The experience in the developing of reverberation chambers and «Echonic rooms»

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Abstract. This work represents the results of a study of the acoustic characteristics of a room, which is intended (with appropriate additional equipment), according to the project, for the studies of the characteristics of various types of machines of small dimensions. The obtained results show us, that the investigated room, in case the sound-scattering boards with sound-reflecting elements are installed inside, could be attributed to the category of «Echonic» rooms, with the parameters close to reverberation chambers. Therefore, this allow one to carry out practical works to reduce the noise of machines and equipment that do not have high directivity indicators. At the same time, works aimed at reducing the noise of machines in such a «live» room are less laborious compared to similar work in echo-free chambers. Besides, such rooms are less fire hazardous.

In order to meet new and forward-looking noise regulations, breakthrough solutions, which are based on the researches, are needed. It is difficult to implement them without the presence of research laboratories with sufficient material and technical base in order to solve the assigned tasks. Without carrying out test measurements, it is impossible to predict the sound-insulating or sound-absorbing properties of new structures with a high degree of accuracy. It is problematic to study the noise of engines of operating machines, including vehicles, polluting the environment with excessive noise along with air pollution during their operation [1]. Such kind of experiments are more convenient to carry out in echonic rooms or so-called reverberation chambers. The results obtained in the chamber could be used in the design of various objects, in the development and modernization of new acoustic materials and for educational activities [2]. For example, any construction company or manufacturer of high-pitched technical devices could submit a request to test a new project. This capability significantly increases the quality and reliability of acoustic design. Equipped educational centers could act as the research laboratories. That would provide wide access to the results obtained and could make a significant contribution to the development of educational activities [2].

To design successfully a reverberation chamber or to refine a room to the desired characteristics, it is necessary to take into account the experience of early research and development.
In [3], there are described the methods with the help of which it is possible to predict adequately the behaviour of the field in the reverberation chamber, which could help in the design and selection of acoustic modifications of the room. It is well known that the value of the measured output sound power of a source emitting a pure tone could vary with its position both between different chambers and in the same reverberation chamber [4]. Improving the diffuseness of the sound field in the measuring room-chamber is necessary in order to qualify this reverberation chamber as suitable one for measurements [5]. In reverberation chambers with the volume from small to standard (200 m$^3$), the stationary diffusers with convex surfaces, which are strategically placed on walls and ceiling surfaces, are sufficient to create the acoustic diffusion in the room, necessary to achieve low values of standard deviation for both stationary and transient test signals [6].

In many sound absorption laboratories, rotary diffusers are commonly used to increase the diffusion of the test chambers. It is also possible to use volumetric diffusers. The results of their usage give a higher diffusion rate than the usage of panel diffusers [8]. The diffusion efficiency also depends on the location of the diffusers and the material from which they are made. Altogether, these factors affect the required percentage of the room filling with reflectors [9]. It should also be borne in mind that the sound absorption coefficient of the same reflector can vary greatly due to differences in the shape and size of the reverberation chambers [10]. The dependence of the reverberation characteristics on the shape of the room is described in [11]. Let us pay attention to the reverberation time. It could also be increased by equipping the room with many speaker-microphone pairs. Each pair should be tuned to a specific narrow-band frequency range. By increasing the loop gain for a microphone-speaker pair, one could arbitrarily lengthen the reverberation time at this frequency [12]. It should be noted that the best results were obtained in the case when the microphone was located away from the edge of the room, rather than in a corner. Presumably, the microphone in the corner interacts with more modes, than the microphone located elsewhere in the room [7].

Analysis of the data [13] also underlines the fact that tests done in a small reverberation chamber (this type could be attributed to the investigated one) could give results, which are similar to the results obtained in large chambers.

A reverberation chamber could be considered as the opposite one to the anechoic chamber because its boundaries reflect rather than absorb the incident sound energy. The chambers are well-sound and vibration-insulated rooms, in which sound waves are almost completely reverberated from reflective surfaces. Reverb chambers are characterized by the presence of a diffuse sound field in which the density of sound energy at different points in the field and the angular distribution of the sound energy flux at each point are constant. To increase the reflection, the inner surface of the chamber is lined with materials with minimal sound absorption. The diffuseness of the sound field is achieved by the irregular shape of the reverberation chamber, the creation of irregularities on the walls, and also by hanging reflective elements in random order. Sound and vibration isolation should be provided in the reverberation chamber, the microclimate conditions, which include such parameters as temperature, pressure and humidity [14].

Reverberation chambers are designed to determine the sound power of noise sources, losses during the passage of sound through partitions, objectively assessing the effectiveness of the investigated means of noise reduction (for example, noise suppressors), characteristics of microphones and sound absorption coefficients of materials. The chambers are characterized by the reverberation time and the uniformity of the sound field [15].

Initially, the cameras were designed as much asymmetrical as it was possible. The skew of walls and ceilings is necessary to create a high-quality scattered field and reduce the resonant effect of the natural frequencies of the room on the measurement results. Today, fairly good results could be achieved with any room configuration. For this, suspended reflectors, diffusers and moving blades are used, in order to provide an even distribution of sound in the room [16].

The volume of the reverberation chamber should be of such kind that at least six measurement points must be located in the area of the reflected sound field. For measurements, it is necessary to use more accurate measuring instruments and data processing methods than in the case of the interrupted
noise method. Microphones used for measurement must have an omnidirectional reception characteristic. Measurements are carried out with different microphones located at a distance of at least 1.5 m from each other, 2 m from any source of noise, and 1 m from any surface of the chamber and sample. The roll-off curves of the audio signal measured at different points on the microphones may not coincide with each other. Noise in the reverberation chamber should be generated by an omnidirectional sound source. The sound source should be located at different points at a distance of at least 3 m from each other. Reverb chambers with a volume less than that specified in Table 1 or greater than 300 m$^3$ should be verified for suitability for broadband noise measurements [17].

**Table 1.** Minimum chamber volume depending on the geometric mean frequency of the lower one-third octave band of the measurement frequency range.

| Average geometric frequency of the lower 1/3 octave band of the measurement frequency range, Hz | Minimum chamber volume, m$^3$ |
|---|---|
| 100 | 200 |
| 125 | 150 |
| 160 | 100 |
| 200 and over | 70 |

Measurements are made in accordance with GOST R 8.568-97. State System for Ensuring Uniform Measurement. Test equipment certification. Basic provisions.

From Table 1 it follows that the calculations could be carried out starting with a frequency of 160 Hz [18].

![Figure 1](image.png)

**Figure 1.** Linear dimensions of the chamber and positions of the sound source and microphone during research, where $i'$ is the position of the noise source, $i''$ is the position of the microphone in the «closer to the ceiling zone», $i'''$ is the position of the microphone in the «closer to the floor area», shaded area - an approximate area of the diffuse field.

The shape and dimensions of the investigated room are shown in Figure 1. The height of the chamber is $c = 2.9$ m. The volume is $V = 120$ m$^3$.

During the measurements, the reference sound source (Bruel Kjaer Reference Sound Source 4204) was installed at the locations shown in Figure 1 by $i$ positions. The measurements were carried out at the points marked in Figure 1 positions $i'$ and $i''$, at a distance of 1.5 meters from the floor [19] and 1.5
meters from the ceiling, respectively. The measurements were carried out using a LAN-XI vibration and noise analyser Bruel & Kjaer 3050. The environmental conditions shown in Table 2 were measured using the «Testo-622 Combined Instruments».

During the study, the average value of the background noise was measured, the unevenness of the sound field was determined, and the reverberation time was determined. When determining the unevenness of the sound field [20], [21] measurements were made at 10 points in Figure 1 for 5 positions of the sound source. Analysing all 50 series of measurements, the unevenness of the sound field was found for each 1/3 octave band.

When determining the reverberation time, a series of measurements was carried out in 3 measurements in 4 positions (1'2'3'4' in Figure 1) of the source in one position of the receiver 3'. To measure reverberation time, the sound source must be non-directional. Therefore, the explosion of a balloon was analysed as a sound source.

To start the research, the results of monitoring the parameters characterizing the environmental conditions were obtained. They are shown in Table 2.

| Table 2. Results of control of parameters characterizing the conditions of certification. |
|---------------------------------------------------------------|
| **Index** | **Value** | **Measured value** |
|---------------------------------|------------|-------------------|
| Ambient air temperature, °C     | from 10 to 35 | 20.1              |
| Atmosphere relative humidity, % | less 80     | 60.3              |
| Atmospheric pressure, kPa       | from 86 to 104 | 100.0             |

Three sets of measurements were made. The first experiment - measuring the average value of the background noise, the results are shown in Figure 2. The equivalent noise level is 35.3 dBA.

![Figure 2. Measured mean values of background noise.](image)

The second set of measurements - the final results are shown in Figure 3. The unevenness of the sound field is calculated as the difference between the maximum and minimum sound pressure values for each frequency separately based on the results of 50 experiments.
Figure 3. Calculated values of the sound field unevenness in the chamber for each 1/3 octave band.

In all cases, the measured noise levels exceed the background noise level by at least 35 dB, so the measured values are considered satisfactory.

High values of unevenness at frequencies 160, 200, 250, 6300 - 20000 must be reduced. This could be done by installing scattering screens [22], or resonators [23].

Table 3. The results of measuring the reverberation time in the positions of the microphone 1,2,3,4.

| № of measurement | 1  | 2  | 3  | dT average |
|-------------------|----|----|----|------------|
| dT60              | 1.97 | 2.59 | 2.4 | 2.32       |
|                   | 2.04 | 2.28 | 2.24 | 2.19       |
|                   | 2.50 | 2.69 | 2.12 | 2.44       |
|                   | 2.58 | 2.53 | 2.16 | 2.42       |
| dT average general|       |       |     | 2.34       |

Third experiment - From the results of each measurement, the average reverberation time was calculated for each of the 4 experiments, and then the average value among those obtained. As a result, an average value of the reverberation time was obtained equal to 2.34 s, which corresponds to the requirements of the methodology program. The values are shown in Table 3.

As an experiment, the average value of the background noise was measured, the unevenness of the sound field was determined, and the reverberation time was determined. Based on the results obtained, the equivalent noise level in the room is 35.3 dB. Having analysed the values of the sound field unevenness in the chamber for each 1/3 octave band, we see that the deviation does not exceed 3 dB in the frequency range from 315 to 6300 Hz. For other frequencies, it is necessary to reduce the unevenness of sound propagation! The average value of the reverberation time in the chamber was 2.23 seconds. The room chosen in this way meets all requirements, with the exception of the uneven sound field. For this reason, the diffuseness of the room needs to be increased by installing reflectors (diffusers) to eliminate unevenness.

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