FINAL REPORT ON KEY COMPARISON EURAMET.AUV.V-K2

Author:

Joanna Kolasa, GUM, Poland

Co-Author:

Daniela Virovska, BIM, Bulgaria

CONTENTS

1. INTRODUCTION

This report presents the results of the EURAMET comparison in the area of “vibration” (which in this case means sinusoidal linear acceleration), EURAMET.AUV.V-K2. The participants of this bi-lateral comparison are: Central Office of Measures (GUM), acting as pilot and linking laboratory, and Bulgarian Institute for Metrology (BIM). The main goal of the comparison is to disseminate KCRV established in CCAUV.V-K2 comparison to the BIM.

The Technical Protocol [1] specifies in detail the aim and the task of the comparison, the conditions of measurement, the transfer standards used, measurement instructions, time schedule and other items.

2. PARTICIPANTS

The following two laboratories are the participants of this bilateral comparison:

Central Office of Measures (GUM) - pilot	Joanna Kolasa Elektoralna 2 00-139 Warsaw, Poland Phone: + 48 22 581 92 07 E-mail: joanna.kolasa@gum.gov.pl
Bulgarian Institute for Metrology (BIM)	Daniela Virovska 52-B, G.M.Dimitrov Blvd. 1040 Sofia, Bulgaria Phone: +359 2 9740896 E-mail: d.virovska@bmi.government.bg

3. TASK AND PURPOSE OF THE COMPARISON

The aim of this bilateral comparison is the measurement of the magnitude of the complex sensitivity of two accelerometers with primary means in accordance with ISO 16063-11 “Methods for the calibration of vibration and shock transducers – Part 11: Primary vibration calibration by laser interferometry”, in frequency range from 10 Hz to 1 kHz.

BIM is motivated to participate in the comparison to confirm technical competence and to get evidences to support BIM CMCs for primary calibration of vibration transducers. The last comparison in which BIM took part was in 2006. Since this period situation in BIM has changed as BIM lost expertise.

The reported sensitivities and associated uncertainties are then to be used for the calculation of the Degrees of Equivalence (DoE) between the participating NMIs. One laboratory (GUM) is acting as pilot and linking laboratory, as it had taken part in the CCAUV.V-K2. The second participant (BIM) will be linked to the KCRV of this former comparison via the pilot laboratory. The results of the comparison will be used as an evidence to be the foundation for the registration of their CMCs considering primary calibration of vibration transducers.

The principal task of the comparison is to measure magnitude of charge sensitivity of two accelerometers (one of single-ended design and one of back-to-back design) at different frequencies and amplitudes specified in [1].
The charge sensitivity is calculated as the ratio of the amplitude of the output charge of the accelerometer to the amplitude of the acceleration at its reference surface. The reference surface is the base/mounting surface of the accelerometer of single-ended design and the top surface of the accelerometer of back-to-back design. The magnitude of complex charge sensitivity is given in picocoulombs per meters per second squared: pC/(m/s^2).

4. STABILITY OF THE OBJECTS

Two types of piezoelectric standard accelerometers (property of GUM) were used as transfer standards:

- type 8305 (back-to-back, BB), SN 21655958, Brüel & Kjær,
- type 8305 WH2335 (single-ended, SE), SN 2208358, Brüel & Kjær.

As both accelerometers serve in GUM for current control of measurements quality they have been calibrated many times in the past. During the preparatory period, starting from December 2018, the accelerometers were calibrated once a month. The objects have been calibrated also after their return to GUM.

These results together can serve as evidences of long-term stable behaviour of both artefacts.

Table 1. Long-term stability of BB accelerometer type 8305 SN 1655958 at 80 Hz

Date month, Year	Charge sensitivity in pC/(m/s^2)	Relative expanded uncertainty (k=2) in %
June 2007	0,12307	0,5
March 2010	0,12306	0,5
August 2011	0,12305	0,5
December 2018	0,12299	0,5
January 2019	0,12298	0,5
February 2019	0,12301	0,5
March 2019	0,12296	0,5
April 2019	0,12299	0,5
June 2019	0,12299	0,5

Table 2. Long-term stability of SE accelerometer type 8305 WH2335 SN 2208358 at 80 Hz

Date month, Year	Charge sensitivity in pC/(m/s^2)	Relative expanded uncertainty (k=2) in %
August 2011	0,12643	0,5
June 2012	0,12651	0,5
August 2013	0,12623	0,5
November 2013	0,12645	0,5
January 2014	0,12648	0,5
October 2015	0,12625	0,5
January 2016	0,12626	0,5
January 2018	0,12658	0,5
December 2018	0,12657	0,5
January 2019	0,12656	0,5
February 2019	0,12656	0,5
March 2019	0,12655	0,5
April 2019	0,12660	0,5
June 2019	0,12659	0,5

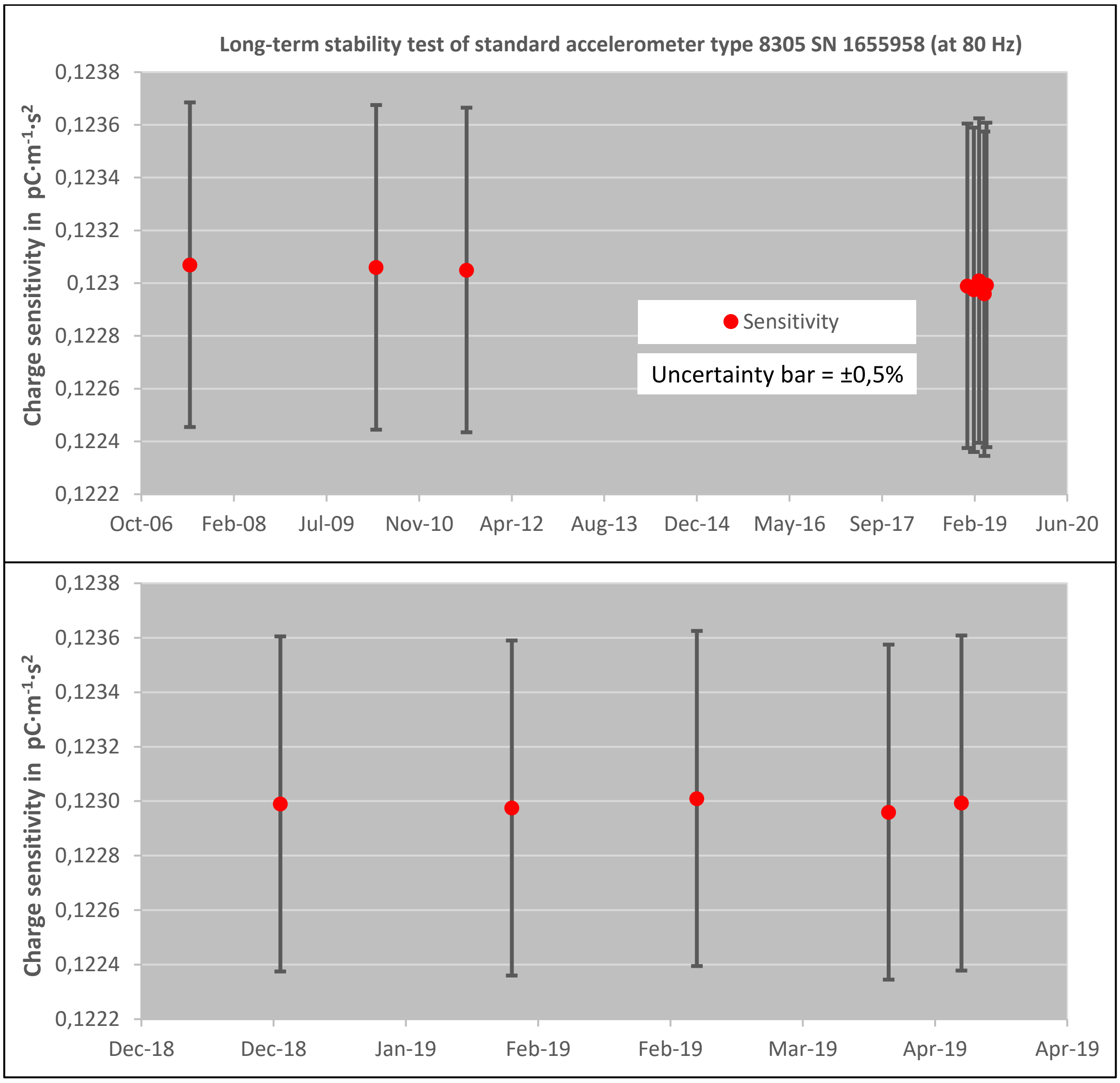

Figure 1. Long-term stability of BB accelerometer

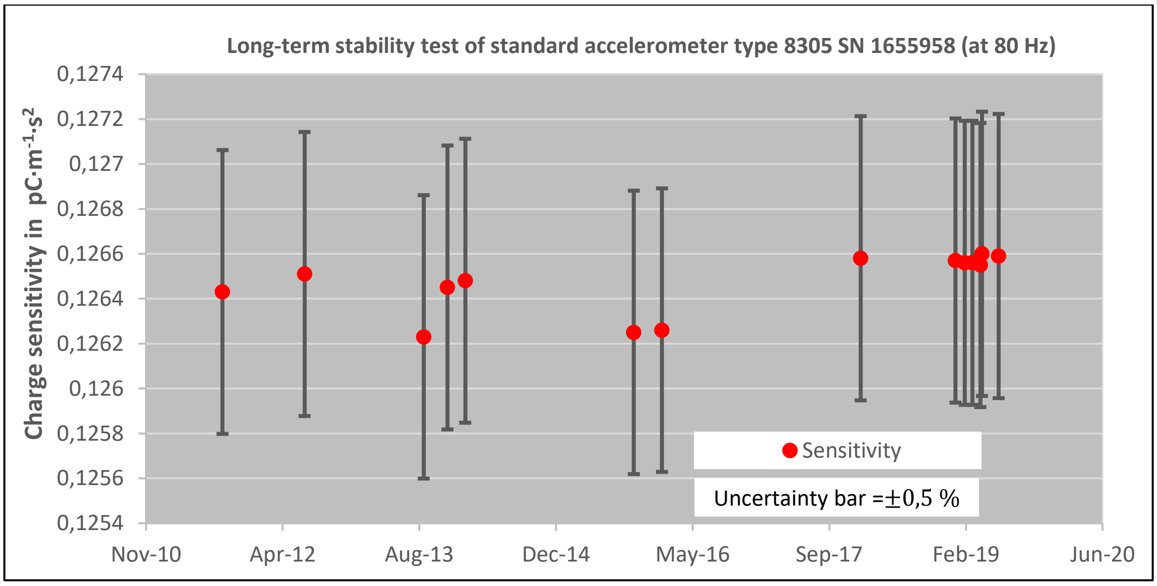

Figure 2. Long-term stability of SE accelerometer

5. RESULTS OF THE PARTICIPANTS

Each laboratory reported their results in the form of the Calibration report signed by the author and also in the spreadsheet templates (Excel format).

The results obtained by the GUM and BIM in the EURAMET.AUV.V-K2 comparison, together with the associated expanded uncertainties with a coverage factor $k = 2$, are presented in the Table 3 and Table 4 and in graphical form at the Figure 3 and Figure 4.

Table 3 Results for the BB accelerometer type 8305 SN 1655958

Frequency	GUM		BIM	
	Magnitude of charge sensitivity	Rel. expanded uncertainty (k = 2)	Magnitude of charge sensitivity	Rel. expanded uncertainty (k = 2)
Hz	in pC·m^{-1}·s^{2}	in %	in pC·m^{-1}·s^{2}	in %
10	0,12311	0,6	0,12375	0,5
12,5	0,12310	0,6	0,12341	0,5
16	0,12306	0,6	0,12333	0,5
20	0,12304	0,5	0,12316	0,5
25	0,12303	0,5	0,12335	0,5
31,5	0,12300	0,5	0,12328	0,5
40	0,12302	0,5	0,12303	0,5
50	0,12300	0,5	0,12360	0,5
63	0,12300	0,5	0,12330	0,5
80	0,12299	0,5	0,12327	0,5
100	0,12306	0,5	0,12310	0,5
125	0,12303	0,5	0,12333	0,5
160	0,12305	0,5	0,12341	0,5
200	0,12304	0,5	0,12346	0,5
250	0,12304	0,5	0,12343	0,5
315	0,12303	0,5	0,12347	0,5
400	0,12304	0,5	0,12356	0,5
500	0,12305	0,5	0,12344	0,5
630	0,12307	0,5	0,12347	0,5
800	0,12313	0,5	0,12355	0,5
1000	0,12315	0,5	0,12358	0,5

Table 4 Results for SE accelerometer type 8305WH2335 SN 2208358

Frequency	GUM		BIM	
	Magnitude of charge sensitivity	Rel. expanded uncertainty (k = 2)	Magnitude of charge sensitivity	Rel. expanded uncertainty (k = 2)
Hz	in $pC \cdot m^{-1} \cdot s^2$	in %	in $pC \cdot m^{-1} \cdot s^2$	in %
10	0,12629	0,6	0,12712	0,5
12,5	0,12637	0,6	0,12693	0,5
16	0,12649	0,6	0,12690	0,5
20	0,12651	0,5	0,12675	0,5
25	0,12653	0,5	0,12676	0,5
31,5	0,12656	0,5	0,12675	0,5
40	0,12658	0,5	0,12665	0,5
50	0,12658	0,5	0,12673	0,5
63	0,12657	0,5	0,12680	0,5
80	0,12659	0,5	0,12684	0,5
100	0,12663	0,5	0,12683	0,5
125	0,12663	0,5	0,12690	0,5
160	0,12659	0,5	0,12710	0,5
200	0,12672	0,5	0,12696	0,5
250	0,12671	0,5	0,12706	0,5
315	0,12672	0,5	0,12695	0,5
400	0,12672	0,5	0,12699	0,5
500	0,12675	0,5	0,12710	0,5
630	0,12678	0,5	0,12707	0,5
800	0,12686	0,5	0,12703	0,5
1000	0,12689	0,5	0,12683	0,5

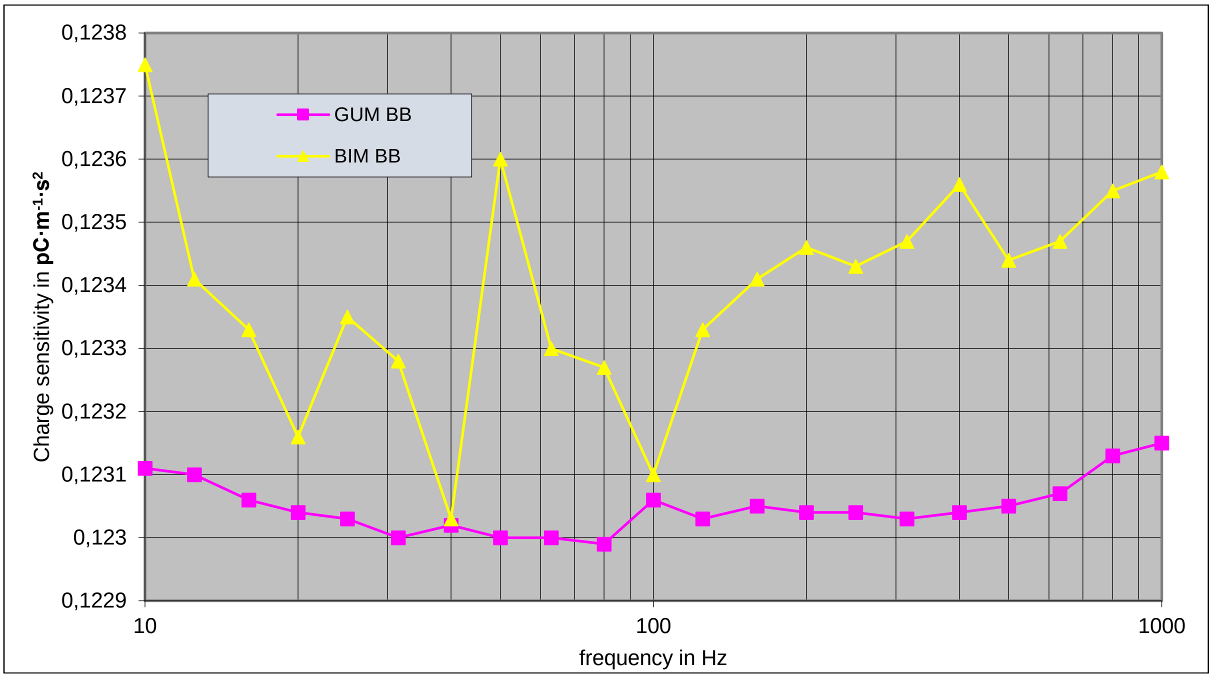

Figure 3. Results of the participant for BB accelerometer type 8305 SN 1655958

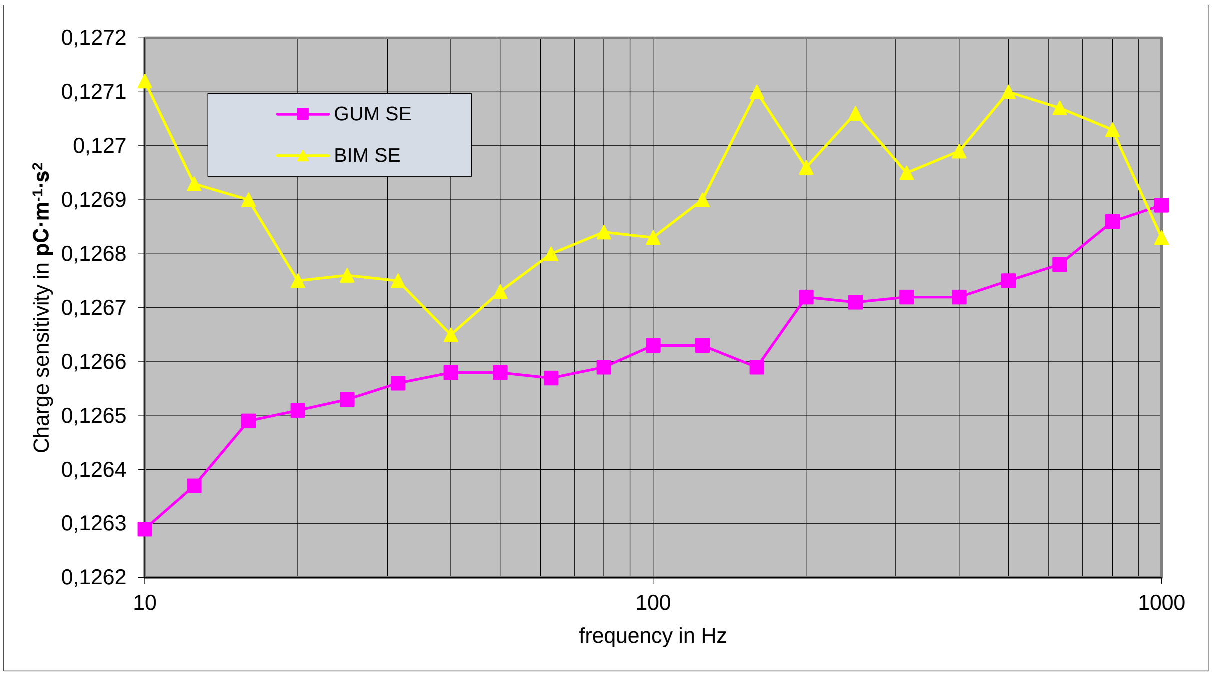

Figure 4. Results of the participant for SE accelerometer type 8305WH2335 SN 22008358

6. LINKING OF THE RESULTS OF EURAMET.AUV.V-K2 TO CCAUV.V-K2

The linking laboratory for EURAMET.AUV.V-K2 comparison is GUM, which took part in the CIPM key comparison CCAUV.V-K2.

Because of some problems occurring in CCAUV.V.K-2, described in details in the final report [2], such as instability of BB accelerometer and unpredictable dependency of the results of SE accelerometer due to the shaker armature, KCRV of CCAUV.V.K-2 was given only for SE transducer in the frequency range limited to 5 kHz.

As the frequency range of EURAMET.AUV.V-K2 is limited to 1 kHz, the linking of the results for both accelerometers (SE and BB) in EURAMET.AUV.V-K2 can be realised through the KCRV results of SE accelerometer of CCAUV.V-K2.

The linking procedure is based on [3] and is similar to applied later on, for example for EUROMET.AUV.V-K1 [4], APMP.AUV.V-K3 [5], EURAMET.AUV.V-K3 [6], AFRIMETS.AUV.V-K3 [7] and APMP.AUV.V-K2 [8].

The linking transforms the results (y_i , $u(y_i)$) of the participants of RMO comparison to scaled values z_i and their respective uncertainties $u(z_i)$, which are directly comparable to the results of CIPM comparison (x_i , $u(x_i)$).

The scaling is done with the transformation factor R, which is determined by the ratio of the CIPM weighted mean and the weighted mean of the linking laboratories in RMO [3].

R is estimated by

$$r = \frac{x}{y} \tag{1}$$

with the associated relative standard uncertainty $u_{rel}(r)$:

$$u_{rel}^2(r) = u_{rel}^2(x) + u_{rel}^2(y) - 2 \cdot u_{rel}(x) \cdot u_{rel}(y) \cdot \sum_1^L \frac{x}{|x_l|} \cdot \frac{y}{|y_l|} \cdot \frac{u_{rel}(x)}{u_{rel}(x_l)} \cdot \frac{u_{rel}(y)}{u_{rel}(y_l)} \rho_l \tag{2}$$

where: x – KCRV of CIPM comparison, y – weighted mean related to the results of linking laboratories in RMO comparison, x_l – result of *l*-linking laboratory in CIPM comparison, y_l – result of l-linking laboratory in RMO comparison, ρ_l – correlation factor.

Correlation between the measurements X and Y of the linking laboratory in the CIPM and RMO comparison arises from the fact that the same measurement procedure is used in both measurements (typically systematic effects are the same).

In the situation of only one linking laboratory (GUM is linking laboratory for EURAMET.AUV.V-K2 comparison):

$$u_{rel}^2(r) = u_{rel}^2(x) + u_{rel}^2(y_{GUM}) - 2 \cdot u_{rel}(x) \cdot u_{rel}(y_{GUM}) \cdot \frac{x}{|x_{GUM}|} \cdot \frac{u_{rel}(x)}{u_{rel}(x_{GUM})} \cdot \rho_{GUM} \tag{3}$$

Correlation factor between the GUM results obtained in the CCAUV.V-K2 key comparison and the EURAMET.AUV.V-K2 key comparison ρ_{GUM} is calculated as:

$$\rho_{GUM} = \frac{u_{Brel}^2(y_{GUM})}{u_{rel}^2(y_{GUM})} \tag{4}$$

where $u_{Brel}(y_{GUM})$ is the type B relative standard uncertainty of the linking laboratory (GUM).

From the uncertainty analyses provided by the linking laboratory it can be seen that the correlations of the results of GUM laboratory in both comparisons is very strong as the correlation factor is nearly 1 (from 0,94 to 0,99) and $u_{rel}(x_{GUM}) = u_{rel}(y_{GUM})$.

$$u_{rel}^2(r) = u_{rel}^2(x) \cdot \left(1 - 2 \cdot \frac{x}{|x_{GUM}|}\right) + u_{rel}^2(y_{GUM}) \tag{5}$$

The KCRVs of CCAUV.V-K2 and GUM results in of CCAUV.V-K2, according [2], for SE accelerometer at frequencies from 10 Hz to 1 kHz, are given in Table 5.

Table 5. KCRVs and GUM results in CCAUV.V-K2 for the SE accelerometer

Frequency	**KCRVs of CCAUV.V-K2**			**GUM in CCAUV.V-K2**		
	x_{KCRV}	U_{KCRV} (k=2)	u_{KCRV}	x_{GUM}	U_{GUM} (k=2)	u_{GUM}
Hz	in pC·m^{-1}·s^2	in 10^{-4} pC·m^{-1}·s^2	%	in pC·m^{-1}·s^2	in %	in %
10	0,127692	0,868	0,034	0,12790	0,6	0,30
12,5	0,127718	0,864	0,034	0,12789	0,6	0,30
16	0,127719	0,858	0,034	0,12796	0,6	0,30
20	0,127738	0,836	0,033	0,12786	0,5	0,25
25	0,127721	0,836	0,033	0,12787	0,5	0,25
31,5	0,127722	0,836	0,033	0,12787	0,5	0,25
40	0,127712	0,836	0,033	0,12788	0,5	0,25
50*	-	-	-	-	-	
63	0,127684	0,835	0,033	0,12782	0,5	0,25
80	0,127688	0,835	0,033	0,12784	0,5	0,25
100	0,127663	0,822	0,032	0,1279	0,5	0,25
125	0,127689	0,824	0,032	0,12788	0,5	0,25
160	0,12769	0,829	0,032	0,12785	0,5	0,25
200	0,127713	0,835	0,033	0,12773	0,5	0,25
250	0,127736	0,832	0,033	0,12777	0,5	0,25
315	0,127752	0,862	0,034	0,12780	0,5	0,25
400	0,127764	0,864	0,034	0,12776	0,5	0,25
500	0,127776	0,858	0,034	0,12780	0,5	0,25
630	0,12781	0,857	0,034	0,12785	0,5	0,25
800	0,127847	0,858	0,034	0,12792	0,5	0,25
1000	0,127898	0,873	0,034	0,12794	0,5	0,25

* KCRV of CCAUV.V-K2 was not calculated.

Table 6. Transformation factors calculated for the results of EURAMET.AUV.V-K2

Frequency	**Transformation factor for BB accelerometer**		**Transformation factor for SE accelerometer**	
	r	$u_{rel}(r)$	r	$u_{rel}(r)$
Hz	-	%	-	%
10	1,03722	0,30451	1,01110	0,30467
12,5	1,03751	0,30417	1,01067	0,30486
16	1,03786	0,30401	1,00972	0,30394
20	1,03818	0,24991	1,00971	0,24994
25	1,03813	0,24991	1,00941	0,24995
31,5	1,03839	0,24998	1,00918	0,24993
40	1,03814	0,24996	1,00894	0,24994
50	-	-	-	-
63	1,03808	0,24993	1,00880	0,24992
80	1,03820	0,24996	1,00867	0,25007
100	1,03740	0,24999	1,00816	0,25032
125	1,03787	0,25019	1,00836	0,25069
160	1,03771	0,25124	1,00869	0,25423
200	1,03798	0,25001	1,00784	0,25036
250	1,03817	0,25016	1,00810	0,25018
315	1,03838	0,24982	1,00814	0,24995
400	1,03839	0,24985	1,00824	0,24985
500	1,03841	0,24979	1,00809	0,24985
630	1,03851	0,24985	1,00812	0,24987
800	1,03831	0,24982	1,00778	0,24986
1000	1,03855	0,24983	1,00794	0,24977

The estimates of the transformed BIM results obtained in EURAMET.AUV.V-K2 comparison including the associated relative standard uncertainties are given by:

$$z_{BIM} = r y_{BIM} \qquad (6) \qquad\qquad u^2(z_{BIM}) = y_{BIM}^2 u^2(r) + r^2 u^2(y_{BIM}) \qquad (7)$$

The transformed results can be directly compared with the CIPM KCRV and with the result of the CIPM comparison.

The transformed BIM results and the associated uncertainties, calculated for each frequency according to (6) and (7), are presented in the Table 7.

Table 7. Transformed BIM results for BB accelerometer and SE accelerometer

Frequency	**BB accelerometer**		**SE accelerometer**	
	z_{BIM}	$u(z_{BIM})$	z_{BIM}	$u(z_{BIM})$
Hz	in pC·m^{-1}·s^{2}	in %	in pC·m^{-1}·s^{2}	in %
10	0,12836	0,394	0,12853	0,394
12,5	0,12804	0,394	0,12828	0,394
16	0,12800	0,394	0,12813	0,394
20	0,12786	0,353	0,12798	0,354
25	0,12805	0,353	0,12795	0,354
31,5	0,12801	0,354	0,12791	0,354
40	0,12772	0,354	0,12778	0,354
50	-	-	-	-
63	0,12800	0,354	0,12792	0,353
80	0,12798	0,354	0,12794	0,354
100	0,12770	0,354	0,12786	0,354
125	0,12800	0,354	0,12796	0,354
160	0,12806	0,354	0,12820	0,357
200	0,12815	0,354	0,12795	0,354
250	0,12814	0,354	0,12809	0,354
315	0,12821	0,353	0,12798	0,354
400	0,12830	0,353	0,12804	0,353
500	0,12818	0,353	0,12813	0,353
630	0,12823	0,353	0,12810	0,353
800	0,12828	0,353	0,12802	0,353
1000	0,12834	0,353	0,12784	0,353

7. UNILATERAL DEGREES OF EQUIVALENCE

The unilateral degrees of equivalence (DoEs) are determined as the differences between the transformed BIM results (z_{BIM}) and the key comparison reference values (KCRVs) calculated for each frequency for both accelerometers according to the formula:

$$d_{BIM} = z_{BIM} - x \quad (8)$$

The associated expanded uncertainties, corresponding to coverage factor k = 2, were calculated according to the formula:

$$u^2(d_{BIM}) = u^2(z_{BIM}) + \left[1 - 2\frac{z_{BIM}}{x}\right] u^2(x) \quad (9)$$

The unilateral degrees of equivalence (DoEs) of the BIM results with respect to the KCRVs determined in CCAUV.V-K2 together with the associated expanded uncertainties are presented in the Table 8 and graphically on the Figure 5 and Figure 6.

Table 8. Degrees of equivalence of BIM with respect to the KCRV of CCAUV.V-K2

Frequency	**BB accelerometer**		**SE accelerometer**	
	d_{BIM}	$U(d_{BIM})$ (k=2)	d_{BIM}	$U(d_{BIM})$ (k=2)
Hz	in pC·m^{-1}·s^{2}	in pC·m^{-1}·s^{2}	in pC·m^{-1}·s^{2}	in pC·m^{-1}·s^{2}
10	0,00066	0,00101	0,00084	0,00101
12,5	0,00032	0,00100	0,00057	0,00101
16	0,00028	0,00100	0,00041	0,00100
20	0,00012	0,00090	0,00024	0,00090
25	0,00033	0,00090	0,00023	0,00090
31,5	0,00029	0,00090	0,00019	0,00090
40	0,00001	0,00090	0,00007	0,00090
50	-	-	-	-
63	0,00031	0,00090	0,00023	0,00090
80	0,00029	0,00090	0,00025	0,00090
100	0,00004	0,00090	0,00020	0,00090
125	0,00031	0,00090	0,00027	0,00090
160	0,00037	0,00090	0,00051	0,00091
200	0,00044	0,00090	0,00024	0,00090
250	0,00040	0,00090	0,00035	0,00090
315	0,00046	0,00090	0,00023	0,00090
400	0,00054	0,00090	0,00027	0,00090
500	0,00040	0,00090	0,00035	0,00090
630	0,00042	0,00090	0,00029	0,00090
800	0,00044	0,00090	0,00017	0,00090
1000	0,00045	0,00090	-0,00006	0,00090

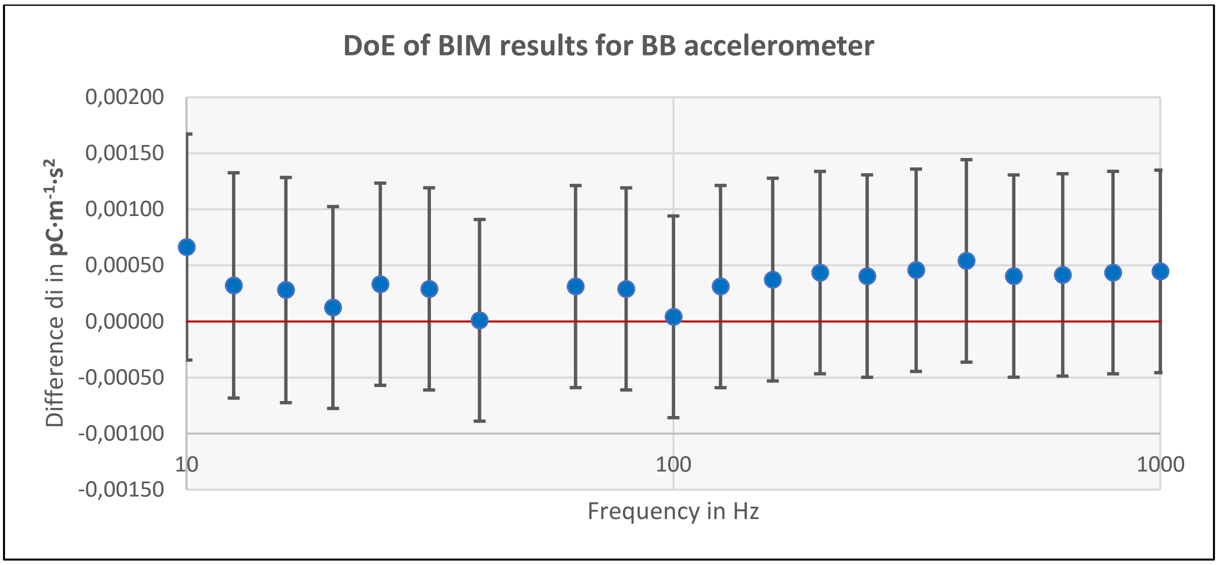

Figure 5. The unilateral degrees of equivalence for BIM results for BB accelerometer with uncertainty bars corresponding to coverage factor *k*=2.

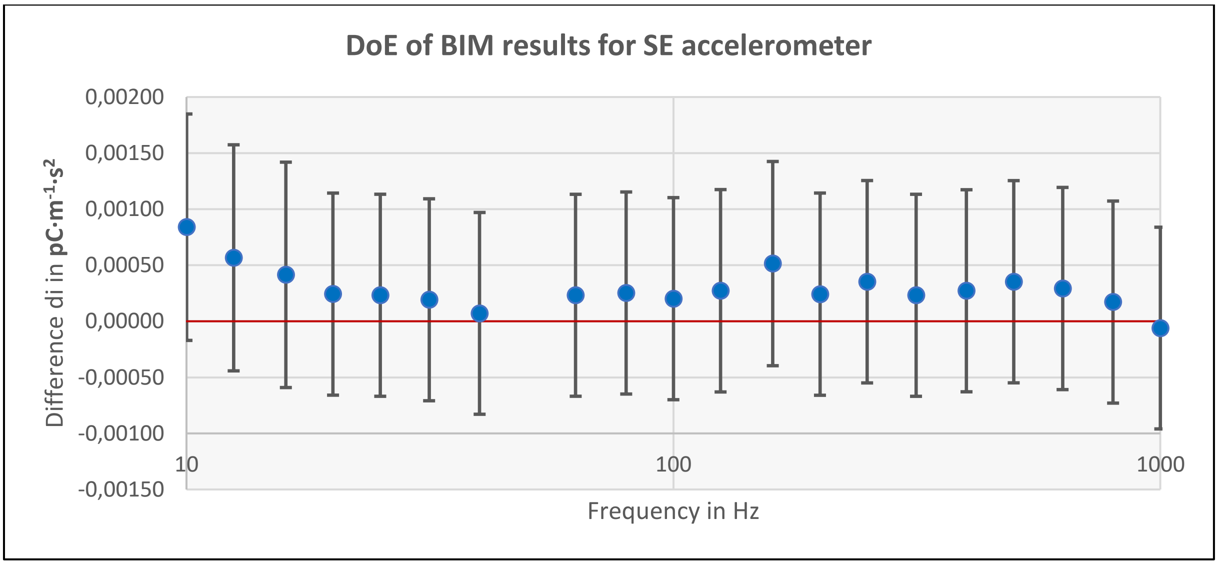

Figure 6. The unilateral degrees of equivalence for BIM results for SE accelerometer with uncertainty bars corresponding to coverage factor *k*=2.

8. BILATERAL DEGREES OF EQUIVALENCE

The differences $D_{BIM-GUM}$ between the laboratories and the associated expanded uncertainties $U_{D_{BIM-GUM}}$ are calculated for each frequency according to the formulae:

$$D_{BIM-GUM} = y_{BIM} - y_{GUM} \quad (10)$$

$$U_{BIM-GUM} = k \cdot \sqrt{u^2(y_{BIM}) + u^2(y_{GUM})} \quad (11)$$

with a coverage factor of k = 2.

The values y_{BIM} , $u(y_{BIM})$ and y_{GUM} , $u(y_{GUM})$ denote the charge sensitivities and associated standard uncertainties of the participants: GUM and BIM, respectively.

The bilateral DoEs between the BIM and the GUM, together with the associated expanded uncertainties, are presented in the Table 9.

Table 9. Bilateral DoE for the BB accelerometer type 8305 SN 1655958 and the SE accelerometer type 8305WH2335 SN 2208358

Frequency	**BB accelerometer**		**SE accelerometer**	
	$D_{BIM-GUM}$	$U_{BIM-GUM}$	$D_{BIM-GUM}$	$U_{BIM-GUM}$
Hz	in pC·m^{-1}·s^{2}	in pC·m^{-1}·s^{2}	in pC·m^{-1}·s^{2}	in pC·m^{-1}·s^{2}
10	0,00064	0,00098	0,00083	0,00100
12,5	0,00031	0,00097	0,00056	0,00100
16	0,00027	0,00097	0,00041	0,00100
20	0,00012	0,00087	0,00024	0,00090
25	0,00032	0,00087	0,00023	0,00090
31,5	0,00028	0,00087	0,00019	0,00090
40	0,00001	0,00087	0,00007	0,00090
50	0,00060	0,00088	0,00015	0,00090
63	0,00030	0,00087	0,00023	0,00090
80	0,00028	0,00087	0,00025	0,00090
100	0,00004	0,00087	0,00020	0,00090
125	0,00030	0,00088	0,00027	0,00090
160	0,00036	0,00088	0,00051	0,00091
200	0,00042	0,00088	0,00024	0,00090
250	0,00039	0,00088	0,00035	0,00090
315	0,00044	0,00088	0,00023	0,00090
400	0,00052	0,00088	0,00027	0,00090
500	0,00039	0,00088	0,00035	0,00090
630	0,00040	0,00088	0,00029	0,00090
800	0,00042	0,00088	0,00017	0,00090
1000	0,00043	0,00088	-0,00006	0,00090

9. CONCLUSIONS

This key comparison demonstrates that the BIM results are consistent with the KCRVs of CCAUV.V-K2 comparison within the uncertainty of the unilateral DoE of the linked EURAMET.AUV.V-K2 results and can be treated as the supporting evidence for future CMC submissions based on this key comparison. However, it should be underlined that at frequencies from 10 Hz to 16 Hz the consistency of the results is influenced by the uncertainty values of the single linking laboratory (GUM), which are slightly higher than the BIM uncertainties.
The observable variability of the results obtained by the BIM in the whole measuring frequency range (see Figure 1 and 2) and high values of sensitivities obtained by the BIM at 10 Hz (see Figure 5 and 6) may indicate some measurement problems and require deeper analysis.

10. REFERENCES

[1] J. Kolasa, Technical Protocol for EURAMET.AUV.V-K2 Comparison, 2018 https://kcdb.bipm.org/AppendixB/appbresults/EURAMET.AUV.V-K2/EURAMET.AUV.V-K2_Technical_Protocol.pdf

[2] Th. Bruns, G.P. Ripper, A. Taubner, Final Report on the CIPM Key Comparison CCAUV.V-K2, Metrologia 2014, 51, Tech. Suppl. 09002 https://www.bipm.org/utils/common/pdf/final_reports/AUV/V-K2/CCAUV.V-K2.pdf

[3] C. Elster , A.Link, W. Wöger, Proposal for linking the results of CIPM and RMO key comparisons, 2003, Metrologia,, 40, 189-194.[4] H.-J. von Martens et al., Final Report of Key Comparison EURAMET.AUV.V-K1, Metrologia, 2006, 43, Tech. Suppl. 09002 https://www.bipm.org/utils/common/pdf/final_reports/AUV/V-K1/EUROMET.AUV.V-K1.pdf

[5] Q.Sun, I.Veldman, Final Report on Key Comparison APMP.AUV.V-K3, Metrologia 2013 50 Tech. Suppl. 09001, https://www.bipm.org/utils/common/pdf/final_reports/AUV/V-K3/APMP.AUV.V-K3_Final_Report.pdf

[6] C. Bartoli et al., Final Report on Key Comparison EURAMET.AUV.V-K3, Metrologia 2015 52 Tech. Suppl. 09003 https://kcdb.bipm.org/AppendixB/appbresults/euramet.AUV.V-K3/EURAMET.AUV.V-K3_FinalReport.pdf

[7] I.Veldman, G.P.Ripper, Final Report on Key Comparison AFRIMETS.AUV.V-K3 (AFRIMETS.AUV.V-S2), Metrologia 2012 49 Tech. Suppl. 09001, https://www.bipm.org/utils/common/pdf/final_reports/AUV/V-S2/AFRIMETS.AUV.V-S2.pdf

[8] T. Usuda et al., Final Report on Key Comparison APMP.AUV.V-K2, Metrologia 2017 54 Tech. Suppl. 09004, https://www.bipm.org/utils/common/pdf/final_reports/AUV/V-K2/APMP.AUV.V-K2.pdf

[9] I. A. Kharitonov , A. G. Chunovkina, Evaluation of regional key comparison data: two approaches for data processing, Metrologia, 43, (2006), 470 - 476

[10] C. Elster, A.G.Chunovkina, Wöger W., Linking of a RMO key comparison to a related CIPM key comparison using the degrees of equivalence of the linking laboratories, 2010, Metrologia, 47, 96-102.

[11] M. Ojanen et al.,na, Wöger W., Uncertainty evaluation for linking a bilateral key comparison with corresponding CIPM key comparison, 2009, Metrologia, 46, 397-403.

[12] COOMET R/GM/14:2006 Recommendation, Guidelines for data evaluation of COOMET key comparison, http://www.coomet.org/

TECHNICAL PROTOCOL
FOR EURAMET.AUV.V-K2 COMPARISON
(vibration acceleration)

Joanna Kolasa, GUM

Version of December 28th, 2018

1. Introduction

The Bulgarian Institute for Metrology (BIM) - National Metrology Institute in Bulgaria in the field of vibration has forwarded to the Central Office of Measures (GUM) the request for bilateral comparison concerning the primary calibration of vibration transducers and asked GUM to pilot the comparison.

BIM is motivated to participate in this bilateral comparison in order to confirm technical competence and to get evidences to support BIM CMCs for primary calibration of vibration transducers. The last comparison in which BIM took part was EUROMET.AUV.V-K1.1 in 2006. Since this period, situation in BIM has changed as BIM lost expertise. GUM participated in the CCAUV.V-K2 and is hence in position to provide linking to other institutes.

The comparison will be registered as EURAMET.AUV.V-K2 key comparison. It is intended to disseminate the KCRV established in CCAUV.V-K2 comparison to BIM.

This document outlines the devices and the conditions for this bilateral comparison with GUM as pilot and is in line with the Technical Protocol of CCAUV.V-K2. It should be applied in conjunction with the CIPM MRA-D-05 document.

2. Participants

The following two laboratories are the participants of this bilateral comparison:

Central Office of Measures (GUM) - pilot	Joanna Kolasa Elektoralna 2 00-139 Warsaw, Poland Phone: + 48 22 581 92 07 E-mail: joanna.kolasa@gum.gov.pl
Bulgarian Institute for Metrology (BIM)	Daniela Virovska 52-B, G.M.Dimitrov Blvd. 1040 Sofia, Bulgaria Phone: +359 2 9740896 E-mail: d.virovska@bmi.government.bg

3. Aim and task of the comparison

The aim of this bilateral EURAMET comparison is to measure the magnitude sensitivity of two standard accelerometers with primary means in accordance with ISO 16063-11 "Methods for the calibration of vibration and shock transducers -- Part 11: Primary vibration calibration by laser interferometry". The reported sensitivities and associated uncertainties are then to be used for the calculation of the Degrees of Equivalence (DoE) between the participating NMIs. One laboratory (GUM) will be acting as pilot and linking laboratory, as it had taken part in the CCAUV.V-K2. The second participant (BIM) will be linked to the KCRV of this former comparison via the pilot laboratory. The results of the comparison will be used as an evidence to be the foundation for the registration of their CMCs considering primary calibration of vibration transducers.
In the frame of this EURAMET comparison, the magnitude of charge sensitivity of two standard accelerometers, a single-ended (SE) and back-to-back (BB), will be measured at different frequencies and acceleration amplitudes as specified in clause 3. The charge sensitivity shall be calculated as the ratio of the amplitude of the output charge of the accelerometer to the amplitude of the acceleration at its reference surface. The reference surface is the base/mounting surface of the accelerometer of single-ended design and the top surface of the accelerometer of back-to-back design. The magnitude of complex charge sensitivity shall be given in picocoulombs per meters per second squared: pC/(m/s^2).

4. Device under test

As transfer standards two piezoelectric accelerometers are to be used:

- standard accelerometer (single-ended, SE) BK type 8305 WH2335 SN 2208358
- standard accelerometer (back-to-back, BB) BK type 8305 SN 1655958.

Both accelerometers will be provided by GUM (property of GUM).

5. Conditions of measurement

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

The frequency range of the measurements was agreed to be from 10 Hz to 1 kHz. Specifically the laboratories are supposed to measure at the following frequencies (all values in Hz)" 10, 12.5, 16, 20, 25, 31.5, 40, 50, 63, 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000.

The charge amplifier used for the calibration is not provided within the set of the artefacts, it must therefore be provided by the individual participant and calibrated properly.

The calibrations should be carried out in accordance with the usual procedure of the laboratory for the calibration of customer accelerometers.

Specific conditions for the measurements are:

- acceleration amplitudes: 5 m/s^2 to 70 m/s^2.
- ambient temperature and accelerometer temperature during the calibration: (23 ± 3) ºC (actual values to be stated within tolerances of ± 0.3 ºC).
- relative humidity: max. 75 %.
- mounting torque of the accelerometer: (2.0 ± 0.1) Nm.

6. Measurement instructions

- The measurand is the magnitude of the complex charge sensitivity.
- The motion of the SE accelerometer should be measured on the moving part of the vibration exciter, close to the accelerometer's mounting surface, since the mounting (reference) surface is usually not directly accessible.
- The motion of the BB accelerometer mounted in the normal position should be measured with the laser directly on the (polished) top surface of the transducer without any additional reflector or dummy mass.
- The mounting surfaces of the accelerometer and the moving part of the exciter shall slightly be lubricated before mounting.
- The cable between accelerometer and charge amplifier should be taken from the set of DUT delivered to the laboratory.
- In order to reduce the influence of non-rectilinear motion, the measurements should be performed for at least three different laser positions which are equally spaced over the respective measurements surface.
- It is advised that the measurement results should be compiled from complete measurement series carried out at different days under nominally the same conditions, except that the accelerometer is remounted and the cable reattached. The standard deviation of the subsequent measurements should be included in the report.
- The charge amplifier used for the measurement of the accelerometer's response should be calibrated with the equipment traceable to national measurements standards.

7. Communication of the results

For transparency, GUM will perform an initial calibration of the accelerometers and submit the calibration results to the EURAMET AUV secretary before sending the artefacts to BIM. BIM shall perform calibration of the artefacts and submit its calibration report to the EURAMET AUV secretary as well as the pilot laboratory within 4 weeks after the calibration.

The calibration report shall contain detailed description of:

- the calibration equipment
- the calibration method(s) used
- the ambient conditions
- the mounting technique

- the calibration results including the relative expanded uncertainty
- the uncertainty budget

In addition to the calibration report, the measurements results shall be submitted to the pilot laboratory by electronic mail, with the data in Excel format.

For reporting the calibration results, clause 10 of ISO 16063-11:1999 shall be taken into account. For uncertainty, the following instructions are given:
The list(s) of the principal components of the uncertainty budget shall be in accordance with ISO 16063-11:1999, Annex A for the primary calibration by laser interferometry. In each case, the uncertainties shall be determined in accordance with the Guide to the expression of uncertainty in measurement.

8. Circulation type

From GUM to BIM and back: GUM will send the accelerometers to BIM. BIM calibrates the accelerometers and send them back to GUM, which will perform its own calibration.

9. Time schedule

- Calibration and transportation time period: a total time period of 4 weeks is allocated for each laboratory covering both calibration and transportation.
- Total circulation period: 2 months
- Start of circulation period: April 2019
- End of circulation period: June 2019
- Final report: 2019.

10. Transportation and financial aspects

The transfer standards will be transported in a closed box by an international transportation service (e.g. TNT, UPS). The transportation has to include an insurance covering a value of 9.000,-euro in the case the set of accelerometers gets damaged or lost during transportation.

Each participating laboratory is responsible for its own costs of measurements, transportation as well as any damage that may occur within its country. Pilot laboratory is responsible for other costs of the organization of the comparison.

11. Linking

The results of the BIM obtained in this comparison will be linked to the CCAUV.V-K2 key comparison through GUM. The degrees of equivalence will be computed for Bulgaria with respect to the CCAUV.V-K2 KCRV by linking both sensor's results to the one SE sensor results as no KCRV was determined for the BB amplitude sensitivity.

The BIM uncertainty budget

i	Standard uncertainty component $u(x_i)$	Source of uncertainty	Contribution [%]
1	$u(\hat{u}_V)$	Accelerometer output voltage measurement	0,06
2	$u(\hat{u}_f)$	Voltage filtering effect on accelerometer output amplitude measurement (frequency band limitation)	0,11
3	$u(\hat{u}_D)$	Effect of voltage disturbance on accelerometer output voltage measurement (e.g. hum and noise)	0,08
4	$u(\hat{u}_T)$	Effect of transverse, rocking and bending acceleration on accelerometer output voltage measurement (transverse sensitivity)	0,1
5	$u(\varphi_{M,Q})$	Effect of interferometer quadrature output signal disturbance on phase amplitude measurement	0,03
6	$u(\varphi_{M,F})$	Interferometer signal filtering effect on phase amplitude measurement	0,04
7	$u(\varphi_{M,D})$	Effect of voltage disturbance on phase amplitude measurement	0,01
8	$u(\varphi_{M,MD})$	Effect of motion disturbance on phase amplitude measurement	0,1
9	$u(\varphi_{M,PD})$	Effect of phase disturbance on phase amplitude measurement (e.g. phase noise of the interferometer signal)	0,05
10	$u(\varphi_{M,RE})$	Residual interferometric effects on phase amplitude measurement (e.g. interferometer function)	0,03
11	$u(f_{FG})$	Vibration frequency measurement	0,04
12	$u(S_{RE})$	Residual effects on sensitivity measurement Residual effects on sensitivity measurement (e.g random effects in repeat measurements, experimental deviation of arithmetic mean, temperature)	0,13

$u_{rel}(S)$	*Uncertainty (%) for accelerometer sensitivity (standard uncertainty k=1)*	0,26

Uncertainty (%) for accelerometer sensitivity S at 95 % confidential level (k=2)	**0,52**

APPENDIX B: MEASUREMENT UNCERTAINTY BUDGET

The GUM Uncertainty budget

Quantity	Voltage measurement	Vibration signal frequency	Vibration velocity	Amplifier gain	Frequency response	Transverse motion	THD	Hum	Noise	Base strain	Geometric location of laser spot	Transducer mounting	Cable mounting	Relative motion	Temperature change	Linearity	Instability of vibration signal with time	Magnetic field	Residual interferometric effects	Standard deviation of mean (max)	Expanded uncertainty rounded
	V_x	ω	V	G	K_F	K_T	K_D	K_H	K_N	K_B	K_{GL}	K_{MT}	K_{MC}	K_{REL}	K_{TK}	K_L	K_l	K_M	K_{RES}	K_P	U
distribut	normal	rectang	normal	normal	normal	rectang	rectang	rectang	normal	rectang	normal	normal	rectang	rectang	normal	rectang	normal	rectang	rectang	normal	$k = 2$
Hz	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	%
10	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00200	0,0001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00020	0,6
12,5	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00200	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00024	0,6
16	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00200	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00009	0,6
20	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00005	0,5
25	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00005	0,5
31,5	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00008	0,5
40	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00007	0,5
52	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00007	0,5
63	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00006	0,5
80	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00009	0,5
102	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00013	0,5
125	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00019	0,5
160	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00047	0,5
202	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00015	0,5
252	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00012	0,5
315	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00010	0,5
400	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00009	0,5
500	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00006	0,5
630	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00007	0,5
800	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00007	0,5
1000	0,00045	0,00001	0,00010	0,00040	0,00050	0,00010	0,00001	0,00010	0,00001	0,00001	0,00150	0,00140	0,00100	0,00001	0,000015	0,00001	0,00001	0,00050	0,00050	0,00009	0,5