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NMISA, KEBS, BKSV tri-lateral vibration comparison results

Anderson Maina[1], Ian Veldman[2], Henning Ploug[3]

[1] Kenyan Bereau of Standards, Bundesallee 100, 38116 Braunschweig, Kenya
[2] National Measurement Instiitute of South Africa, CSIR Campus, Pretoria, South Africa
[3] Brüel & Kjær Calibration Laboratory, Skodsborgvej 307, DK-2850 Nærum, Denmark

ABSTRACT
National Metrology Institutes (NMIs) and calibration laboratories perform Inter Laboratory Comparisons (ILC) as part of their processes to validate their measurement capabilities (MCs). In the area of vibration (quantity acceleration) the Kenyan Bureau of Standards (KEBS) piloted an ILC, inclusive of two additional participating laboratories for this purpose. This technical review documents the calibration results and findings of the ILC.

Section: RESEARCH PAPER

Keywords: vibration comparison; degrees of equivalence; comparison reference value

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Corresponding author: Ian Veldman, e-mail: csveldman@nmisa.org

1. INTRODUCTION

This report presents the results of a comparison in the area of vibration (quantity of acceleration).

It was agreed in the technical protocol [1] that the comparison reference values (CRVs) be obtained from the NMISA primary vibration calibration system [2] and the degrees of equivalence between the values of the participating laboratories and the CRVs be determined.

The Technical Protocol [1] of April 2012 specifies in detail, the aim and the task of the comparison, the conditions of measurement, the transfer standards used, measurement instructions, time schedule and other items. A brief overview of the protocol is given in the sections 4 to 6. Section 2 lists the participants with the task of the Inter Laboratory Comparison (ILC) described in section 3. Section 7 deals with the measurement results, artefact stability analysis and degrees of equivalence. In section 8, possible correlation between the Comparison Reference Value (CRV) and the NMISA results is investigated.

2. PARTICIPANTS

Three laboratories, namely Kenya Bureau of Standards (KEBS), National Metrology Institute of South Africa (NMISA), and Brüel & Kjær Calibration Laboratory (BKSV) participated in the comparison as shown in Table 1.

3. TASK AND PURPOSE OF THE COMPARISON

The aim of the comparison was to compare measurements of the sensitivity of accelerometers as measured using secondary (back to back) means in accordance with ISO 16063-21 "Vibration calibration by comparison to a reference transducer" [3].

During the circulation period the three laboratories calibrated two accelerometers (see section 5), as the transfer standards.

The laboratories were tasked to measure the magnitude of the sensitivity of the accelerometers at different frequencies and

Table 1. Overview of styles and font sizes used in this template.

Participating Laboratory	Acronym	Country	Calibration period
Brüel & Kjær	BKSV	Denmark	6 to 24 Aug 2012
Kenyan Bureau of Standards	KEBS	Kenya	8 to 25 Jan 2013
National Metrology Institute of South Africa	NMISA	South Africa	8 to 26 Apr 2013

acceleration amplitudes as specified in section 4 and clause 3 of [1]. The reference surface was defined as the mounting surface of the accelerometer. For the double ended accelerometer, the bottom mounting surface was defined as the reference surface. This accelerometer was viewed as a single ended accelerometer for the purpose of this comparison only.

Dependent on the participating laboratory's measurement capability (MC), the sensitivity reported excluded effects from the applicable conditioning amplifier/power supply unit (PSU) used. For all instances, the participating laboratory provided the amplifier to be used. If the sensitivity reported by the laboratory included effects by the amplifier, these effects were taken into account in the reported uncertainty of measurement (UoM). No amplifier/PSU accompanied the circulation of the transfer standards.

4. CONDITIONS OF MEASUREMENT

The participating laboratories observed fully the conditions stated in the Technical Protocol, i.e.

Frequencies in Hz:

10, 12.5, 16, 20, 25, 31.5, 40, 63, 80, 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1500, 1600, 2000, 2500, 3000, 3150, 3500, 4000, 4500, 5000, 5500, 6000, 6300, 6500, 7000, 7500, 8000, 8500, 9000, 9500, 10000.

Amplitudes:

The range of acceleration amplitudes was between 1 m/s² and 100 m/s².

1 m/s² to 200 m/s² was admissible (considering the displacement and acceleration limitations of the vibration exciters).

Ambient temperature and accelerometer temperature during the calibration:

(23 ± 3) °C (actual values were stated within tolerances of ± 0.5 °C).

Relative humidity:

max. 75 % RH

Mounting torque of the accelerometer:

(2 ± 0.1) N·m

5. TRANSFER STANDARDS

During the preparatory stage, NMISA investigated the characteristics (long-term stability, linearity, etc.) of the reference standard accelerometers (property of NMISA) to be used as transfer standards. The following accelerometers were selected:

Accelerometer 1: Brüel & Kjær 8305 S serial number 1033874, with nominal sensitivity of 0.1 pC/(m/s²).

Accelerometer 2: PCB 301M15 serial number 1032, with a nominal sensitivity of 10 mV/(m/s²) .

Stability measurements for both accelerometers were made at the beginning, middle and end of the circulation period using NMISA primary calibration system [2]. The results of these stability measurements are given in section 7.

6. CIRCULATION TYPE AND TRANSPORTATION

Each participating laboratory was accorded three weeks for measurement. At the beginning, middle and the end of the circulation the transfer standards were measured at the NMISA laboratory using primary means [2] in order to determine reference values and to monitor the stability of the transducer sets.

The transfer standards were transported in a metal case via courier or by a representative of each participating laboratory in the following order.

NMISA (Stability & CRV) → BKSV (Measurements) → NMISA (Stability & CRV) → KEBS (Measurements) → NMISA (Stability & CRV) → NMISA (Measurements).

7. RESULTS OF THE MEASUREMENTS

7.1. Monitoring of stability

The two transfer standards were monitored for stability in the beginning, middle and end of the circulation period using primary means [2].

The laboratory used calculated E_n values as a stability evaluation measure. The method used for the evaluation of the measurement results was to calculate the deviation, E_n, normalised with respect to the UoM as follows:

$$E_n = s/U_c\ , \qquad (1)$$

where s is the standard deviation of the sensitivity values over the comparison period. U_c is the expanded uncertainty of measurement of the NMISA. $|E_n| \leq 1$ were considered acceptable.

Stability results for the two sensors; Brüel & Kjær 8305 S and PCB 301M15, are given in Table 2 and Table 3 respectively and illustrated in Figure 1 and Figure 2.

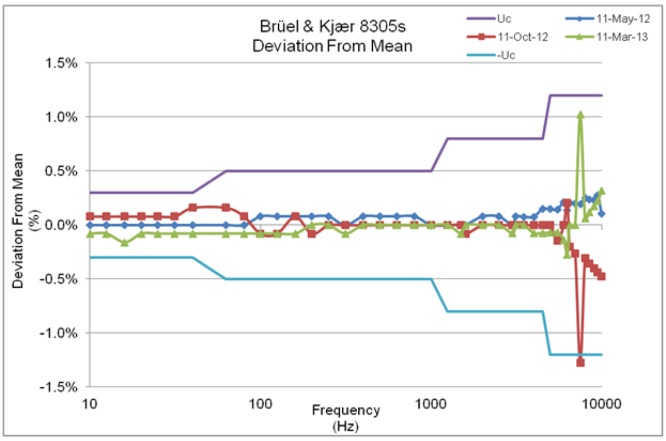

Figure 1. Results of monitoring of stability during circulation period for Brüel & Kjær 8305 S sensor.

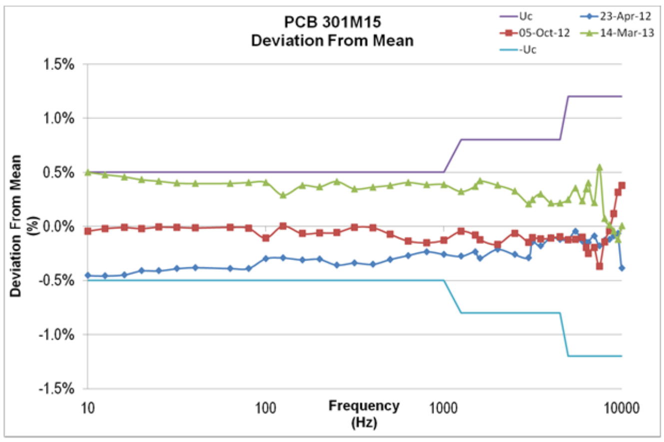

Figure 2. Results of monitoring of stability during circulation period for PCB 301M15 sensor.

Table 2. Results of monitoring of stability during circulation period for Brüel & Kjær 8305 S sensor.

Frequency (Hz)	11-May-12 Sensitivity (pC/(m/s²))	11-Oct-12 Sensitivity (pC/(m/s²))	11-Mar-13 Sensitivity (pC/(m/s²))	*S* (fC/(m/s²))	U_c (fC/(m/s²))	E_n
10.0	0.124 3	0.124 4	0.124 2	0.10	0.37	0.27
12.5	0.124 3	0.124 4	0.124 2	0.10	0.37	0.27
16.0	0.124 4	0.124 5	0.124 2	0.15	0.37	0.41
20.0	0.124 4	0.124 5	0.124 3	0.10	0.37	0.27
25.0	0.124 4	0.124 5	0.124 3	0.10	0.37	0.27
31.5	0.124 4	0.124 5	0.124 3	0.10	0.37	0.27
40.0	0.124 4	0.124 6	0.124 3	0.15	0.62	0.25
63.0	0.124 4	0.124 6	0.124 3	0.15	0.62	0.25
80.0	0.124 4	0.124 5	0.124 3	0.10	0.62	0.16
100	0.124 5	0.124 3	0.124 3	0.12	0.62	0.19
125	0.124 5	0.124 3	0.124 3	0.12	0.62	0.19
160	0.124 5	0.124 5	0.124 3	0.12	0.62	0.19
200	0.124 4	0.124 2	0.124 3	0.10	0.62	0.16
250	0.124 4	0.124 3	0.124 3	0.06	0.62	0.09
315	0.124 4	0.124 4	0.124 3	0.06	0.62	0.09
400	0.124 5	0.124 4	0.124 4	0.06	0.62	0.09
500	0.124 5	0.124 4	0.124 4	0.06	0.62	0.09
630	0.124 6	0.124 5	0.124 5	0.06	0.62	0.09
800	0.124 7	0.124 6	0.124 6	0.06	0.62	0.09
1 000	0.124 8	0.124 8	0.124 8	0.00	0.62	0.00
1 250	0.125 1	0.125 1	0.125 1	0.00	1.00	0.00
1 500	0.125 6	0.125 6	0.125 5	0.06	1.00	0.06
1 600	0.125 6	0.125 5	0.125 6	0.06	1.00	0.06
2 000	0.126 3	0.126 2	0.126 2	0.06	1.01	0.06
2 500	0.127 4	0.127 3	0.127 3	0.06	1.02	0.06
3 000	0.128 8	0.128 8	0.128 7	0.06	1.03	0.06
3 150	0.129 3	0.129 2	0.129 2	0.06	1.03	0.06
3 500	0.130 4	0.130 3	0.130 3	0.06	1.04	0.06
4 000	0.132 4	0.132 3	0.132 2	0.10	1.06	0.09
4 500	0.134 7	0.134 5	0.134 4	0.15	1.08	0.14
5 000	0.137 3	0.137 1	0.137 0	0.15	1.65	0.09
5 500	0.140 3	0.139 9	0.140 0	0.21	1.68	0.12
6 000	0.143 7	0.143 4	0.143 2	0.25	1.72	0.15
6 300	0.146 3	0.146 4	0.145 7	0.38	1.75	0.22
6 500	0.147 7	0.147 1	0.147 4	0.30	1.77	0.17
7 000	0.152 0	0.151 3	0.151 7	0.35	1.82	0.19
7 500	0.156 8	0.154 5	0.158 1	1.82	1.88	0.97
8 000	0.162 2	0.161 3	0.161 9	0.46	1.94	0.24
8 500	0.168 1	0.167 1	0.167 9	0.53	2.01	0.26
9 000	0.174 5	0.173 4	0.174 4	0.61	2.09	0.29
9 500	0.181 6	0.180 3	0.181 5	0.72	2.17	0.33
10 000	0.190 4	0.189 3	0.190 8	0.78	2.28	0.34

The values reported for the Brüel & Kjær 8305 S sensor showed good stability over the circulation period.

The values reported for the PCB 301M15 sensor suggested a change in sensitivity with time of up to 1 % from the beginning to the end of the circulation period. The effect of this change was compensated for by an increase in the uncertainty of the CRV for the PCB accelerometer. No correction was applied to the data reported by the participants.

7.2. Comparison Reference Value

The CRVs were obtained from the mean of measurements carried out at the beginning, middle and end of the circulation period by NMISA primary vibration calibration system.

The chi-square goodness of fit test was used to check the consistency of the CRV(x_{ref}) against the results of the participating laboratories (x_i) as follows:

Table 3. Results of monitoring of stability during circulation period for PCB 301M15 sensor.

Frequency (Hz)	23-Apr-12 Sensitivity (mV/(m/s²))	05-Oct-12 Sensitivity (mV/(m/s²))	14-Mar-13 Sensitivity (mV/(m/s²))	s (µV/(m/s²))	U_c (µV/(m/s²))	E_n
10.0	10.27	10.31	10.37	50	52	0.98
12.5	10.25	10.30	10.35	50	52	0.97
16.0	10.24	10.28	10.33	45	51	0.88
20.0	10.22	10.26	10.31	45	51	0.88
25.0	10.21	10.25	10.29	40	51	0.78
31.5	10.19	10.23	10.27	40	51	0.78
40.0	10.18	10.21	10.25	35	51	0.69
63.0	10.14	10.18	10.22	40	51	0.79
80.0	10.12	10.16	10.20	40	51	0.79
100	10.10	10.12	10.18	42	51	0.82
125	10.08	10.11	10.14	30	51	0.59
160	10.06	10.09	10.13	35	50	0.70
200	10.05	10.07	10.11	31	50	0.61
250	10.03	10.06	10.11	40	50	0.80
315	10.01	10.04	10.08	35	50	0.70
400	9.99	10.02	10.06	35	50	0.70
500	9.97	9.99	10.04	36	50	0.72
630	9.95	9.96	10.02	38	50	0.76
800	9.94	9.95	10.00	32	50	0.65
1 000	9.91	9.93	9.98	36	50	0.73
1 250	9.89	9.91	9.95	31	79	0.39
1 500	9.88	9.90	9.94	31	79	0.39
1 600	9.87	9.89	9.94	36	79	0.46
2 000	9.86	9.86	9.92	35	79	0.44
2 500	9.84	9.86	9.90	31	79	0.39
3 000	9.83	9.84	9.87	21	79	0.26
3 150	9.83	9.84	9.87	21	79	0.26
3 500	9.83	9.83	9.87	23	79	0.29
4 000	9.83	9.83	9.87	23	79	0.29
4 500	9.83	9.83	9.86	17	79	0.22
5 000	9.83	9.83	9.87	23	118	0.20
5 500	9.86	9.85	9.90	26	118	0.22
6 000	9.87	9.87	9.90	17	119	0.15
6 300	9.88	9.87	9.93	32	119	0.27
6 500	9.89	9.88	9.95	38	119	0.32
7 000	9.92	9.91	9.95	21	119	0.17
7 500	9.96	9.94	10.03	47	120	0.39
8 000	9.98	9.97	10.00	15	120	0.13
8 500	10.00	10.01	10.02	10	120	0.08
9 000	10.03	10.05	10.03	12	120	0.10
9 500	10.05	10.09	10.05	23	121	0.19
10 000	10.05	10.12	10.09	35	121	0.29

$$\chi^2_{obs} = \frac{(x_1 - x_{ref})^2}{u^2(x_1)} + \cdots + \frac{(x_N - x_{ref})^2}{u^2(x_N)} \,. \tag{2}$$

The consistency check fails if

$$P_r\{\chi^2(\nu) > \chi^2_{obs}\} < 0.05 \,. \tag{3}$$

The CRVs for both accelerometers as reported by the NMISA using primary accelerometer calibration methods [2] are reported in Table 4. Table 5 shows the results of the consistency check for the reported stability measurements over time both accelerometers.

7.3. the Participants

The participants results were communicated to the pilot laboratory via an electronic spreadsheet circulated with the protocol [1]. The official results were communicated to the pilot laboratory in the form of calibration certificates. The calibration certificates had to be issued in the same format as the laboratory would do for their customers.

Results of Table 6 shows the measurement results of the participants for the sensor Brüel & Kjær 8305 S while the results for the participants for the PCB 301M15 sensor is reported in Table 7.

Table 4. CRVs as by NMISA primary calibration for sensors Brüel & Kjær 8305 S and PCB 301M15.

Frequency (Hz)	Brüel & Kjær 8305 S		PCB 301M15	
	x_{ref} (pC/(m/s²))	$U(x_{ref})$ (%)	x_{ref} (mV/(m/s²))	$U(x_{ref})$ (%)
10.0	0.124 3	0.3	10.32	0.5
12.5	0.124 3	0.3	10.30	0.5
16.0	0.124 4	0.3	10.28	0.5
20.0	0.124 4	0.3	10.26	0.5
25.0	0.124 4	0.3	10.25	0.5
31.5	0.124 4	0.3	10.23	0.5
40.0	0.124 4	0.3	10.21	0.5
63.0	0.124 4	0.5	10.18	0.5
80.0	0.124 4	0.5	10.16	0.5
100	0.124 4	0.5	10.13	0.5
125	0.124 4	0.5	10.11	0.5
160	0.124 4	0.5	10.09	0.5
200	0.124 3	0.5	10.08	0.5
250	0.124 3	0.5	10.07	0.5
315	0.124 4	0.5	10.04	0.5
400	0.124 4	0.5	10.02	0.5
500	0.124 4	0.5	10.00	0.5
630	0.124 5	0.5	9.98	0.5
800	0.124 6	0.5	9.96	0.5
1 000	0.124 8	0.5	9.94	0.5
1 250	0.125 1	0.8	9.92	0.8
1 500	0.125 6	0.8	9.91	0.8
1 600	0.125 6	0.8	9.90	0.8
2 000	0.126 2	0.8	9.88	0.8
2 500	0.127 3	0.8	9.87	0.8
3 000	0.128 8	0.8	9.85	0.8
3 150	0.129 2	0.8	9.85	0.8
3 500	0.130 3	0.8	9.84	0.8
4 000	0.132 3	0.8	9.84	0.8
4 500	0.134 5	0.8	9.84	0.8
5 000	0.137 1	1.2	9.84	1.2
5 500	0.140 1	1.2	9.87	1.2
6 000	0.143 4	1.2	9.88	1.2
6 300	0.146 1	1.2	9.89	1.2
6 500	0.147 4	1.2	9.91	1.2
7 000	0.151 7	1.2	9.93	1.2
7 500	0.156 5	1.2	9.98	1.2
8 000	0.161 8	1.2	9.98	1.2
8 500	0.167 7	1.2	10.01	1.2
9 000	0.174 1	1.2	10.04	1.2
9 500	0.181 1	1.2	10.06	1.2
10 000	0.190 2	1.2	10.09	1.2

Table 5. The results of the Chi-Square goodness of fit test for 2 degrees of freedom for both accelerometers.

Frequency (Hz)	Brüel & Kjær 8305 S		PCB 301M15	
	χ^2_{obs}	$P_r(\nu = 3)$	χ^2_{obs}	$P_r(\nu = 3)$
10.0	0.15	≥0.90	0.66	≥0.70
12.5	0.54	≥0.70	0.62	≥0.70
16.0	0.32	≥0.80	0.31	≥0.80
20.0	0.08	≥0.95	0.63	≥0.70
25.0	0.18	≥0.9	0.59	≥0.70
31.5	0.12	≥0.90	0.55	≥0.70
40.0	1.12	≥0.90	0.55	≥0.70
63.0	0.10	≥0.95	0.60	≥0.70
80.0	0.10	≥0.95	0.60	≥0.70
100	0.08	≥0.95	0.51	≥0.70
125	0.04	≥0.95	0.60	≥0.70
160	0.08	≥0.95	0.76	≥0.50
200	0.11	≥0.90	0.50	≥0.70
250	0.12	≥0.90	0.72	≥0.50
315	0.06	≥0.95	0.39	≥0.80
400	0.11	≥0.90	0.50	≥0.70
500	0.12	≥0.90	0.43	≥0.80
630	0.11	≥0.90	0.56	≥0.70
800	0.11	≥0.90	0.53	≥0.70
1 000	0.09	≥0.95	0.58	≥0.70
1 250	0.01	≥0.95	0.46	≥0.70
1 500	0.06	≥0.95	0.56	≥0.70
1 600	0.05	≥0.95	0.51	≥0.70
2 000	0.04	≥0.95	0.48	≥0.70
2 500	0.02	≥0.95	0.65	≥0.70
3 000	0.01	≥0.95	0.45	≥0.80
3 150	0.01	≥0.95	0.45	≥0.80
3 500	0.01	≥0.95	0.49	≥0.70
4 000	0.01	≥0.95	0.36	≥0.80
4 500	0.07	≥0.95	0.32	≥0.80
5 000	0.16	≥0.90	0.11	≥0.90
5 500	0.59	≥0.70	0.25	≥0.80
6 000	0.99	≥0.50	0.22	≥0.80
6 300	1.72	≥0.30	0.21	≥0.90
6 500	0.71	≥0.70	0.09	≥0.95
7 000	0.33	≥0.80	0.14	≥0.90
7 500	0.67	≥0.70	0.42	≥0.80
8 000	2.19	≥0.30	0.68	≥0.70
8 500	0.94	≥0.50	0.61	≥0.70
9 000	1.71	≥0.30	0.73	≥0.50
9 500	0.84	≥0.50	0.26	≥0.80
10 000	0.90	≥0.50	0.12	≥0.90

7.4. Degrees of equivalence between participants and the CRVs

Table 8 and Table 9 show the degrees of equivalence (d_i) between each of the participating laboratories measurements (x_i) and the CRVs (x_{ref}) for the Brüel & Kjær 8305 and PCB 301M15 sensors respectively where;

$$d_i = x_i - x_{ref} \quad (4)$$

and the associated uncertainty of the degree of equivalence $(u(d_i))$ where

$$u(d_i) = \sqrt{u(x_i)^2 + u(x_{ref})^2}\,. \quad (5)$$

In Table 8, cells with yellow shading represent cases where $|d_i| > U(d_i)$.

Table 6. Results of the participants for the sensor Brüel & Kjær 8305 S.

Frequency (Hz)	BKSV		KEBS		NMISA	
	S (pC/(m/s²))	*U S* (%)	*S* (pC/(m/s²))	U_S (%)	*S* (pC/(m/s²))	U_S (%)
10	0.124 5	0.8	0.124 2	0.8	0.124 7	1.0
12.5	0.124 4	0.8	0.124 4	0.8	0.125 2	1.0
16	0.124 5	0.8	0.124 4	0.8	0.125 1	1.0
20	0.124 5	0.8	0.124 3	0.8	0.124 1	1.0
25	0.124 5	0.8	0.124 3	0.8	0.124 9	1.0
31.5	0.124 5	0.8	0.124 3	0.8	0.124 8	1.0
40	0.124 5	0.8	0.124 2	0.8	0.125 7	1.0
63	0.124 4	0.8	0.124 2	0.8	0.124 7	1.0
80	0.124 4	0.8	0.124 2	0.8	0.124 7	1.0
100	0.124 5	0.8	0.124 2	0.8	0.124 6	1.0
125	0.124 4	0.8	0.124 3	0.8	0.124 6	1.0
160	0.124 5	0.6	0.124 2	0.8	0.124 6	1.0
200	0.124 5	0.8	0.124 2	0.8	0.124 6	1.0
250	0.124 6	0.8	0.124 3	0.8	0.124 5	1.0
315	0.124 6	0.8	0.124 3	0.8	0.124 5	1.0
400	0.124 7	0.8	0.124 3	0.8	0.124 5	1.0
500	0.124 7	0.8	0.124 4	0.8	0.124 6	1.0
630	0.124 8	0.8	0.124 4	0.8	0.124 6	1.0
800	0.124 9	0.8	0.124 5	0.8	0.124 7	1.0
1 000	0.125 1	0.8	0.124 8	0.8	0.124 8	1.0
1 250	0.125 2	0.8	0.125 0	1.5	0.125 1	1.3
1 500	0.125 6	0.8	0.125 2	1.5	0.125 4	1.3
1 600	0.125 8	0.8	0.125 4	1.5	0.125 5	1.3
2 000	0.126 4	0.8	0.126 2	1.5	0.126 2	1.3
2 500	0.127 4	0.8	0.127 1	1.5	0.127 3	1.3
3 000	0.128 8	0.8	0.128 7	1.5	0.128 7	1.3
3 150	0.129 3	0.8	0.129 2	1.5	0.129 2	1.3
3 500	0.130 4	0.8	0.130 3	1.5	0.130 4	1.3
4 000	0.132 2	0.8	0.132 3	1.5	0.132 4	1.3
4 500	0.134 4	0.8	0.135 0	1.5	0.134 5	1.3
5 000	0.136 8	0.8	0.137 7	1.5	0.137 1	1.9
5 500	0.139 4	0.8	0.140 9	2.0	0.141 0	1.9
6 000	0.142 3	0.8	0.144 1	2.0	0.143 4	1.9
6 300	0.144 7	0.8	0.147 6	2.0	0.146 1	1.9
6 500	0.146 3	2	0.148 9	2.0	0.149 0	1.9
7 000	0.150 4	2	0.151 6	2.0	0.152 8	1.9
7 500	0.154 8	2	0.157 4	2.0	0.158 1	1.9
8 000	0.159 4	2	0.158 0	2.0	0.160 5	1.9
8 500	0.164 8	2	0.167 6	2.0	0.166 4	1.9
9 000	0.170 6	2	0.172 7	2.0	0.171 8	1.9
9 500	0.178 1	2	0.180 8	2.0	0.179 9	1.9
10 000	0.186 7	2	0.189 6	2.0	0.190 3	1.9

Sets of degrees of equivalence as reported in Table 8 and Table 9 for selected frequencies are shown in graphical form for the Brüel & Kjær 8305 and PCB 301M15 in Figure 3 and Figure 4 respectively.

In section 8 using exclusive statistics [4] it is shown that any correlation between the CRV's and the results of NMISA is small as compared to the NMISA uncertainty.

8. CONSIDERING CORRELATION BETWEEN CRV AND NMISA RESULTS

The aim of this comparison was to compare measurements of the sensitivity of accelerometers as measured using secondary (back to back) means in accordance with ISO

Table 7. Results of the participants for the sensor PCB 301M15.

Frequency (Hz)	BKSV		KEBS		NMISA	
	S (mV/(m/s²))	U_S (%)	S (mV/(m/s²))	U_S (%)	S (mV/(m/s²))	U_S (%)
10	10.29	0.8	10.30	0.8	10.25	1.0
12.5	10.27	0.8	10.29	0.8	10.23	1.0
16	10.26	0.8	10.27	0.8	10.23	1.0
20	10.25	0.8	10.26	0.8	10.18	1.0
25	10.23	0.8	10.27	0.8	10.18	1.0
31.5	10.22	0.8	10.25	0.8	10.16	1.0
40	10.20	0.8	10.23	0.8	10.14	1.0
63	10.16	0.8	10.20	0.8	10.11	1.0
80	10.14	0.8	10.18	0.8	10.09	1.0
100	10.14	0.8	10.16	0.8	10.07	1.0
125	10.11	0.8	10.15	0.8	10.05	1.0
160	10.10	0.6	10.13	0.8	10.02	1.0
200	10.08	0.8	10.09	0.8	10.01	1.0
250	10.06	0.8	10.09	0.8	9.99	1.0
315	10.04	0.8	10.07	0.8	9.99	1.0
400	10.02	0.8	10.05	0.8	9.96	1.0
500	10.00	0.8	10.02	0.8	9.94	1.0
630	9.98	0.8	10.00	0.8	9.91	1.0
800	9.95	0.8	9.97	0.8	9.89	1.0
1 000	9.93	0.8	9.96	0.8	9.87	1.0
1 250	9.90	0.8	9.93	1.5	9.84	1.3
1 500	9.89	0.8	9.91	1.5	9.82	1.3
1 600	9.89	0.8	9.90	1.5	9.81	1.3
2 000	9.86	0.8	9.90	1.5	9.80	1.3
2 500	9.84	0.8	9.88	1.5	9.78	1.3
3 000	9.84	0.8	9.82	1.5	9.77	1.3
3 150	9.84	0.8	9.82	1.5	9.77	1.3
3 500	9.83	0.8	9.80	1.5	9.76	1.3
4 000	9.83	0.8	9.81	1.5	9.77	1.3
4 500	9.83	0.8	9.85	1.5	9.77	1.3
5 000	9.83	0.8	9.86	1.5	9.79	1.9
5 500	9.84	0.8	9.88	2.0	9.81	1.9
6 000	9.85	0.8	9.89	2.0	9.83	1.9
6 300	9.86	0.8	9.94	2.0	9.88	1.9
6 500	9.87	2.0	9.95	2.0	9.89	1.9
7 000	9.88	2.0	9.94	2.0	9.88	1.9
7 500	9.90	2.0	9.95	2.0	9.89	1.9
8 000	9.93	2.0	9.85	2.0	9.90	1.9
8 500	9.96	2.0	9.92	2.0	9.90	1.9
9 000	10.01	2.0	9.93	2.0	9.92	1.9
9 500	10.05	2.0	9.99	2.0	9.99	1.9
10 000	10.10	2.0	10.03	2.0	10.06	1.9

16063-21: 2003 “Vibration calibration by comparison to a reference transducer” [3].

The CRVs were obtained from the mean of measurements carried out at the beginning, middle and end of the circulation period by NMISA primary vibration calibration system [2].

However the same primary system was used to calibrate the NMISA reference transducers used in the comparison.

We adopt exclusive statistics [4] to show that correlation between the CRV's and the results of NMISA is small as compared to the NMISA uncertainty.

Let X be the exclusive weighted mean of the results of non-correlated laboratories, such that

$$X = \left(\sum_{i=1;i\neq j}^{N} x_i u(x_i)^{-2}\right) / \left(\sum_{i=1;i\neq j}^{N} u(x_i)^{-2}\right), \quad (6)$$

Table 8. Degrees of equivalence participants and the CRVs for sensor Brüel & Kjær 8305 S.

Frequency (Hz)	BKSV		KEBS		NMISA	
	d_i (fC/(m/s²))	$U(d_i)$ (fC/(m/s²))	d_i (fC/(m/s²))	$U(d_i)$ (fC/(m/s²))	d_i (fC/(m/s²))	$U(d_i)$ (fC/(m/s²))
10	0.2	1.1	-0.1	1.1	0.4	1.3
12.5	0.1	1.1	0.1	1.1	0.9	1.3
16	0.1	1.1	0.0	1.1	0.7	1.3
20	0.1	1.1	-0.1	1.1	-0.3	1.3
25	0.1	1.1	-0.1	1.1	0.5	1.3
31.5	0.1	1.1	-0.1	1.1	0.4	1.3
40	0.1	1.1	-0.2	1.1	1.3	1.3
63	0.0	1.2	-0.2	1.2	0.3	1.4
80	0.0	1.2	-0.2	1.2	0.3	1.4
100	0.1	1.2	-0.2	1.2	0.2	1.4
125	0.0	1.2	-0.1	1.2	0.2	1.4
160	0.1	1.0	-0.2	1.2	0.2	1.4
200	0.2	1.2	-0.1	1.2	0.3	1.4
250	0.3	1.2	0.0	1.2	0.2	1.4
315	0.2	1.2	-0.1	1.2	0.1	1.4
400	0.3	1.2	-0.1	1.2	0.1	1.4
500	0.3	1.2	0.0	1.2	0.2	1.4
630	0.3	1.2	-0.1	1.2	0.1	1.4
800	0.3	1.2	-0.1	1.2	0.1	1.4
1 000	0.3	1.2	0.0	1.2	0.0	1.4
1 250	0.1	1.4	-0.1	2.1	0.0	1.9
1 500	0.0	1.4	-0.4	2.1	-0.2	1.9
1 600	0.2	1.4	-0.2	2.1	-0.1	1.9
2 000	0.2	1.4	0.0	2.1	0.0	1.9
2 500	0.1	1.4	-0.2	2.2	0.0	1.9
3 000	0.0	1.4	-0.1	2.2	-0.1	2.0
3 150	0.1	1.4	0.0	2.2	0.0	2.0
3 500	0.1	1.4	0.0	2.2	0.1	2.0
4 000	-0.1	1.5	0.0	2.2	0.1	2.0
4 500	-0.1	1.5	0.5	2.3	0.0	2.1
5 000	-0.3	2.0	0.6	2.6	0.0	3.1
5 500	-0.7	2.0	0.8	3.3	0.9	3.2
6 000	-1.1	2.0	0.7	3.4	0.0	3.2
6 300	-1.4	2.1	1.5	3.4	0.0	3.3
6 500	-1.1	3.4	1.5	3.5	1.6	3.3
7 000	-1.3	3.5	-0.1	3.5	1.1	3.4
7 500	-1.7	3.6	0.9	3.7	1.6	3.5
8 000	-2.4	3.7	**-3.8**	**3.7**	-1.3	3.6
8 500	-2.9	3.9	-0.1	3.9	-1.3	3.7
9 000	-3.5	4.0	-1.4	4.0	-2.3	3.9
9 500	-3.0	4.2	-0.3	4.2	-1.2	4.1
10 000	-3.5	4.3	-0.6	4.4	0.1	4.3

where the *j*th or correlated laboratory (NMISA) is excluded.

Since the exclusive weighted mean X is not correlated with the CRV, $|X - \mathrm{CRV}|$ is a simple quantitative measure of the CRV bias, also inherent in the NMISA reference transducers.

Table 10 shows that the absolute values of $|X - \mathrm{CRV}|$ are small in comparison with the uncertainty of NMISA's comparison results. The value at 8000 Hz for the sensor Brüel & Kjær 8305 being the only exception.

Table 9. Degrees of equivalence participants and the CRVs for sensor PCB 301M15.

Frequency (Hz)	BKSV		KEBS		NMISA	
	d_i (µV/(m/s²))	$U(d_i)$ (µV/(m/s²))	d_i (µV/(m/s²))	$U(d_i)$ (µV/(m/s²))	d_i (µV/(m/s²))	$U(d_i)$ (µV/(m/s²))
10	-30	100	-20	100	-70	110
12.5	-30	100	-10	100	-70	110
16	-20	100	-10	100	-50	110
20	-10	100	0	100	-80	110
25	-20	100	20	100	-70	110
31.5	-10	90	20	100	-70	110
40	-10	90	20	100	-70	110
63	-20	90	20	100	-70	110
80	-20	90	20	100	-70	110
100	10	90	30	100	-60	110
125	0	90	40	100	-60	110
160	10	80	40	100	-70	110
200	0	90	10	100	-70	110
250	-10	90	20	100	-80	110
315	0	90	30	90	-50	110
400	0	90	30	90	-60	110
500	0	90	20	90	-60	110
630	0	90	20	90	-70	110
800	-10	90	10	90	-70	110
1 000	-10	90	20	90	-70	110
1 250	-20	110	10	170	-80	150
1 500	-20	110	0	170	-90	150
1 600	-10	110	0	170	-90	150
2 000	-20	110	20	170	-80	150
2 500	-30	110	10	170	-90	150
3 000	-10	110	-30	170	-80	150
3 150	-10	110	-30	170	-80	150
3 500	-10	110	-40	170	-80	150
4 000	-10	110	-30	170	-70	150
4 500	-10	110	10	170	-70	150
5 000	-10	140	20	190	-50	220
5 500	-30	140	10	230	-60	220
6 000	-30	140	10	230	-50	220
6 300	-30	140	50	230	-10	220
6 500	-40	230	40	230	-20	220
7 000	-50	230	10	230	-50	220
7 500	-80	230	-30	230	-90	220
8 000	-50	230	-130	230	-80	220
8 500	-50	230	-90	230	-110	220
9 000	-30	230	-110	230	-120	220
9 500	-10	230	-70	230	-70	220
10 000	10	230	-60	230	-30	230

9. CONCLUSIONS

The ILC reported here was planned as a single event with a protocol equivalent to AFRIMETS.AUV.V-S3. It was supposed to provide support and validation of participating laboratories' MCs in the field of vibration for magnitude sensitivity of accelerometers.

The frequency range covered the scope currently implemented by the participating laboratories.

The circulation of the artefact went without any complications. The analysis of the CRV values and NMISA submitted data indicated no discernible correlation.

The reported degrees of equivalence support the individual laboratories' MCs.

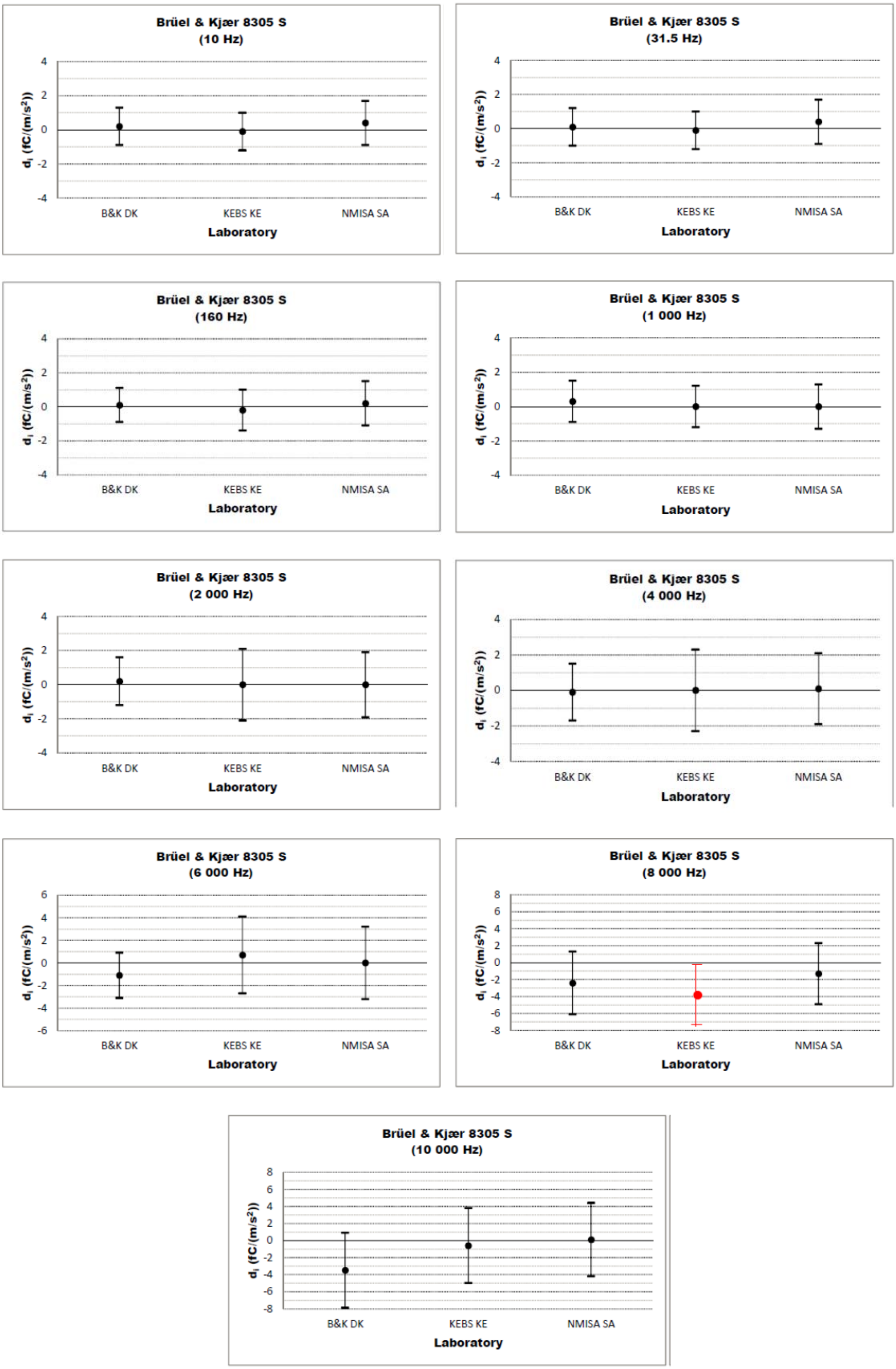

Figure 3. Degrees of equivalence between the participating laboratories and the CRVs for the sensor Brüel & Kjær 8305 in graphical form for select frequencies. Red lines correspond to cases where $|d_i| > U(d_i)$.

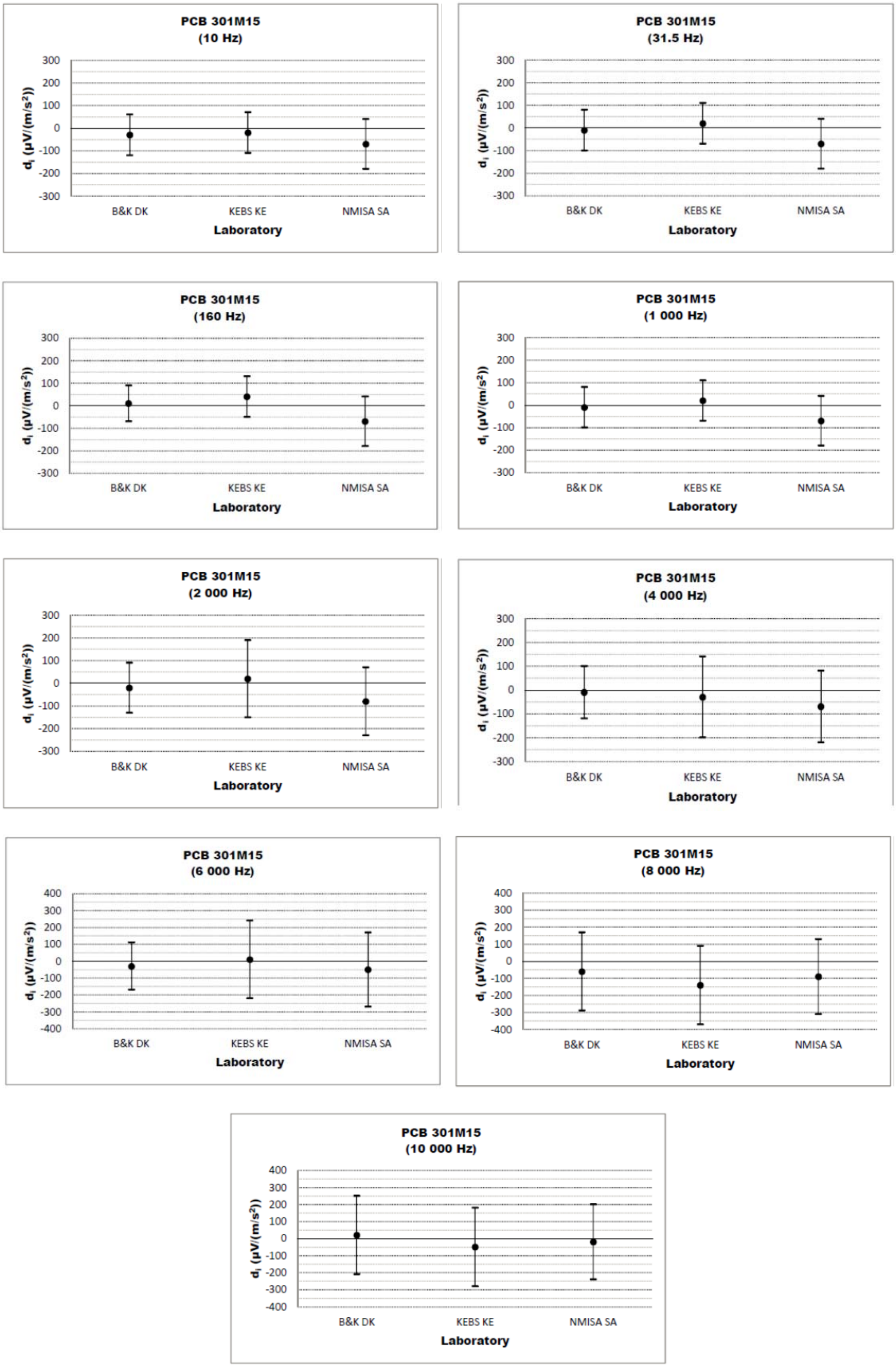

Figure 4. Degrees of equivalence between the participating laboratories and the CRVs for the sensor PCB 301M15 in graphical form for select frequencies.

Table 10. |X - CRV | compared to NMISA comparison uncertainty U_X.

Frequency (Hz)	Brüel & Kjær 8305 S		PCB 301M15	
	|X -CRV| (fC/(m/s²))	U_S (fC/(m/s²))	*|X -CRV|* (µV/(m/s²)))	U_S (µV/(m/s²))
10	0.0	1.2	26	103
12.5	0.1	1.3	21	102
16	0.0	1.3	15	102
20	0.0	1.2	7	102
25	0.0	1.2	1	102
31.5	0.0	1.2	4	102
40	0.1	1.3	4	101
63	0.1	1.2	0	101
80	0.1	1.2	2	101
100	0.1	1.2	18	101
125	0.1	1.2	19	101
160	0.0	1.2	18	100
200	0.0	1.2	4	100
250	0.1	1.2	6	100
315	0.0	1.2	16	100
400	0.1	1.2	16	100
500	0.1	1.2	10	99
630	0.1	1.2	9	99
800	0.1	1.2	0	99
1 000	0.1	1.2	7	99
1 250	0.1	1.6	12	128
1 500	0.1	1.6	13	128
1 600	0.1	1.6	8	128
2 000	0.2	1.6	8	127
2 500	0.0	1.7	21	127
3 000	0.0	1.7	16	127
3 150	0.1	1.7	15	127
3 500	0.1	1.7	14	127
4 000	0.1	1.7	17	127
4 500	0.0	1.7	7	127
5 000	0.1	2.6	2	186
5 500	0.5	2.7	23	186
6 000	0.9	2.7	22	187
6 300	1.0	2.8	21	188
6 500	0.2	2.8	3	188
7 000	0.7	2.9	19	188
7 500	0.4	3.0	54	188
8 000	**3.1**	3.0	92	188
8 500	1.5	3.2	68	188
9 000	2.5	3.3	71	188
9 500	1.7	3.4	41	190
10 000	2.1	3.6	26	191

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