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# Metrological Capabilities of the Acoustic Testing Laboratory - Small Anechoic Chamber at the AGH Department of Mechanics and Vibroacoustics

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**Abstract** The small anechoic chamber is part of the research facilities of the Department of Mechanics and Vibroacoustics in AGH University of Science and Technology in Krakow and is a room corresponding to a free field, whose walls, ceiling and floor provide both very good sound absorption and isolation from external interference. The dimensions of the free space inside the chamber are 4.4 m x 3.8 m. x 3.6 m. The chamber was commissioned in the mid-1980s and has not undergone upgrades since. In December 2021, the upgrade of the small anechoic chamber was completed. As particularly important was the replacement of 5.5 thousand pieces of acoustic wedges made of polyurethane foam, which due to the aging process lost their sound-absorbing properties, for wedges made of mineral wool with glass fiber, adjustment of lighting inside the chamber to current standards, as well as equipping the chamber with a signal crossover and devices to regulate and monitor meteorological conditions inside the chamber. The paper presents a study of the properties of the small anechoic chamber in accordance with accepted standards for this type of rooms and its current research capabilities in the field of vibroacoustics in technology and medicine.

**Keywords:** anechoic chamber, acoustic testing laboratories, acoustic wedges, acoustics metrology.

## 1. Introduction

One of the basic measurement rooms used in vibroacoustic testing is the anechoic chamber. This is an enclosed room, most often with the volume of a cube or cuboid, inside which conditions similar to those existing in a free sound field are maintained. The sound wave incident on the surface of the inner walls of an anechoic chamber is almost completely attenuated by absorbing elements, with which the walls, ceiling and floor are lined [1]. The first idea of such a solution was presented in 1946 by Beranek and Sleeper [2].

They developed an acoustic chamber in which all the walls of the chamber were lined with wedges to absorb the energy of acoustic waves. This idea is still used today. A certain variation of such a chamber is the acoustic anechoic chamber with a reflective floor (semi anechoic chamber), which allows testing of heavy equipment of the engineering, automotive or aerospace industries. There are several companies in the world that design and build anechoic acoustic chambers, semi anechoic chambers and reverberation chambers. Among them, foreign companies can be mentioned: O'Neill Engineered [3], ETS-Lindgren [4], IAC Acoustics [5], Eckel [6], as well as Polish: Artivent Ltd. [7], ISDM Solutions Ltd., [8], Sonitus Ltd. L. P.[9].

Meeting the sound absorption conditions in full audible frequency band (20 Hz - 20 kHz) is a difficult task and requires the use of special sound absorbing systems, for which the reverberant sound absorption coefficient should be about 0.9÷0.95. The most commonly used sound absorbing systems are acoustic scattering-absorbing wedges made of material with a high reverberant sound absorption coefficient. They provide very good sound attenuation, depending on the material and its geometry, even in the range from 50 Hz (50Hz Metadyne® LF Wedge [5]), due to multiple reflections of the sound wave between individual wedges.

At AGH University of Science and Technology, among other specialized vibroacoustic laboratories, there are two anechoic chambers - a large one and a small one. Both anechoic chambers are part of the research specialized rooms of the Department of Mechanics and Vibroacoustics at AGH and are rooms in which the sound field is close to the free sound field. The walls, ceiling and floor of these rooms provide both very good sound absorption and isolation from external interference. The interior dimensions of the large anechoic chamber are: 9.5 m x 7.2 m x 6.8 m, and the dimensions of the small chamber are: 4.4 m x 3.8 m x 3.6 m. [10]. The large anechoic chamber was put into operation in 1974, and the upgrade was carried out after almost 40 years of use. In January 2014 the commissioning was held of this chamber after an upgrade that lasted several months [11]. In contrast, the small anechoic chamber was put into service in the mid-1980s and has not undergone any modernization since then. In terms of the current modernization of this chamber, of particular importance was the replacement of 5500 acoustic wedges made of polyurethane foam (which, due to the aging process, had lost their sound-absorbing properties), the adaptation of the lighting inside the chamber to current standards, as well as the equipping of the chamber with a signal matrix switcher and equipment allowing the regulation and monitoring of meteorological conditions inside the chamber. Efforts to obtain funding for the chamber's modernization from projects had been underway for several years. Finally, in 2021, the modernization of the chamber was successfully carried out.

The work of the team in charge of the modernization began in March 2021 and included: obtaining funding, developing the technical documentation necessary to carry out the modernization, as well as preparing documents for the tender and supervision at every stage of its implementation, including preparatory work before and during execution, consulting and agreeing on any changes, and acceptance. Carrying out the modernization of the chamber in the time regime until the end of December 2021, under conditions of widespread shortages of construction materials, should be considered a huge success. A general view of the chamber after the upgrade, including the entrance, is shown in Figure 1.

**Figure 1.** General view of the small anechoic chamber, condition after retrofit [7].

## 2. Acoustic wedge selection

Since the main task of an anechoic chamber is to provide free-field conditions, therefore the most significant factor in the design and construction of this type of specialized room is the value of the reverberant sound absorption coefficient of the sound-absorbing system assembly, with which the interior surfaces of the chamber are lined. Achieving free field conditions in the full audible band is very difficult. In practice, the measurement range of the anechoic chamber is set so that within its range the absorption coefficient is equal to or greater than 0.95 [1,10,12].

Commonly used materials as well as possible wedge shapes do not absorb sound waves as well at low frequencies as they do at medium and high frequencies. There is a limiting frequency value for which the absorption coefficient is still equal to the assumed value - 0.95. This frequency is called the cut-off frequency of the anechoic chamber. Acoustic diffusing-absorbing wedges are usually made of glass or rock mineral wool or flexible plastic foam (e.g., polyurethane or similar being the manufacturing company's know-how). There is a wide variety of shapes and dimensions of wedges. The most common is the prismatic shape, widely used because of its good sound dissipation properties and relative ease of manufacture (Figure 2).

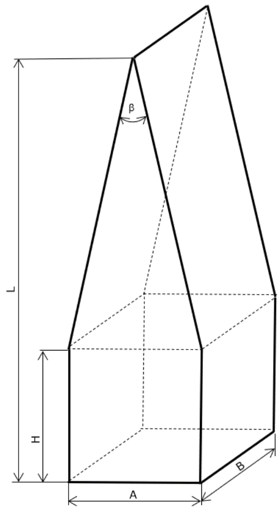


**Figure 2.** Diagram of a prismatic acoustic wedge, where:
*L* - total length, *H* - base height, *A* - base width, *B* - base depth, *β* - apex angle.

The limiting frequency for a prismatic wedge depends on the type of material, the apex angle *β*, the base width A and the overall length L. Knowing the length of the wedge, the required limiting frequency can be determined from an experimental formula [13]:

$$f_g = \frac{86}{L} \text{ [Hz]} \tag{1}$$

or knowing the useful length of the wedge (*l*=*L*-*H*), it is possible to determine the limiting frequency also determined empirically [12]:

$$f_g = 10^{\frac{3.75-l}{1.54}} \text{ [Hz]} \tag{2}$$

Based on the fact that the optimal apex angle for prismatic wedges is in the range of $\beta = 13^{\text{O}} \div 17^{\text{O}}$, wedges with an overall length of *L*=0.8 m and a base height of *H*=0.2 m were adopted in the AGH small anechoic chamber in Krakow. The value of the cut-off frequency of the small anechoic chamber is approximately 108 Hz. If the room was not an anechoic chamber, then to determine the limiting frequency the formula (3) would be use:

$$f_g = \frac{c}{2L} \text{ [Hz]}, \tag{3}$$

where: *c* – sound speed [m/s], *L* - distance between two parallel walls (the largest dimension of the room) [m].

However, in an anechoic chamber there are practically no wave reflections (debatable for low frequencies, below cut-off frequency), so the formula (3) does not apply. The only limitations are precisely those related to the reverberant absorption coefficient of wedges less than 0.95 (for low frequencies). For the internal dimensions of the chamber, and the lack of installed wedges, the limiting frequency would be about 40 Hz.

## 3. Testing of the properties of the small anechoic chamber

### 3.1. Acoustic field distribution testing

An anechoic chamber should ensure in the specified frequency band the existence of a free field in which the value of the sound pressure varies inversely proportional to the distance from the sound source. The sound field in the chamber is considered free if the criteria for test room suitability presented in ISO 3745 standard [14] are met. Appendices A and B of this standard describe the procedures for determining the deviation of the conditions present in the test room from the conditions of an ideal free field or ideal partially free field, and also provide criteria for evaluating the suitability of the test room. To qualify an anechoic chamber, deviations from the law of inverse squares for the sound pressure level measured at successive measurement points to the theoretical sound pressure level are determined. The details of the procedure are described in Annex A.4 of ISO 3745. Finally, based on formula (4):

$$\Delta L_{pi} = L_{pi} - L_p(r_i) \ \text{[dB]}, \tag{4}$$

where: $\Delta L_{pi}$ – deviation from the law of inverse squares [dB], $L_{pi}$ – sound pressure level at the *i*-th measurement point [dB], $L_p(r_i)$ - sound pressure level at distance *r*, estimated from the law of inverse squares [dB], the deviation from the law of inverse squares is calculated and compliance with the maximum permissible deviations given in Table A.2. of ISO 3745 is checked.

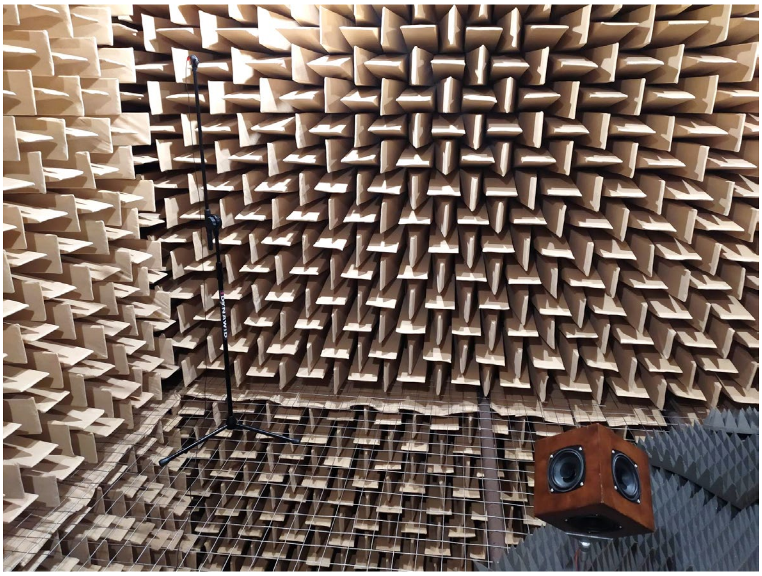

**Figure 3.** View of the hardware implementation of the acoustic field distribution test procedure.

Due to the size of the small anechoic chamber, a reference sound source (omnidirectional sound source, which consists of 6 speakers mounted in a cubic enclosure) was used. This source, shown in Figure 3, was constructed by a team from AGH for testing the isolation of acoustic baffles and enclosures [15] and tested to meet directionality requirements. This source was powered by a Bruel & Kjaer Type 2716C amplifier and SVAN401 signal generator from SVANTEK. Due to the relatively large size of Bruel & Kjaer's OmniPower Sound Source Type 4292, its use in testing was waived in a in a small anechoic chamber. Measurements were made using a ½" G.R.A.S. Type 46AE free field microphone and SVAN958A sound level analyzer from SVANTEK. The tests were carried out at 4 points (1A, 2A, 3A, 4A) 1m away from the reference sound source and at another 4 points (1B, 2B, 3B, 4B) 2m away from the source towards the corners of the anechoic chamber at its top (above the grid). The distribution of the measurement points is shown in Figure 4.

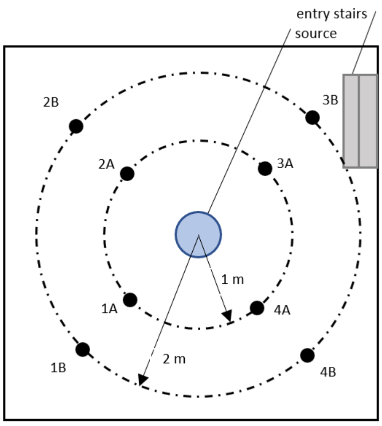


**Figure 4.** Distribution of measurement points.

Measurements were carried out for the direction of incidence of the acoustic wave coinciding with the microphone's principal axis, for an acoustic signal white noise with a sound pressure level (SPL) at the microphone's location at point 1A equal to about 76 dBA. Acoustic field distribution tests were carried out in an anechoic chamber without a reflective surface (floor). The results of comparing the obtained sound pressure level (SPL) drops when doubling the distance from the source with the theoretical values along with the permissible values are shown in Table 1 and Table 2.

**Table 1.** The results of measurements of the distribution of SPL in the 1/3 octave bands of the mid-band frequency range 63÷800 Hz.

| *f* [Hz] | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SPL diff. points 1A-1B [dB] | 2.1 | 5 | 5.9 | 0.6 | 0.3 | 0.8 | 0.5 | 0.2 | 0.2 | 0.1 | 0.2 | 0.1 |
| SPL diff. 5points 2A-2B [dB] | 4.4 | 4.2 | 5.7 | 1.4 | 0.4 | 1.4 | 0.4 | 1.1 | 1.5 | 0.9 | 0.1 | 1.3 |
| SPL diff. points 3A-3B [dB] | 2.6 | 5.5 | 3.8 | 1.1 | 1.1 | 0.2 | 0.6 | 0.7 | 0.2 | 0 | 1.0 | 0.8 |
| SPL diff. points 4A-4B [dB] | 3.5 | 5.7 | 3.3 | 1.5 | 1.4 | 1.4 | 0.2 | 1.5 | 0.7 | 0.5 | 0.1 | 0.9 |
| permissible deviation [dB] | ±1.5 | ±1.5 | ±1.5 | ±1.5 | ±1.5 | ±1.5 | ±1.5 | ±1.5 | ±1.5 | ±1.5 | ±1.5 | ±1.0 |

**Table 2.** The results of measurements of the distribution of SPL in the 1/3 octave bands of the mid-band frequency range 1÷16 kHz.

| *f* [Hz] | 1k | 12.5k | 1.6k | 2k | 3.15k | 4k | 5k | 6.3k | 8k | 10k | 12.5k | 16k |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SPL diff. points 1A-1B [dB] | 0 | 0.1 | 0.1 | 0.9 | 0.9 | 1.0 | 0.8 | 1.3 | 1.4 | 1.4 | 1.5 | 1.5 |
| SPL diff. points 2A-2B [dB] | 0.2 | 0.6 | 0.2 | 0.2 | 0.2 | 1 | 1.0 | 1.4 | 1.4 | 1.4 | 0.7 | 1.5 |
| SPL diff. points 3A-3B [dB] | 0.5 | 0.8 | 1.0 | 0 | 0.6 | 0.8 | 0.6 | 0.3 | 0.4 | 1.5 | 1.4 | 1.5 |
| SPL diff. points 4A-4B [dB] | 0.6 | 0.6 | 0.9 | 0.7 | 0.6 | 0.8 | 0.4 | 0.7 | 1.4 | 0.5 | 1.1 | 1.5 |
| permissible deviation [dB] | ±1.0 | ±1.0 | ±1.0 | ±1.0 | ±1.0 | ±1.0 | ±1.0 | ±1.5 | ±1.5 | ±1.5 | ±1.5 | ±1.5 |

The tests shows that the acoustic field in the small anechoic chamber using an omnidirectional source and white noise meets the requirements for a free field by ISO 3745 above the chamber's cut-off frequency, that is, in the range of 125 Hz to 16k Hz.

### 3.2 Background noise level testing

The testing of background noise level in the small anechoic chamber was carried out synchronously in two measurement paths in which the following apparatus was used:

- Path 1: 1" Bruel & Kjaer type 4145 measurement microphone together with a 2639 Bruel & Kjaer preamplifier and a SVAN912AE sound level analyzer. The microphone had a nominal sensitivity of 50 mV/Pa, a microphone thermal noise of 10 dB(A) and a measurement bandwidth of 3 Hz ÷ 18 kHz.
- Path 2: 1" Type 40 HF low-noise microphone from G.R.A.S, along with a 26HF preamplifier and a 12HF G.R.A.S amplifier, and a Siemens LMS Scadas Mobile measurement system with a VM8E measurement card and Simcenter TestLab Neo software. The microphone had a nominal sensitivity of 1100 mV/Pa, a microphone thermal noise of -2 dBA and a measurement bandwidth of 6 Hz ÷ 12.5 kHz.

A general view of measurement systems – path 1 and path 2 is shown in Figure 5. Both microphones were placed on tripods at a height of 0.5 m above the grid (floor) level of the small anechoic chamber. On the tripod shown on the left in Figure 5, the microphone was mounted together with preamplifier of path 1, while on the tripod on the right, the microphone was mounted together with preamplifier of path 2.

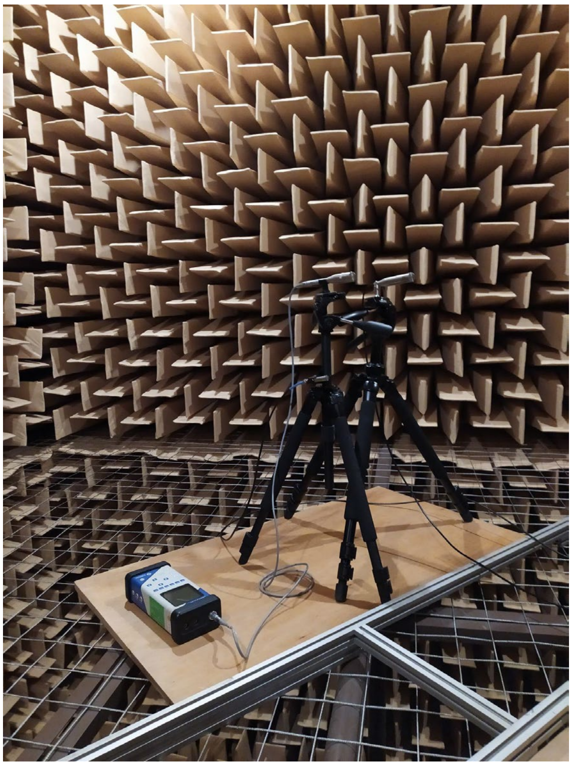

**Figure 5.** View of the measurement systems used to measure background noise levels: Path 1 (left tripod) and Path 2 (right tripod).

The results of measurements of background noise level in the 1/3 octave bands are shown in Figures 6 and 7. The results of the background sound pressure level represent the value averaged over the 1 minute duration of the measurement. Multiple measurements of the chamber's acoustic background made on different days and at different times of the day showed little deviation from the presented values - the change in sound level did not exceed ±1 dBA.

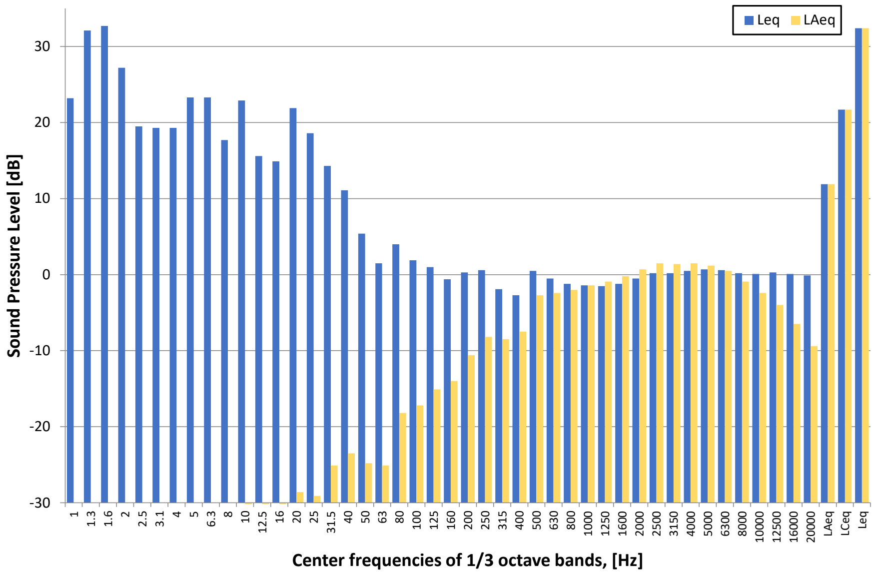


**Figure 6.** Spectrum of the background sound pressure level in a small anechoic chamber - measurement path 1. Sound pressure level in 1/3 octave and total bands with correction A (LAeq), and with correction C (LCeq), and without correction (Leq).

Figure 6 shows the spectrum of the background sound pressure level in the small anechoic chamber measured using measurement path 1 (B&K microphone 4145). Both the frequency-corrected spectrum with A characteristics (yellow) and the spectrum without correction (blue) are shown. The total background sound level LAeq is about 11.5 dBA.
Figure 7 shows the spectrum of the background sound level in the small anechoic chamber measured using measurement path 2 (microphone 40 HF G.R.A.S). Both the spectrum corrected with frequency A characteristics and the spectrum without correction are shown. The total background sound level LAeq is about 8 dBA.

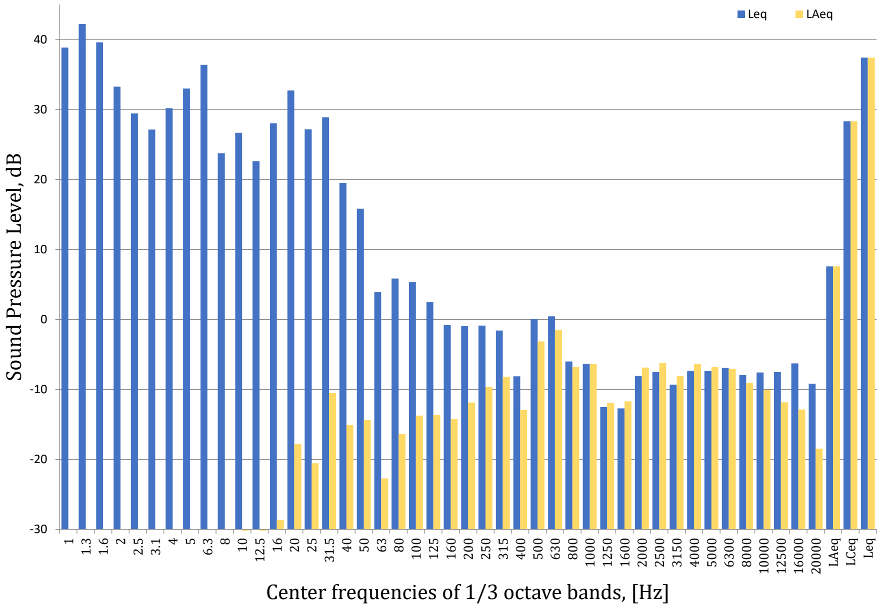


**Figure 7.** Spectrum of the background sound pressure level in a small anechoic chamber - measurement path 2. Sound pressure level in 1/3 octave and total bands with correction A (LAeq) and with correction C (LCeq), and without correction (Leq).

Analyzing the results of the spectra of the background noise level in the small anechoic chamber, it can be seen that the limit frequency of the chamber, calculated from equations (1) and (2), is visible on the spectrum. Namely, the sound pressure level from the frequency of 125 Hz to the frequency of 1 Hz increases linearly. This fact is related not only to the lack of attenuation at a sound absorption coefficient of 0.95 below 108 Hz, but also to the penetration of low-frequency vibrations from the external environment into the chamber. The chamber has been founded on multi-layered resilient elements, i.e. a steel plate is placed between the chamber and the element, followed by layers made of rubber, hardwood, concrete and softwood. The entire chamber is founded on a separate foundation separate from the rest of the building. The foundation system of the chamber has not been upgraded since 1984. Comparing the currently obtained measurement results with those carried out in the 1990s. [10] a reduction in the background sound level of about 6 dBA should be recognized.

## 4. Summary

The first post-retrofit measurements of the background noise level inside the anechoic chamber of the small AGH University of Science and Technology in Cracow indicate that it is about 8 dBA, regardless of the measuring instruments used (a low-noise microphone from G,R,A.S., or a 4145 B&K measurement microphone).

Comparing the currently obtained background measurement results with those also measured with the 4145 B&K measurement microphone included in the 1998 paper [10], an improvement in the background sound level of about 6 dB was obtained, which indicates an improvement in its acoustic properties after the upgrade. Due to the low level of background noise in the chamber, testing of equipment generating low sound levels is possible.

The tests shows that the acoustic field in the small anechoic chamber using an omnidirectional source and white noise meets the requirements for a free field by ISO 3745 above the chamber's cut-off frequency, that is, in the range of 125 Hz to 16k Hz. The modernized anechoic chamber allows scientific research in the field of vibroacoustics in technology and medicine. Among other things, research is conducted using the chamber in cooperation with the Jagiellonian University's Collegium Medium (Institute of Physiotherapy, Department of Otolaryngology) and the Academy of Music in Cracow (Department of Vocal Performance). The chamber is also used for calibration of microphones and sound level meters in the free field. These tests (determination of the frequency characteristics of the effectiveness and directivity of acoustic measurement instruments and their accessories) are performed as part of the type approval of new instruments.

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**Additional information**

The authors declare no competing financial interests.

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