UDC 616.164:628.517.2(045)

Yuliya S. Shevchenko, student
Oleksandr M. Beregovoj, Sn. Researcher
Alexei A. Kozlitin, asst.
Oksana Y. Kravchuk, assoc. Prof.

ESTIMATION METHODS FOR ACOUSTIC IMPROVEMENT OF ROOMS USING MEASUREMENTS OF REVERBERATION TIME

Estimation methods for reverberation time as a main approach for evaluation of premise acoustic characteristics has been considered. The veracity of results, obtained in reverberation camera has been proved. Assessment of acoustic characteristics of lecture-hall has been carried out.

Розглянуто методи визначення часу реверберації як основного критерію оцінки акустичних характеристик приміщення. Доведено достовірність результатів, отриманих у ревербераційній камері. Проведено оцінку акустичних характеристик аудиторії.

Introduction

One of the most important factors we should take into consideration speaking about sound travel from sound source to the recipient is room configuration and sizes.

The room geometric characteristics can totally change information we hear. This fact is very often neglected in room designing.

The direct and reflected sound signals should be in balance comply with the minimal room dimension requirements and shouldn't be violated. But at the same time during room projecting, its sizes are chosen according to necessary capacity, in other words the task is solved only from economical point of view, but that is not correct. As a result such problems as disturbance of normal speech intelligibility, echo, and formation of standing waves that distort sound perception appear. Presently it is very important to develop various effective techniques for estimation of acoustic room parameters.

Task formulation

To apply the method of determination of room acoustic characteristics using estimated reverberation time.

To prove that this method is suitable for assessment of rooms of various types and it can be applied to lecture-room.

Analysis of methodologies

There are plenty of various methodologies for evaluation of different acoustic characteristics. Among them are:

– general global approach for predicting speech intelligibility (on the base of room dimensions, total effective surface and absorption coefficient) [1];

– ray-tracing approach for predicting speech intelligibility (considering also directivity of a source; noisiness of audience and absorption coefficient) [2];

– mapping iso-intelligibility contours for tracing areas with poor intelligibility [3];

– multilanguage method of the RASTI evaluation (rapid speech transmission index) − method of estimation of speech intelligibility by investigating speech transmission index in 11 countries and 16 different conditions and fine band analysis [4].

Diffusive field formation

Acoustic oscillations in rooms after multiple reflections of waves from room surfaces create complex sound field.

This acoustic field is determined by sound source characteristics, geometrical sizes and form of the room, sound absorption coefficient of room surfaces.

The main assumption in room acoustics calculation is that diffusive field in the room is isotropic (the directions of sound energy flows have equal probability) and homogeneous (the density of acoustic energy in the field is constant).

These assumptions are valid when there are no focusing elements, geometrically symmetrical limiting surfaces; minimal room size is larger than average wave length.

In this case acoustic waves in the room are considered to be non-coherent (the phenomenon of wave interference is not present), sound field can be represented as set of plane waves characterized by vector and angular variables.

At any point of the room, pressure is defined by the oscillations amplitude. Plane pressure waves are distributed so much at random that the energy density in the room does not depend on point of space and the energy flow is isotropic.

ISSN 1813-1166. NAU Proceedings. 2008. №2

On the base of this assumption we can carry out measuring experiments in some definite control points of the room space and consider them as reference point rather than multiple measuring.

As the sound field in the room is diffusive, a number of modes are excited.

Oscillation modes in the room can be conditionally divided into the following groups: axial (wave vectors $\vec{k}$ are parallel to the coordinate axes – $(k_x,0,0)$, $(k_y,0,0)$,$(k_z,0,0)$), tangential (wave vectors are parallel to coordinate planes – $(k_x,k_y,0)$, $(k_x,0,k_z)$, $(0,k_y,k_z)$) and oblique (none of the components of wave vector equals 0).

Amount of oscillation modes in the rectangular room in the frequency range $f, f+\Delta f$ equals

$$\Delta N = \left(\frac{L}{8c_0} + \frac{\pi S f}{2c_0^2} + \frac{4\pi V f^3}{c_0^2}\right)\Delta f.$$

$L = l_x + l_y + l_z$; $S = 2(l_x l_y + l_x l_z + l_y l_z)$;

$V = l_x l_y l_z$,

where

l_x, l_y, l_z are dimensions of the rectangular room.

This formula shows that in the high frequencies range of acoustic oscillation wave quantity in the definite frequency band is proportional to the square of frequency. The higher the frequency the greater amount of modes is excited and the more diffusive the field is.

There are two types of special rooms for measuring acoustic characteristics of noise sources: reverberation and anechoic room.

Anechoic room is well sound- and vibration-proof room, where acoustic waves are practically completely absorbed by the surfaces. Sound intensity of non-directional acoustic sources in this room decreases inversely proportional to the square of the distance from the recipient to the source. Here absorption coefficient can reach 0.99 at frequencies, higher than 100 Hz.

A reverberation room can be considered an antipodal to an anechoic room, because its surfaces reflect incident sound energy. In this room acoustic waves are fully reflected, creating diffusive field in the room.

In such rooms for covering surfaces the following materials are used: specially processed concrete, steel fences, marble and other building constructions with low sound absorption coefficient.

Reverberation time

The slope of the decay curve (the intensity level is plotted against time when the power is shut off) indicates the degree of fidelity with which the room follows transient fluctuations in speaker output (fig. 1).

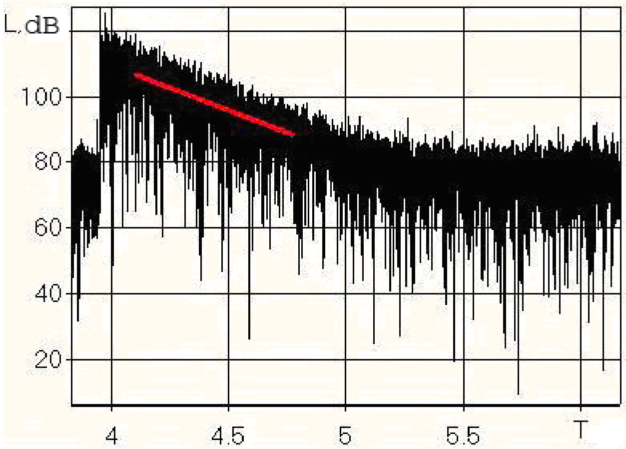


Fig. 1. The decay curve of sound pressure versus time

Reverberation time is the time required for average sound pressure level in a room to decrease 60 dB after a steady state source is shut off.

Analysis of an extremely simplified example of sound in a room indicates the sort of compromise between reinforcement and absorption that must be reached for any kind of room, even if the sound is not uniformly distributed through its extent. The analysis has also indicated that a useful criterion to indicate the degree of uniformity of the sound distribution is the shape of the decay curve for the sound after the source is shut off.

The most satisfactory reverberation time is determined by sound intelligibility for particular purpose, and therefor it depends on room type (for example, classroom, concert hall, studio, office). If reverberation time in the room is long then at speech generation residual sound exceeds direct sound. At low reverberation time information is perceived clearly, but without necessary background.

Optimal values of reverberation time for frequency 500Hz can be determined by the following empirical dependence:

– for speech transmission

$$T_0 = 0.3\lg V - 0.05; \qquad (1)$$

– for symphony music

$$T_0 = 0.5\lg V - 0.3.$$

Reverberation room

The first example of reverberation time measuring is based on the measurements carried out in reverberation room of the National Aviation University.

The room dimensions are: volume – 173.7 m^3; total area of bounding surfaces – 180.6 m^2.

Reverberation time was measured when petard exploded.

On the base of a series of experiments and statistic processing of result the average reverberation time for this room was obtained.

Calculations were held by using Spectran application program and Microsoft Excel. The proximity of result to actual physical values can be proved by confidence interval with 95 % of confidence level. The results of average reverberation time are given in tab. 1.

Table 1

Results of average reverberation time with confidence level in octave frequency band

Frequency, Hz	Average Value, s	Reliable interval, s
63	9,43	1,38
125	7,51	0,50
250	6,97	0,39
500	6,11	0,20
1000	5,33	0,19
2000	4,40	0,18
4000	2,97	0,08
8000	2,10	0,72

Results of calculation of reliable intervals are shown in fig. 2.

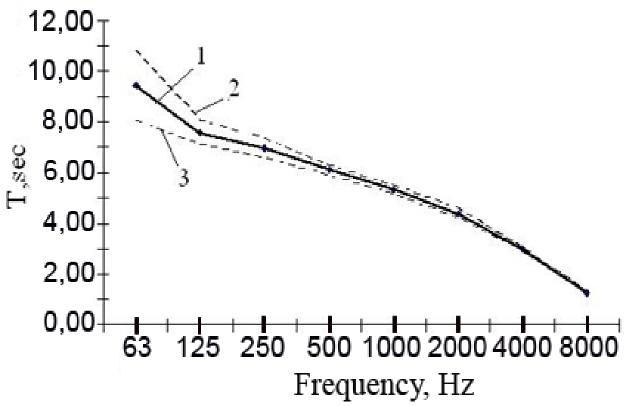


Fig. 2. Confidence level for 95% reliability for reverberation time, measured in reverberation room:
1 – reverberation time;
2, *3* – confidence intervals

Thus the figure shows that the room gives adequate results of reverberation time measuring for frequencies from 125 Hz to 4000 Hz. For frequency 1000 Hz a reliable interval is 0.19 s.

Some problems appear for frequencies lower than 125 Hz when diffusivity of the field is disrupted. This happens because of discrepancy between linear room sizes and generated low-frequency waves. The wavelengths are not always properly correlated with linear room sizes. Discrepancies at high frequencies are explained by waves damping within the room. It causes the same defect of the sound field diffusiveness at high frequencies.

Series of reverberation time measuring and calculation of confidence level, which we were carrying out, proved the effectiveness and accuracy of reverberation room as an instrument of various acoustic parameters estimation at a defined level of validity.

Another example of experiment, carried out in reverberation room was measuring of fan sound power. Experiments were held by two methods: direct and comparative one.

Measuring process technique for both methods and formula for sound power calculations were stated in state standard GOST 12.1.024-81 and GOST 27243-87 [5; 6; 7].

Direct method supposes calculation of sound power on the base of sound pressure level and reverberation time. Thus, sound power level of the fan can be presented as:

$$L_p = \bar{L} - 10\lg T + 10\lg V + 10\lg\left(1 + \frac{\lambda S}{8V}\right) - 14,$$

where

$\bar{L}$ is the average octave sound pressure level;

T is reverberation time, s;

V is the room volume, m^3;

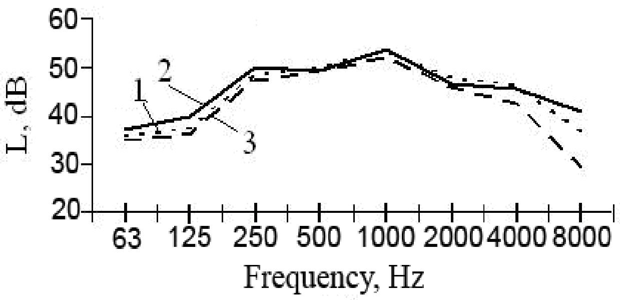
λ is wave length for octave frequencies bands, m.

Comparative method assumes calculation of sound power on the base of known values for exemplary sound source. Sound power level is calculated like this:

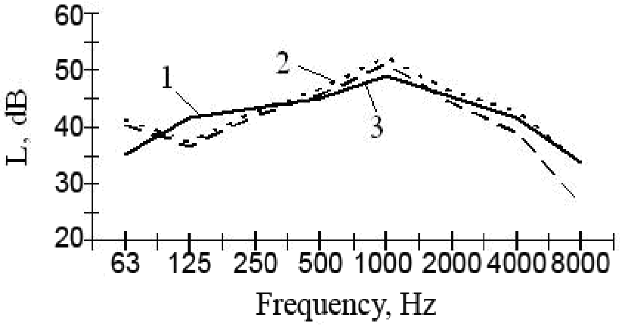
$$L = L_p + I_e - 20\lg R - \Delta L - 11$$

Calculation result of fan sound power in octave frequency band is showed in fig. 3.

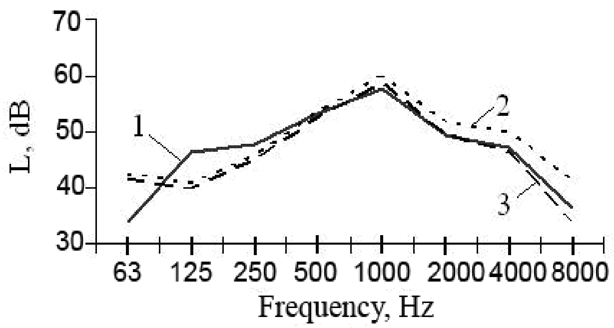
Three lines are depicted in figures: results obtained by comparative method with standard methods of sound pressure level estimation; result obtained by measuring and calculation made in Spectran application program; results obtained from computer sound pressure measuring and results processed with the help of Microsoft Excel program.



a



b



c

Fig. 3. Measurement of sound power level for fans:
a: for ВЕНТС 100ЛДБ, where *1* – Excel evaluation; *2* – Comparative method; *3* – Spectran evaluation;
b: for ВЕНТС 100ДБ, where *1* – Comparative method; *2* – Excel evaluation; *3* – Spectran evaluation;
c: for ВЕНТС 100 LD, where *1* – Comparative method; *2* – Excel evaluation; *3* – Spectran evaluation

We can see that dotted and dashed curves practically everywhere correspond to each other, except at high frequencies. This fact is explained by damping short waves in the air and non-uniformity of sound field diffusivity. In this case we may get some erratic results.

The divergence of the continuous line can be explained by human factor as measurement of sound pressure is a very complicated procedure and may lead to some degree of discrepancy.

But in general such results are acceptable and can be considered accurate as difference of sound power does not exceed 4–5 dB for the highest divergence. Such results show that we can have the same result, applying different methods of measuring and different approaching techniques can be applied in the reverberation room.

The results prove that when reverberation room is properly designed we can receive adequate experimental outcome for different approaches.

Classroom evaluation with the help of reverberation time approach method

Measuring reverberation time is the main parameter for all types of rooms. We propose estimation of reverberation time for room acoustic evaluation.

To show how it can work in everyday condition we carried estimation of usual classroom in building 9 of the National Aviation University. This room is designed to deliver lectures and hold practical classes in it. So, it means that the main task is usual speech transmission.

Given approach presupposes that if reverberation time is higher than optimal calculated for given room volume than the reflected sound waves will overlap direct sound, creating the so-called echo. This would distort normal information perception and sound will not be intelligible. If reverberation time will be lower than optimal than information will lack any background and will be received as short duration signals.

According subjective perception acoustic characteristics of this room are far from perfect. It is very difficult to deliver lectures and hold practical classes in this room. Therefore the estimation of reverberation time was carried out.

Measuring reverberation time was organized with the help of petard explosion. Such method gives a possibility to obtain sound intensity decay, necessary in estimation of reverberation time.

Measuring was carried out by Brul&Kier equipment (the measuring tract).

The Spectran application program was used for time calculation within the octave frequency band.

Typical room size: volume – 135.47 m^3; area of boundary surfaces – 162.63 m^2, including 13.28 m^2 of the window surface.

The obtained results are given in tab. 2.

Table 2

Reverberation time, measured in the classroom

Frequency, Hz	Average reverberation time, s
63	1,98
125	1,28
250	1,23
500	1,29
1000	0,98
2000	0,96
4000	0,89
8000	0,62

General decay of reverberation time with frequency is observed. But at the same time these data have to be evaluated according to some reference value to obtain adequate picture of subjective sound receptivity in this classroom.

Reverberation time was evaluated according to reference point of 500 Hz, using established formula (1) for optimal reverberation times.

The reverberation time at frequency 500 Hz is used to estimate acoustic properties of the room. According to the formula (1) the optimum reverberation time for room volume of which is 135.47 m^3 is 0.59 s. The result for classroom was 1.29 s.

Thus, some amount of echo is created in the classroom. As a result information can not be received effectively and clearly. Besides, such information dissipation may cause general noisiness that leads to nervous system irritation and may cause tiredness and inability for further efficient work.

Thus, the reverberation time itself as a main parameter has already proved the violation of acoustic characteristics of the lecture-room. We can conclude that room construction was made, for roominess, but not to get appropriate acoustic qualities of the room.

Such situation requires some changes for improving improper room design. Some measures could be as follows:

– installation of dissipating components on walls, corners;

– covering surfaces with high absorption coefficient materials to reduce sound reflection;

– installation of some pieces of furniture that will contribute to sound waves dissipation and absorption;

– redecoration of classroom for improving acoustics qualities of the room.

Conclusion

1. Reverberation room can be used as an effective instrument in determination of acoustic characteristics of rooms. It proves the accuracy of results obtained in it.
2. Reverberation time is the main characteristics of acoustic room quality. Estimation of reverberation time and evaluation of it against optimal criteria is one of the methods of assessment of room acoustic qualities.
3. The investigated room was analyzed using the method of reverberation time determination and evaluated against optimal criteria for reverberation time speech transmission. The results showed that investigated classroom acoustic characteristics are unsuitable for normal speech transmission. Some ways of solving this problem were introduced.

References

1. *Steeneken H. J. M., Hougast* T. Some Applications of the Speech Transmission Index (STI) in Auditoria // Acustica. – 1982. – Vol. 51. – P. 229–234.
2. *Van Rietschote H. F., Hougast T.* Predicting Speech Intelligibility in Rooms from the Modulation Transfer Function. V: The Merits of the Ray-tracing Model Versus General Room Acoustics // Acustica. – 1983.– Vol. 53. – P. 72–78.
3. *Hougast T., Steeneken H. J. M.* A Review of the MTF Concept in Room Acoustics and Its Use for Estimation Speech Intelligibility in Auditoria // The Journal of the Acoustical Society of America. – 1985. – Vol. 77. – P. 1069–1077.
4. *Hougast T., Steeneken H. J. M.* A Multi-Language Evaluation of the RASTI-Method for Estimating Intelligibility in Auditoria //Acustica. – Vol. 54. – 1984. – P. 185-199.
5. *Philip M. Mors, Uno Ingard K.* Theoretical Acoustics. McGraw-Hil Inc. – 1968. – 927 p.
6. ГОСТ 12.1.024-81. Шум. Определение шумовых характеристик источников шума в реверберационной и заглушенной камерах. – Введ. 01.07.81.
7. ГОСТ 27243-87. Шум. Ориентировочный метод определения звукового уровня мощности шума машин при помощи образцового источника звука. – Введ. 01.01.88.

The editors received the article on 10 April 2008.