					
						requency	(Hz)										
	Standard uncertainty component			Probability distribution	Factor												
~	$u(x_i)$	Source of uncertainty	description	model	$\mathbf{x}_i$	10	12,5	16	20	25	31,5	40	50	63	80	100	125
-	$u(\varPhi_{u,V})$	accelerometer output phase measurement	results of different calibrations measured against hp3458A	normal (k=1)	-	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
2	$u\left( \Phi_{u,F}\right)$	voltage filtering effect on accelerometer output phase measurement	No analog filtering applied. Special digital filter has negligible effect.	retangular	0,58	0,00	0,00	0,00	0,00	0,00	00'0	0,00	0,00	0,00	0,00	0,00	0,00
ო	$u(\Phi_{u,D})$	effect of voltage disturbance on output phase measurement (e.g hum and noise)	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)		0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	$u(\Phi_{u,T})$	effect of transverse, rocking and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,58	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
ى س	$\mu(\Phi_{s,Q})$	effect of interferometer quadrature output signal effect of interferometer quadrature output signal effects. voltage amplitude deviation deviation from 90 degrees nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in <i>i</i> = 3														
و	$u(\Phi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation )	No analog filtering applied.	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
7	$u(\Phi_{s,VD})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
œ	$u(\Phi_{s,MD})$	effect of motion disturbance on displacement phase masurement (e.g. drift; relative motion between accelerometer reference surface and the spot sensed by the interformeter)	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
6	$u(\varPhi_{s,PD})$	effect of phase disturbance on displacement phase measurement (e.g. phase noise of the interferometer signals)	Estimated to be less than	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\Phi_{s, \rm RE})$	residual interferometric effects on displacement phase measurement	Estimated to be less than	normal (sqrt(N))	0,30	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
÷	$u(\Delta \Phi_{RE})$	residual effects on phase shift measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	measured (for N=6, std dev of the mean)	normal (sqrt(N))	0,41	00'0	0,00	0,00	0,00	0,00	0,00	0,00	00'0	0,00	0,00	0,01	0,01
12	$u\left(\Delta \Phi_{A,cal}\right)$	amplifier phase shift calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
13	и (е <sub>Т. А</sub> )	reference amplifier tracking (deviations in phase for different amplification settings)	Not applicable. A single calibrated setting is used.	retangular	0,58	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	,0002	,0002	,0002 0	,0002
14	$u\left(e_{\mathrm{T,f,A}} ight)$	deviations from linear phase-frequency characteristic of reference amplifier	Not applicable. A single calibrated setting is used.	retangular	0,58	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0 2000,	0 2000,	0 2000,	2000,
15	$u(\lambda cal)$	deviations from linear phase-frequency characteristic of reference accelerometer	Effect included in the standard deviation of the mean	normal (k=2)	0,5	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
16	$u(e_{1,a,A})$	amplitude effect on phase shift of reference amplifier	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,01	0,01	0,01	0,01	0,01
17	$u\left(e_{\mathrm{L},a,\mathrm{p}} ight)$	amplitude effect on phase shift of reference accelerometer	Estimated to be less than (amplitude range up to $100 \text{ m/s}^2$ )	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
18	$u\left(e_{\mathrm{LA}} ight)$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
19	$u(e \dots)$	instability of reference accelerometer phase shift	Estimated to be less than	retangular	0.58	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

F									ŀ	-				_	_	_	
						Incertainty	/ contributi	ion u rei,i(y)	(_)								1
					Ţ	requency	(Hz)										
	Standard uncertainty component u(x <sub>i</sub> )	Source of uncertainty	description	Probability distribution model	Factor x <sub>i</sub>	. 9	12,5	16	50	25	31,5	40	20		80		125
-	$u(\hat{u}_V)$	accelerometer output phase measurement (ADC resolution)	results of different calibrations measured against hp3458A	retangular	0,58	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05 (	0,05	0,05	0,05
~	$u(\hat{u}_{D})$	voltage filtering effect on accelerometer output phase measurement	No filtering applied	retangular	0,58	0,00	00'0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	00'00	00'00	00,0
m	$u(\hat{u}_{T})$	effect of voltage disturbance on accelerometer output phase measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	-	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	и (s <sub>0</sub> )	effect of transverse, rocking and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,58	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06
ى ت	u (s <sub>H</sub> )	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. distes, voltage amplitude deviation, deviation from 90o nominal angle difference)	already included in $i = 3$			0,0	00'0	00,0	00'0	00,0	0,0	0,0	00,00	8	8	8	8
9	u (sF)	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	No filtering applied	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	10,0	10,0	0,01
~	u (svD)	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	,02	,02	0,02
∞	n (SMD)	effect of motion disturbance on diaplacementphase measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
6	u (spD)	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,58	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
10	u (s <sub>RE</sub> )	residual interferometric effects on phase amplitude measurement	Estimated to be less than	ormal (sqrt(N))	0,30	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02 0	0,02	0,02	0,02
=	u (s <sub>FG</sub> )	vibration frequency measurement (frequency generator and indicator)	Estimated to be less than (standard limit)	normal (k=2)	0,5	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	,0001	0001 0,	0001 0,	0001	0001
12	u (S <sub>RE</sub> )	residual effects on sensitivity measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	measured (for N=6, std dev of the mean)	normal (sqrt(N))	0,41	0,00	00'0	0,00	00'0	0,00	0,00	00'0	0,00	0,00	8,	0,00	00,00
13	u(G)	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,5	00,0	00,0	0,00	0,00	0,00	0,0	00'0	0,00	0,00	00'0	00,0	00,0
14	u(G)	environmental effects on laser wavelength . Estimated to be less than $(dT = +/- 3 C, dP = +/- 70 hPa, dU = +/- 20 )$ %)	Estimated to be less than (Temp range from 21 to 25 degrees)	retangular	0,58	0,00	00'0	0,00	0,00	0,00	00'0	0,00	00'0	0 00'0	00'(	00'(	00'0
15	$u(\lambda cal)$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,5	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	03 03	03 03	0,03
17	$u\left(e_{1,a,A}\right)$	amplitude effect on gain of reference amplifier	Estimated to be less than	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	,01	0,01
18	и (е <sub>L, a, p</sub> )	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	10,0	10,0	0,01
19	$u \left( e_{1,A} \right)$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,58	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
20	$u \left( e_{\mathrm{LP}} \right)$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,58	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	,01	0,01
_			Estimated to be less than $(dT = +/-1 \text{ oC})$		0,58			-									-

## Appendix B: Uncertainty Budgets of the participants

Š	ertainty buc	dget - Absolute Interferometric calibration of a single-	ended standard accelerometer														
	CHARG	RE SENSITIVITY - PHASE SHIFT															
					•	-	-	•	•		-		-	-		-	
	Standard uncertainty			Probability													
<i>i</i>	$u(x_i)$	Source of uncertainty	description	model	315	400	500	630	800	1000	1250	1600	2000	2200	2500	3000	3150
-	$u\left(\varPhi_{u,V}\right)$	accelerometer output phase measurement	results of different calibrations measured against hp3458A	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
N	$u(\Phi_{u,F})$	voltage filtering effect on accelerometer output phase measurement	No analog filtering applied. Special digital filter has negligible effect.	retangular	0,00	0,00	0,00	0,00	0,00	00'0	0,00	0,00	0,00	0,00	0,00	0,00	0,00
ო	$u(\varPhi_{u,D})$	effect of voltage disturbance on output phase measurement (e.g hum and noise)	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	$u(\varPhi_{v,T})$	effect of transverse, rocking and bending acceleration on accelerometer output phase measurement (transverse sensitivity )	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,20
2	$u(\Phi_{s,Q})$	effect of interferometer quadrature output signal disturbance on displacement phase measurement (e.g. offsets, voltage amplitude deviation, deviation from 90 degrees nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in <i>i</i> = 3														
9	$u(\Phi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation )	No analog filtering applied.	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
~	$u(\Phi_{s,VD})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0 <sup>,03</sup>
∞	$(\Phi_{s,MD})$	effect of motion disturbance on displacement phase measurement (e.g. drift; relative motion between acceleremeter reterence surface and the spot sensed by the interferometer)	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
6	$u(\varPhi_{s,PD})$	effect of phase disturbance on displacement phase measurement (e.g. phase noise of the interferometer signals)	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\Phi_{s,\rm RE})$	residual interferometric effects on displacement phase measurement	Estimated to be less than	ormal (sqrt(N))	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
=	$u\left(\Delta \Phi_{RE} ight)$	residual effects on phase shift measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	measured (for N=6, std dev of the mean)	normal (sqrt(N))	0,01	0,01	0,02	0,00	00'0	0,01	0,01	0,02	0,02	0,03	0,03	0,05	0,07
12	$u\left(\Delta \Phi_{A,cal}\right)$	) amplifier phase shift calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
13	$u(e_{T,A})$	reference amplifier tracking (deviations in phase for different amplification settings)	Not applicable. A single calibrated setting is used.	retangular	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002	0,0002
14	$u \left( e_{\mathrm{T,f,A}} \right)$	deviations from linear phase-frequency characteristic of reference amplifier	Not applicable. A single calibrated setting is used.	retangular	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007	0,0007
15	$u(\lambda cal)$	deviations from linear phase-frequency characteristic of reference accelerometer	Effect included in the standard deviation of the mean	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
16	u (e <sub>1, a, A</sub> )	amplitude effect on phase shift of reference amplifier	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
17	$u\left(e_{\mathrm{L},a,\mathrm{p}} ight)$	amplitude effect on phase shift of reference accelerometer	Estimated to be less than (amplitude range up to 100 $\mbox{m/s}^2)$	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
18	$u \left( e_{1,\mathrm{A}} \right)$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
6	n(e)	linstability of reference accelerometer phase shift	Estimated to be less than	retangular	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

## Appendix B: Uncertainty Budgets of the participants

					_			_	_	-	_	_	_	_			
	Standard uncertainty component			Probability distribution													
<i>.</i>	$u(x_i)$	Source of uncertainty	description	model	315	400	500	630	800	1000	1250	1600	2000	2200	2500	3000	3150
1	$u\left(\hat{u}_{V}\right)$	accelerometer output phase measurement (ADC resolution)	results of different calibrations measured against hp3458A	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
~	$u \left( \hat{u}_{\text{D}} \right)$	voltage filtering effect on accelerometer output phase measurement	No filtering applied	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
ო	$u (\hat{u}_T)$	effect of voltage disturbance on accelerometer output phase measurement	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
4	и (s <sub>0</sub> )	effect of transverse, rocking and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,06	0,12
5	( <sup>H</sup> s) <i>n</i>	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90o nominal angle difference)	already included in $i = 3$		00'0	0,00	00'0	00'0	00'0	0,00	00'0	00'0	00'0	00'0	0,00	00'0	0,00
9	u (s <sub>F</sub> )	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation )	No filtering applied	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
~	u (svD)	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
80	n (S <sub>MD</sub> )	effect of motion disturbance on diaplacementphase measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
6	u (spD)	effect of phase disturbance on phase amplitude measurement	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
10	u (s <sub>RE</sub> )	residual interferometric effects on phase amplitude measurement	Estimated to be less than	ormal (sqrt(N))	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
÷	u (s <sub>FG</sub> )	vibration frequency measurement (frequency generator and indicator )	Estimated to be less than (standard limit)	normal (k=2)	0,0001	0,0001	0,0001	,0001	,0001	0,0001	,0001	,0001	0,0001	,0001	0,0001	,0001	0,0001
12	$u\left(S_{RE} ight)$	residual effects on sensitivity measurement ( e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	measured (for N=6, std dev of the mean)	normal (sqrt(N))	0,00	0,01	0,01	0,00	0,00	0,00	0,00	0,01	0,01	0,01	0,01	0,02	0,03
13	u(G)	laser wavelength calibration	calibration of laser + bandwidth (1200 MHz)	normal (k=2)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	00'00	0,00	0,00
14	u(G)	environmental effects on laser wavelength . Estimated to be less than $(dT = +/- 3 C, dP = +/- 70 hPa, dU = +/- 20 \%)$	Estimated to be less than (Temp range from 21 to 25 degrees)	retangular	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15	$u(\lambda cal)$	amplifier gain calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
17	$u\left(e_{1,a,\mathrm{A}}\right)$	amplitude effect on gain of reference amplifier	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
18	$u\left(e_{\mathrm{L},a,\mathrm{P}} ight)$	amplitude effect on sensitivity (magnitude) of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
19	$u\left(e_{1,\mathrm{A}}\right)$	instability of reference amplifier gain, and effect of source impedance on gain	Estimated to be less than	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
20	$u \left( e_{\mathrm{LP}} \right)$	instability of sensitivity (magnitude) of reference accelerometer	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
			Estimated to be less than $(dT = +/-1 \text{ oC})$														

Unc	sertainty buc	dget - Absolute Interferometric calibration of a single-	ended standard accelerometer														
	CHARG	<b>3E SENSITIVITY - PHASE SHIFT</b>															
					-	-	-	-	-	-	-	-	-	-	-	-	
	Standard			Probability													
.~	component	t Source of uncertainty	description	distribution model	4500	5000	5500	6000	6300	6500	2000	7500	8000	8500	0006	9500	10000
-  -	$u(\Phi_{u,V})$	accelerometer output phase measurement	results of different calibrations measured against hp3458A	normal (k=1)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
~	$u(\Phi_{v,F})$	voltage filtering effect on accelerometer output phase measurement	No analog filtering applied. Special digital filter has negligible effect.	retangular	00'0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	00'00	0,00	0,00	0,00	0,00
۳	$u(\Phi_{u,D})$	effect of voltage disturbance on output phase measurement (e.g hum and noise)	effect on sensitivity by simulated noise on interferometer and accel channels	normal (k=1)	0,05	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10	0,10
4	$u(\Phi_{u,T})$	effect of transverse, rocking and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	The residual effect on sensitivity is estimated by the error to a LS fit, which is to be less than	retangular	0,20	0,20	0,20	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40	0,40
2	$u(\Phi_{s,Q})$	effect of interferometer quadrature output signal disturbance on displacement phase measurement (e.g. offsets, voltage amplitude deviation, deviation from 90 degrees nominal angle difference)	Ellipse fit correction implemented. Residual effect already included in <i>i</i> = 3														
9	$u(\Phi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation )	No analog filtering applied.	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
~	$u(\Phi_{\mathrm{s},\mathrm{VD}})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
œ	$u(\Phi_{s,MD})$	effect of motion disturbance on displacement phase measurement (e.g. drift; relative motion between acceleremeter reference surface and the spot sensed by the interferometer)	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
6	$u(\varPhi_{s,PD})$	effect of phase disturbance on displacement phase measurement (e.g. phase noise of the interferometer signals)	Estimated to be less than	retangular	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
10	$u(\Phi_{s,\rm RE})$	residual interferometric effects on displacement phase measurement	Estimated to be less than	normal (sqrt(N))	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
=	$u\left(\Delta \Phi_{RE} ight)$	residual effects on phase shift measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean )	measured (for N=6, std dev of the mean)	normal (sqrt(N))	0,06	0,14	0,30	0,38	60'0	0,10	0,11	0,28	0,21	60'0	0,16	0,30	0,36
12	$u\left(\Delta \Phi_{A,cal}\right)$	.) amplifier phase shift calibration	calibration of amplifier BK 2650 with constant charge input	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
13	u (e <sub>T, A</sub> )	reference amplifier tracking (deviations in phase for different amplification settings)	Not applicable. A single calibrated setting is used.	retangular	0,0002	0,0002	0,0002	,0002 (	0,0002	0,0002	0,0002	0,0002	0,0002 0	,0002	,0002 (	,0002	0,0002
14	$u \left( e_{\mathrm{T,f,A}} \right)$	deviations from linear phase-frequency characteristic of reference amplifier	Not applicable. A single calibrated setting is used.	retangular	0,0007	0,0007	0,0007	00001	0,0007	0,0007	00001	0,0007	0,0007 0	,0007 0	00001	0002	2000,0
15	$u(\lambda cal)$	deviations from linear phase-frequency characteristic of reference accelerometer	Effect included in the standard deviation of the mean	normal (k=2)	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
9	$u(e_{1,a,A})$	) amplitude effect on phase shift of reference amplifier	Estimated to be less than	retangular	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
17	$u\left(e_{1,a,p} ight)$	amplitude effect on phase shift of reference accelerometer	Estimated to be less than (amplitude range up to 100 m/s <sup>2</sup> )	retangular	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
18	$u\left(e_{\mathrm{LA}} ight)$	instability of reference amplifier phase shift, and effect of source impedance on phase shift	Estimated to be less than	retangular	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
19	() n	instability of reference accelerometer phase shift	Estimated to be less than	retangular	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

	8	2 L	0	•		0	-	0	9		N	5	5	0			-		0	-
	1000	0'0	0,0	0,16	0,2;	)0 <sup>°</sup> 0	.0 <b>*</b> 0	0,0	0,0	;0 <sup>*</sup> 0	0,0	1 0,000	0,15	0'0	0,0	0'0	0'0	.0 <sup>*</sup> 0	0,0	0,0
	9500	0,05	0,00	0,10	0,23	0,00	0,01	0,02	0,03	0,03	0,02	0,000	0,12	0,00	0,00	0,03	0,01	0,01	0,02	0,01
	0006	0,05	0,00	0,10	0,23	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,06	00'0	0,00	0,03	0,01	0,01	0,02	0,01
	8500	0,05	0,00	0,10	0,23	0 <sup>,</sup> 0	0,01	0,02	0,03	0,03	0,02	0,0001	0,04	0,00	0,00	0'03	0,01	0,01	0,02	0,01
	8000	0,05	0,00	0,10	0,23	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,09	0,00	0,00	0,03	0,01	0,01	0,02	0,01
	7500	0,05	0,00	0,10	0,23	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,11	0,00	0,00	0,03	0,01	0,01	0,02	0,01
	7000	0,05	0,00	0,10	0,23	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,04	0,00	0,00	0,03	0,01	0,01	0,02	0,01
	6500	0,05	0,00	0,10	0,23	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,04	0,00	0,00	0,03	0,01	0,01	0,02	0,01
	6300	0,05	0,00	0,10	0,23	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,04	0,00	0,00	0,03	0,01	0,01	0,02	0,01
	6000	0,05	0,00	0,10	0,23	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,16	0,00	0,00	0,03	0,01	0,01	0,02	0,01
	5500	0,05	0,00	0,10	0,12	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,12	0,00	000	0,03	0,01	0,01	0,02	0,01
	5000	0,05	0,00	0,10	0,12	0,00	0,01	0,02	0,03	0,03	0,02	0,0001	0,06	0,00	0,00	0,03	0,01	0,01	0,02	0,01
	4500	0,05	0,00	0,05	0,12	00'0	0,01	0,02	0,03	0,03	0,02	0,0001	0,03	0,00	0,00	0,03	0,01	0,01	0,02	0,01
												_								
	bability tribution nodel	angular	angular	nal (k=1)	angular		angular	angular	angular	angular	al (sqrt(N))	nal (k=2)	al (sqrt(N))	nal (k=2)	angular	nal (k=2)	angular	angular	angular	angular
	Probability distribution model	retangular	retangular	normal (k=1)	ed retangular		retangular	retangular	retangular	retangular	normal (sqrt(N))	normal (k=2)	normal (sqrt(N))	) normal (k=2)	n retangular	int normal (k=2)	retangular	up retangular	retangular	retangular
	Probability distribution description	results of different calibrations measured retangular against hp3458A	No filtering applied	effect on sensitivity by simulated noise on normal (k=1) interferometer and accel channels	The residual effect on sensitivity is estimated retangular by the error to a LS fit, which is to be less than	already included in $i = 3$	No filtering applied	retangular Estimated to be less than	Estimated to be less than	Estimated to be less than	Estimated to be less than	Estimated to be less than (standard limit) normal (k=2)	normal (sqrt(N)) measured (for N=6, std dev of the mean)	calibration of laser + bandwidth (1200 MHz) normal (k=2)	Estimated to be less than (Temp range from 21 to 25 degrees)	calibration of amplifier BK 2650 with constant normal (k=2) charge input	Estimated to be less than retangular	Estimated to be less than (amplitude range up retangular to 100 m/s $^2$ )	Estimated to be less than	Estimated to be less than $(t_{\pm+}, t_{-}, t_{-})$
	Probability distribution Source of uncertainty model	accelerometer output phase measurement (ADC results of different calibrations measured retangular resolution) against hp3458A	voltage filtering effect on accelerometer output phase No filtering applied measurement	effect of voltage disturbance on accelerometer output effect on sensitivity by simulated noise on normal (k=1) phase measurement	effect of transverse, rocking and bending acceleration on The residual effect on sensitivity is estimated retangular acceleration of transverses by the error to a LS fit, which is to be less sensitivity.	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, volge difference deviation, deviation from 900 nominal angle difference.	interferometer signal fittering effect on phase amplitude No fittering applied measurement (frequency band limitation )	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measurement (e.g. random noise in the photoelectric	effect of motion disturbance on diaplacementphase Estimated to be less than measurement	effect of phase disturbance on phase amplitude Estimated to be less than retangular measurement	residual interferometric effects on phase amplitude Estimated to be less than normal (sqrt(N)) measurement	vibration frequency measurement (frequency generator Estimated to be less than (standard limit) normal (k=2) and indicator )	residual tetras on sensitivity measurement (e.g. random defect in repeat measurements, experimental standard deviation of arthmetic mean.) normal (sart(N)) deviation of arthmetic mean.)	laser wavelength calibration laser + bandwidth (1200 MHz) normal (k=2)	environmental effects on laser wavelength. Estimated to Estimated to be less than (Temp range from retangular be less than $(dT = 4^{-2} 0, dP = 4^{-2} 0 P P + 2, 20 P P + 2, 20 P P P + 20 P + 2$	calibration of amplifier BK 2650 with constant normal (k=2) charge input	amplitude effect on gain of reference amplifier Estimated to be less than retangular	amplitude effect on sensitivity (magnitude) of reference Estimated to be less than (amplitude range up accelerometer to 100 m/s <sup>5</sup> ) to 100 m/s <sup>5</sup> )	Instability of reference amplifier gain, and effect of source Impedance on gain	Instability of sensitivity (magnitude) of reference accelerometer Estimated to be less than (aT =+/-1 oC
	Standard Standard uncertainty distribution distribution and a source of uncertainty description model	accelerometer output phase measurement (ADC results of different calibrations measured retangular $u(\hat{u}_{\gamma})$ resolution )	voltage filtering effect on accelerometer output phase No filtering applied retangular $u(\hat{u}_{1D})$ measurement	effect of voltage disturbance on accelerometer output effect on sensitivity by simulated noise on normal (k=1) $u(\hat{u}_{\uparrow})$ phase measurement interferometer and accel channels	effect of transverse, rocking and bending acceleration on The residual effect on sensitivity is estimated retangular acceleration processe by the error to a LS fit, which is to be less $u(s_0)$ sensitivity sensitivity.	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. distes, voltage amplitude deviation, deviation from 90o <i>u</i> (s, <sub>1</sub> ) norminal and pediferences	interferometer signal fittering effect on phase amplitude No fittering applied (SF) measurement (frequency band limitation )	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric w (s <sub>vp</sub> ) measuring chains)	effect of motion disturbance on diaplacementphase Estimated to be less than retangular <i>u</i> (w <sub>D</sub> ) measurement	effect of phase disturbance on phase amplitude Estimated to be less than ut (SPD) measurement	residual interferometric effects on phase amplitude Estimated to be less than normal (sqrt(N) measurement	vibration frequency measurement (frequency generator Estimated to be less than (standard limit) normal (k=2) u (sp.6) and indicator )	residual effects on sensitivity measurement (e.g. random effect in repeat measurements: soperimental standard measured (for N=6, std dev of the mean) $u(S_{\rm RE})$ deviation of arithmetic mean )	u(G) laser wavelength calibration u(G) laser vavelength calibration	environmental effects on laser wavelength. Estimated to Estimated to Estimated to be less than (Temp range from tetangular $u(G) = \frac{1}{90}$ ) and $G = \frac{1}{100}$ , $G = \frac{1}{100}$ , $G = \frac{1}{1000}$ , $G = \frac{1}{10000}$ , $G = \frac{1}{10000000000000000000000000000000000$	calibration of amplifier BK 2650 with constant normal (k=2) $u(\lambda cal)$ amplifier gain calibration	$u(c_{1,a,A})$ amplitude effect on gain of reference amplifier Estimated to be less than retangular	amplitude effect on sensitivity (magnitude) of reference Estimated to be less than (amplitude range up $u(e_{L_n,1})$ accelerometer range up to 100 m/s <sup>2</sup> )	instability of reference amplifier gain, and effect of source Estimated to be less than retangular in $u(e_{1,\lambda})$ impedance on gain	Instability of sensitivity (magnitude) of reference Estimated to be less than retangular accelerometer (r_1,) Estimated to be less than (1T =+/· 1 oC Estimated to be less than (1T =+/· 1 oC

### NIM:

# Table of expanded measurement uncertainties of national standard

measuring system	( <i>k</i> =2),	NIM,	China
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Frequency range	National primary vib	ration measuring system
Hz	magnitude %	phase shift $^\circ$
10 1 k	0.5	0.5
> 1 k 5 k		0.75
> 5 k 10 k	1.0	1.5

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

Frequency range Hz	Relative total measurement uncertainty	Expanded measurement uncertainty
10 5 k	0.23 %	0.46 %
> 5 k 10 k	0.41 %	0.82 %

Absolute *Total measurement uncertainty* and *Expanded measurement uncertainty* (*k*=2) are:

Frequency range Hz	Absolute total measurement uncertainty	Expanded measurement uncertainty
10 1 k	0.23 °	<b>0.46</b> °
> 1 k 5 k	0.35 °	0.70 °
> 5 k 10 k	0.67 °	1.34 °

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)	3.0×10 <sup>-4</sup>
2	и(û <sub>F</sub> )	voltage filtering effect on accelerometer output amplitude measurement (frequency band limitation)	10 Hz <5 kHz: 5.0×10 <sup>-4</sup> ; 5 k Hz 10 kHz: 2.0×10 <sup>-3</sup>
3	и( $\hat{u}_{D}$ )	effect of voltage disturbance on accelerometer output voltage measurement (e.g. hum and noise)	10 Hz <5 kHz: 1.0×10 <sup>-3</sup> ; 5 k Hz 10 kHz: 2.5×10 <sup>-3</sup>
4	и( $\hat{u}_{T}$ )	effect of transverse, rocking and bending acceleration on accelerometer output voltage measurement (transverse sensitivity)	10 Hz <5 kHz: 1.5×10 <sup>-3</sup> ; 5 k Hz 10 kHz: 2.0×10 <sup>-3</sup>
5	и( $\hat{\varphi}_{M,Q}$ )	effect of interferometer quadrature output signal disturbance on phase amplitude measurement (e.g. offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	1.0×10 <sup>-3</sup>
6	$u(\hat{arphi}_{M,F})$	interferometer signal filtering effect on phase amplitude measurement (frequency band limitation)	1.0×10 <sup>-5</sup>
7	$u(\hat{\varphi}_{M,VD})$	effect of voltage disturbance on phase amplitude measurement (e.g. random noise in the photoelectric measuring chains)	1.0×10 <sup>-5</sup>
8	$u(\hat{arphi}_{M,MD})$	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)	10 Hz <5 kHz: 1.0×10 <sup>-4</sup> ; 5 k Hz 10 kHz: 1.0×10 <sup>-3</sup>
9	$u(\hat{\varphi}_{M,PD})$	effect of phase disturbance on phase amplitude measurement (e.g. phase noise of the interferometer signals)	1.0×10 <sup>-5</sup>
10	$u(\hat{\varphi}_{M,RE})$	residual interferometric effects on phase amplitude measurement (interferometer function)	5.0×10 <sup>-4</sup>
11	$u(f_{\rm FG})$	vibration frequency measurement (frequency generator and indicator)	1.0×10 <sup>-5</sup>
12	$u(S_{\rm RE})$	residual effects on sensitivity measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean)	5.0×10 <sup>-4</sup>

> Uncertainty budget for magnitude measurement results

#### Uncertainty budget for phase shift measurement results

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	Uncertainty contribution $u_i(y)$
1	$u(\varphi_{u,V})$	accelerometer output phase measurement (waveform recorder; e.g. ADC-resolution)	0.10°
2	$u(\varphi_{u,F})$	voltage filtering effect on accelerometer output phase measurement (frequency band limitation)	10 Hz <1 kHz: 0.10°; 1 kHz <5 kHz: 0.10°; 5 kHz 10kHz: 0.20°;
3	$u(\varphi_{u,D})$	effect of voltage disturbance on accelerometer output phase measurement (e.g. hum and noise)	10 Hz <1 kHz: 0.10°; 1 kHz <5 kHz: 0.25°; 5 kHz 10kHz: 0.50°;
4	$u(\varphi_{u,T})$	effect of transverse, rocking and bending acceleration on accelerometer output phase measurement (transverse sensitivity)	10 Hz <1 kHz: 0.05°; 1 kHz <5 kHz: 0.10°; 5 kHz 10kHz: 0.25°;
5	$u(\varphi_{s,\mathbf{Q}})$	effect of interferometer quadrature output signal disturbance on displacement phase measurement (e.g. offsets, voltage amplitude deviation, deviation from 90° nominal angle difference)	0.05°
6	$u(\varphi_{s,F})$	interferometer signal filtering effect on displacement phase measurement (frequency band limitation)	0.05°
7	$u(\varphi_{s, VD})$	effect of voltage disturbance on displacement phase measurement (e.g. random noise in the photoelectric measuring chains)	0.01°
8	$u(\varphi_{s,MD})$	effect of motion disturbance on displacement phase measurement (e.g. drift; relative motion between the accelerometer reference surface and the spot sensed by the interferometer)	10 Hz <1 kHz: 0.05°; 1 kHz <5 kHz: 0.10°; 5 kHz 10kHz: 0.25°;
9	$u(\varphi_{s,PD})$	effect of phase disturbance on displacement phase measurement (e.g. phase noise of the interferometer signals)	0.05°
10	$u(\varphi_{s,RE})$	residual interferometric effects on displacement phase measurement (interferometer function)	0.05°
11	$u(\Delta \varphi_{RE})$	residual effects on phase lag measurement (e.g. random effect in repeat measurements; experimental standard deviation of arithmetic mean)	0.01°

## NPLI:

The Components of the Measurement uncertainty will be published seperately in a dedicated paper.