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COMPARATIVE CALIBRATIONS OF MEASURING MICROPHONES PERFORMED IN A FREE FIELD

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Comparison of calibrations of measuring microphones obtained in two laboratories – Laboratory of Physikalisch-Technische Bundesanstalt in Braunschweig (Germany) and Laboratory of Vibroacoustics at the University of Science and Technology in Kraków (Poland) is presented in the paper. However, the performed calibrations were not the official Inter-Laboratory Comparisons (ILC), since those comparisons in the field of *Calibrations of reference microphones in a free field* are still at the preparatory stage.

The paper contains comparisons of the calibration results (together with uncertainty of measurements) obtained in both laboratories for exactly the same devices as well as the traceability of the results. According to the guidelines of the Polish Centre for Accreditation – given in the DA-05 document – the index E_n constitutes the assessment criterion.

The selected problems related to calibrations and influencing their results – are discussed by the authors. They have drawn a special attention to comparisons of the calibration results obtained in various laboratories. Those problems are connected – among others – with the lack of basic data in the Calibration Certificates concerning e.g. traceability of the results, reference microphones, methods of measurements and uncertainty of measurements assessments. The paper contains suggestions concerning further co-operation of laboratories in this field.

Keywords: free-field calibration, microphone frequency responses, Inter-Laboratory Comparisons.

1. Introduction

Economic and trade cooperation in the contemporary world as well as the Agreement signed in 1999, called – in short – MRA[(1)], concerning mutual recognition of

[(1)] MRA: Mutual Recognition Arrangement; *Mutual recognition arrangement of national measurement standards and of calibration and measurement certificates issued by national metrology institutes*, International Committee for Weights and Measures.

measurement standards and Calibration Certificates cause the need of providing reliable and traceable results. Ensuring traceability of measurements is realized by participation in the key international comparisons and in the Inter-Laboratory Comparisons. Those are mutual comparisons of the results obtained for the same units of measure standards in various laboratories. The role of the reference laboratory is played in Poland by the laboratories of the Central Office of Measurements (GUM).

The Laboratory of Vibroacoustics AGH was performing inter-laboratory comparisons with the reference laboratory from the Central Office of Measurements in the field of microphone sensitivity to acoustic pressure by means of the reference microphone and the determination of its response to an electrostatic actuator. The results were also compared with the results of the laboratories of Brüel & Kjær and Norsonic AS Company. The comparison results were very good. The details are published in the paper [1].

Calibrations of microphones in the free field being done in the Laboratory of Vibroacoustics, AGH, are the only ones in Poland. Having no possibility of comparing our results with the reference laboratory GUM, we are using for comparisons the results of calibrations obtained in foreign laboratories.

Among those methods is the standard concerning the basic calibration method in the free field by means of the reciprocity method (PN-EN 61094 – 3). This is a very accurate method, however seldom applied. There are no standards concerning the comparison methods most often used by laboratories performing calibrations in the free field. Therefore generally known theoretical principles of the most often used substitution method are – in practice – realized in various ways depending on the knowledge and invention of researchers. Thus, the differences in the calibration results are to be expected.

2. Comparison of frequency responses

Calibration of microphones, which were previously calibrated in the PTB laboratory were performed in AGH. Two microphones were calibrated: microphone type 40 AE made by the GRAS Company and microphone type 7052H made by the ACO Pacific, Inc.

As the standard reference microphone the microphone of the B&K Company, type 4191, was used. This microphone has the Calibration Certificate from the PTB laboratory and the detailed Calibration Card from the producer. The PTB Certificates do not contain information concerning traceability of the calibration results and the applied reference microphones (basic data required by the Polish Centre for Accreditation (PCA)). The B&K Company declares in the Calibration Card of the microphone 4191 the traceability concerning its response for $f = 250$ Hz obtained from the Danish Primary Laboratory of Acoustics (DPLA) and from the National Institute of Standards and Technology (NIST), USA.

Frequency response in the free field of this microphone taken from the PTB Calibration Certificate and from the B&K Calibration Card is presented in Fig. 1.

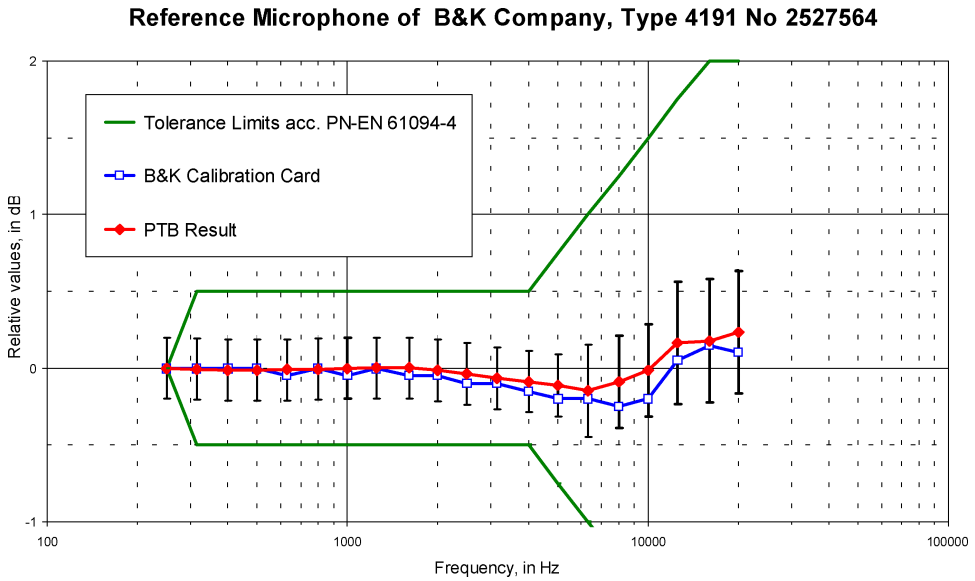

Fig. 1. Frequency responses of the reference microphone, 4191 type, in the free field. Uncertainty of calibration declared by the PTB is marked in the graph.

Theoretical assumptions of acoustic calibrations are quite easy. However, obtaining high accuracy (up to 0.01 dB) in real conditions of the anechoic room are extremely difficult and time consuming [3].

Frequency characteristics are determined – in the AGH laboratory – by the comparison of responses of microphones under testing with responses of the reference microphone of the free field. Both responses are measured in the same measuring system, for the same signal and in exactly the same conditions. The measurement is being done by placing at first the reference microphone in the given measuring point and then substituting it by the microphone under testing. The result is corrected by unevenness of the reference microphone characteristics (Fig. 1). The detailed description of the applied measuring method and the automatic measuring system assisted by the computer software PomAk is given in papers [3, 4].

The data contained in the PTB Calibration Certificates concerning the AGH reference microphone and the microphones under testing were carefully analysed. Both laboratories are applying the same measuring method. It means the comparison substitution method. However, the details of its realization in the PTB are not known to the authors of the hereby paper. The PTB Certificates indicate that measurements are performed at only one distance between the source and the microphone, equal 1 m. The AGH Laboratory performs measurements at three distances: 1 m, 1.5 m, and 1.8 m. Cumulative results of all characteristics of microphones being compared are presented in Figs. 2 and 3.

Figures contain frequency characteristics in relation to the characteristics of the reference standard microphone given by the PTB and B&K (Fig. 1). In the case of micro-

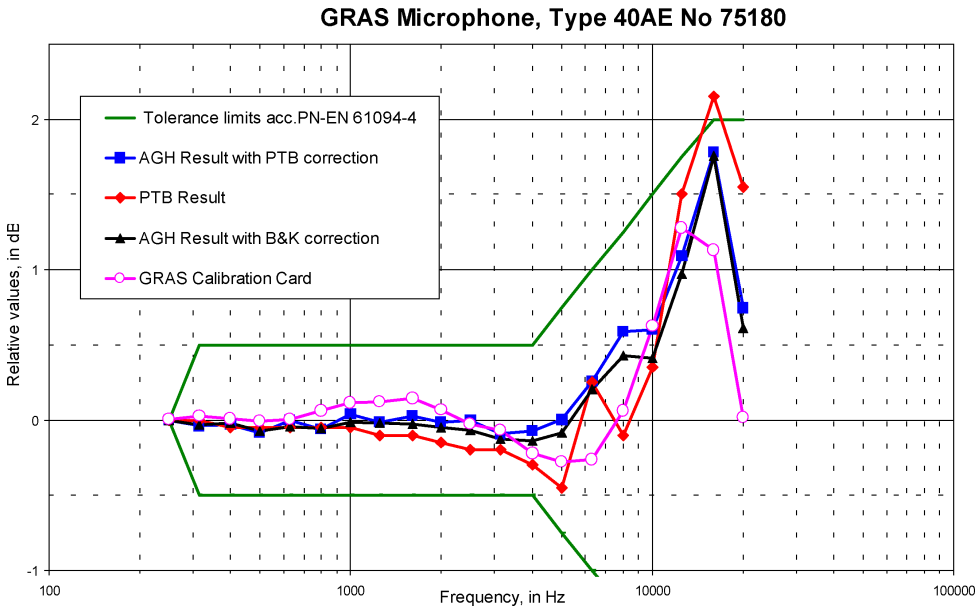

Fig. 2. Frequency characteristics of the microphone 40 AE determined by AGH, PTB, GRAS.

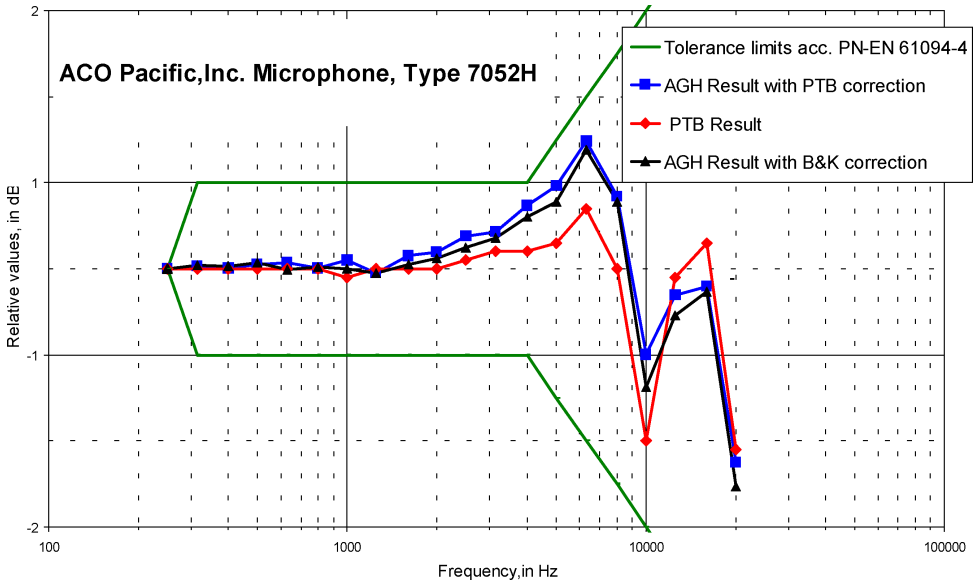

Fig. 3. Frequency characteristics of the microphone 7052H determined by AGH and PTB.

phone 40 AE of the GRAS Company (Fig. 2) the characteristics given in the Calibration Card are also shown. The GRAS Company declares traceability of its results with the National Physical Laboratory (NPL), UK.

3. Determination of traceability – index E_n

Knowing frequency characteristics values as well as uncertainty of measurements at the calibration declared by the laboratories listed in Table 1, it is possible to asses the traceability of laboratories participating in the comparison procedure.

Table 1. Uncertainty of measurements declared by the PTB, NPL and AGH laboratories.

Frequency, Hz	Expanded uncertainty U_{95}		
	PTB	NPL	AGH
Hz	dB	dB	dB
100–5000	≤ 0.2	≤ 0.2	≤ 0.21
6300–1000	≤ 0.3	≤ 0.3	≤ 0.32
12500–20000	≤ 0.4	≤ 0.4	≤ 0.44

The assessment of the measurements traceability was performed according to the guidelines of the PCA (document DA-5 [5]) by calculating the index E_n value from the following formula:

$$E_n = \frac{x_{\mathrm{lab}} - X_{\mathrm{ref}}}{\sqrt{U_{\mathrm{lab}}^2 + U_{\mathrm{ref}}^2}},$$

where x_{lab} – measurement result obtained in the AGH laboratory, X_{ref} – measurement result obtained in the reference laboratory (PTB or NPL), U_{lab} – uncertainty of measurement in the AGH laboratory, U_{ref} – uncertainty of measurement in the reference laboratory (PTB or NPL).

The assessment of the comparison results is considered satisfactory when $|E_n| \leq 1$.

The AGH laboratory was the investigated one – in the performed comparisons, while the PTB and NPL laboratories were considered the reference laboratories.

Calculations of index E_n for the microphone 40 AE were performed on the bases of data contained in the PTB and AGH Certificates and data given in its Calibration Card (reference to the NPL). Calculations for the microphone 7052H of the ACO Company were performed on the bases of data from PTB and AGH only, since its Calibration Card did not contain sufficiently accurate data. The calculation results are shown in Table 2.

When the correction of unevenness of the characteristics of the free field of the reference microphone given in the PTB Certificate was applied the results obtained for index E_n were not satisfactory for some measured frequencies. Measurements done with the microphone 40 AE did not bring positive results for 3 out of 20 measured frequencies (at frequencies: 5, 8 and 20 kHz – Table 2, column 2).

For the microphone 7052H unsatisfactory result was at 5 and 10 kHz (Table 2, column 6). Therefore calculations of the index were performed also for frequency characteristics of the microphone given in the B&K Card (Fig. 1). When these characteristics were applied the results from AGH are fully traceable to the results from PTB and to the

Table 2. Calculation results for index E_n.

Frequency, Hz	Index E_n					
	Microphone 40 AE of the GRAS Company				Microphone 7052H-ACO	
	Reference laboratory – PTB laboratory		Reference laboratory – GRAS Calibration Card → NPL		Reference laboratory – PTB laboratory	
	corr. 4191 PTB	corr.4191 B&K	corr. 4191 PTB pop.	corr. 4191 B&K	corr. 4191 PTB	corr. 4191 B&K
1	2	3	4	5	6	7
250	0.00	0.00	0.00	0.00	0.00	0.00
315	−0.13	−0.11	−0.23	0.02	0.06	0.07
400	0.06	0.10	−0.14	0.04	0.01	0.05
500	−0.11	−0.08	−0.27	0.04	0.08	0.12
630	0.17	0.03	−0.01	−0.14	0.12	−0.02
800	−0.05	−0.03	−0.43	0.02	0.02	0.04
1000	0.30	0.13	−0.27	−0.17	0.35	0.18
1250	0.29	0.28	−0.47	0.00	−0.09	−0.10
1600	0.44	0.26	−0.40	−0.18	0.26	0.09
2000	0.47	0.34	−0.30	−0.12	0.34	0.21
2500	0.68	0.46	0.08	−0.22	0.48	0.26
3150	0.38	0.26	−0.09	−0.12	0.40	0.28
4000	0.78	0.56	0.51	−0.22	0.92	0.70
5000	**1.57**	**1.27**	0.99	−0.30	**1.14**	0.83
6300	0.02	−0.10	**1.18**	−0.12	0.89	0.78
8000	**1.57**	**1.20**	**1.20**	−0.37	0.96	0.59
10000	0.57	0.14	−0.06	−0.43	**1.15**	0.72
12500	−0.69	−0.89	−0.32	−0.20	−0.17	−0.37
16000	−0.62	−0.67	**1.10**	−0.05	−0.43	−0.48
20000	**−1.35**	**−1.57**	**1.23**	−0.23	−0.13	−0.36

results from NPL (data of microphone 40 AE given by the GRAS Company) – Table 2, columns 5 and 7.

4. Analysis of results and assessment of comparisons

As it can be seen from Table 2, the calibration results of AGH laboratory are more traceable to the results issued by the NPL and B&K laboratories than to the results of the renowned PTB laboratory. Better comparison results with the PTB are achieved when data from the B&K Calibration Card of the reference microphone are taken for calculations than when the data from the Calibration Certificate – issued by the PTB

– are used. These results suggest that microphones 40 AE of the GRAS Company and 7052H of ACO Pacific, Inc. were calibrated with reference to the different reference microphone than the microphone 4191 of the B&K Company (applied in our laboratory as the reference microphone).

The measuring technique as well as assessing measurement uncertainties in the free field requires creative invention and experience of researchers – since there are no guidelines concerning calibrations. The basic principles of the comparative calibration method in the free field are generally known, however, details concerning relevant factors such as: measuring distance or distances (between source and microphone), kind of the sound source or the way of microphone fitting are worked out individually by laboratories. Thus, this is the reason of discrepancy between the results.

Definition of microphone sensitivity in the free field concerns an acoustic pressure in the undisturbed field of a plane progressive sound wave. Thus, the distance between the microphone and the source should be long enough to assure conditions of a plane wave field – around the microphone – and to decrease interactions occurring in the acoustic field in between the source and the object being in the place of incidence of the sound wave. On the other hand, when the distance between the source and the microphone increases the influence of reflections from internal surfaces of the anechoic room also increases. Therefore Standards PN-EN 61094-3 [2] and PN-EN 61672-2 [6] recommend performing calibrations at more than one measuring distance. This enables assessment of the component of uncertainty of the calibration related to the actual metrological condition of the anechoic room. The AGH Laboratory follows those recommendations while the PTB Laboratory does not take them into consideration.

The microphone sensitivity in the free field depends also on the geometrical configuration of the housing containing the microphone preamplifier and on the stand, on which it is placed.

Application of several measuring distances will be reflected in the uncertainty (it will increase the scatter of results), while the method of fitting is undistinguished in the uncertainty (it will constitute one of the systematic errors).

5. Conclusions

The performed comparative calibrations were not the official Inter-Laboratory Comparisons (ILC). However, the results obtained by the Laboratory of Vibroacoustics AGH in comparison with the results of the reference PTB Laboratory are not satisfactory for AGH Laboratory.

Comparison of the results indicates an obvious necessity of performing inter-laboratory comparisons in order of obtaining the measurement traceability. Therefore the planned calibrations in the scope of: *Calibrations of reference microphones in a free field* will be so important. They will be carried by CIPM[(2)] [7].

[(2)] CIPM – International Committee of Measures (CIPM — Comité International des Poids et Mesures).

The use of a uniform pattern of Calibration Certificates, especially within the countries being signatory of International Laboratory Accreditation Cooperation (ILAC) MRA, should be recommended. The Certificate should contain information concerning the measurement traceability, applied reference standards, used measuring method, data concerning the measuring equipment.

The performed comparisons have shown that calibrations in the free field require cooperation of the few laboratories doing such tests. It would allow unification of measuring methods (selection of proper sound sources, measurement distances, clamps fitting the equipment) and the ways of uncertainty assessment (clear determination of error sources, which must exist in the uncertainty budget). Such activities have been undertaken in other metrological domains many years ago.

Acknowledgment

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