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# A NEW METHOD FOR THE DETERMINATION OF THE BOOMINESS RADIUS

V. Stauskis

## 1. Introduction

A listener in any place of the hall is always reached by the sound energy consisting of three components: direct sound, early reflections, and diffusive sound. Perception of sound by the listener will depend on the spatial and time structure of the hall.

The direct sound is very important for the music perception, because it always reaches the listener first, providing initial information about the musical composition. The early reflections form clarity and spatial qualities of the music sound. The diffusive sound field shapes the reverberation process that characterizes the acoustics of the hall.

The ratio between the direct sound energy and the diffusive sound energy is considered to be one of the guidelines in evaluating the hall acoustics. Approximation to the ideal diffusive field by the real sound fields is evaluated by some authors as the hall's acoustic criterion [1,2]. In these and other works, the notion of the diffusive sound field includes homogeneity, isotropism and the incoherence of the sound waves arriving to the given point of the hall. Shchirzhecki [3] has analyzed the acoustic ratio, or the boominess radius, while investigating the sound field isotropism in five directions and recording only the sound pressure in three octave bands. The measurements according to the directivity chart embraced half of the upper sound field area over the listeners' rows at the point under investigation.

J. Mourjopoulos [4] examined the critical distance, under which the direct sound energy is equal to the diffusive sound energy. The distance was calculated by this author from the formula $cd = 0.057\sqrt{T/V}$. The ratio between the direct sound energy and the reverberant sound energy, on the one hand, and between the early energy and the late energy, on the other hand, were investigated both in an anechoic and reverberant rooms. In this case, the early energy was taken as the energy from 0 to 50 ms, and the late energy as the one from 51 ms to ∞. The results of measurements of the energy change depending on the distance to the sound source are presented in Mourjopoulos' work.

J. Jetz [5] investigated the interdependence of the critical distance and the medium-frequency band.

The critical distance was calculated by T. Gorne et alia [6] from the formula and the limit of the distance was used for the investigations into the sound field structure inside and outside the critical distance, employing various types of microphones.

W. Reichardt [7] proposes a simple formula $r = \sqrt{A/50}$ for the calculation of the boominess radius under the impulse excitation conditions. The formula is based on the sound absorption, i.e. the reverberation time of the hall. Such approach is shared by other authors.

The aim of this work is to demonstrate that the reverberation time cannot be the only criterion characterizing the boominess radius, to define the methods for the determination of the boominess radius, or the critical distance, in real halls, using the integral sound field attenuation curve, and to determine the dependence of the boominess radius on the distance to the sound source.

## 2. The boominess radius criterion

The reverberation time and the volume of the hall appear in the formulas for the calculation of the boominess radius. Such formulas were used by Reichardt [7] to calculate the diagram describing the dependence of the boominess radius on the volume, the reverberation time and the overall sound absorption of the hall. The boominess radius, under which the direct sound energy and the total impulse energy are equal, was used by Reichardt for the calculation of the statistical clarity index for both speech and music as well as the statistical spatial index for music. It was established by calculations that the boominess radius varies from 3 m to 6 m in the halls of most common types. At the same time, a conclusion was made that the distance smaller than this radius was not important for designing because only the first rows of listeners fall within this distance. Reichardt proposes to concentrate on the rows for whom the distance/boominess radius ratio $r/r_m$ is large. Thus, the boominess radius is directly related to the subjective indicators of music perception.

The hall reverberation time calculated from the theoretical formulas is constant for all points of the hall and is independent of the distance to the sound source. It means that the boominess radius, whose calculation in the same hall is based on the reverberation time only, will be a constant value, while the reverberation time calculated on the basis of a nonfiltered signal obtained experimentally will be a variable that depends on the volume of the hall and other acoustic factors. The reverberation time for small volume halls will be slightly different; in large-volume halls, the difference may be greater. Even greater difference in the reverberation time, however, leaves the boominess radius calculated from the theoretical formulas unaffected. These formulas do not assess the direct sound energy and the assessment of the diffusive sound energy, which depends strongly on the distance to the sound source, is not clear. At the same time, the boominess radius established experimentally depends on the distance to the sound source and other factors. Therefore one may assert that the reverberation time cannot be the only criterion based on which the boominess radius is calculated.

### 3. Method

The sound field growth and the sound field attenuation integral curves obtained by the Schroeder method will be used for the determination of the boominess radius. With this method, the integration is performed from 0 to ∞ when measuring the field attenuation, and from 0 to ∞ when measuring the field growth. In this case, any point of the field attenuation curve will characterize the sound field energy at the "t1" moment, with the energy equalling the sum of the reflection energies within the time interval from ∞ to "t1".

The sound field growth curve enables to determine the energy of the direct sound, while the field attenuation curve - the diffusive sound energy. Based on these curves, one may find the moment at which the direct sound energy will be equal to the diffusive sound energy. This moment will be different for various spots of the hall, because the direct sound energy will always decrease along with the increase in the distance between the microphone and the sound source. The direct sound will always be more energetic near the sound source, while the moment at which it equals the diffusive sound energy will occur sooner, this period always becoming longer along with the increase in the distance to the source.

The graph in Fig 1 shows the growth and attenuation of the sound energy. The boominess radius will be established from this graph.

The essence of the method is as follows. The energy of the direct sound is determined from the sound field growth curve. Point 1 is found in the sound field attenuation curve, which characterizes the moment at which the direct sound energy equals the diffusive sound energy. However, it still not is the

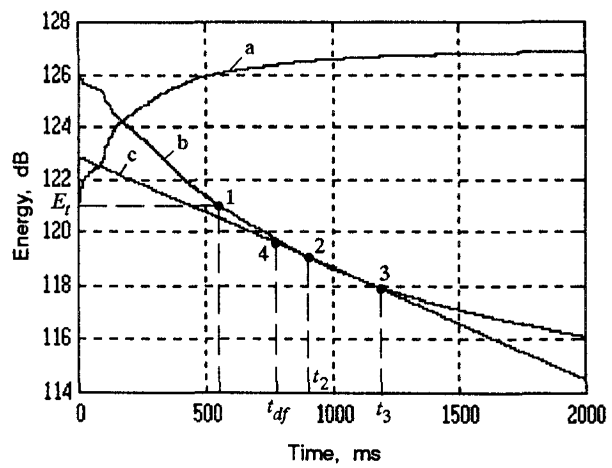


Fig 1. The growth and the attenuation of the sound field energy of a nonfiltered signal in relation to time. a - sound field growth curve; b - sound field attenuation curve; c - straight line approximating the diffusive sound field interval

diffusive sound energy that must be assessed when determining the boominess radius. One must find points 2 and 3 and time values $t_2$ and $t_3$ in the field attenuation curve. It will be assumed that these points describe the beginning and the end of the diffusive sound, i.e. the diffusive sound field interval. This time interval will be approximated along the straight line "c". Point 4 will be found in the sound field attenuation curve, at which it departs from the straight line by 0.1 dB. It is this point that will characterize the diffusive sound field energy at certain moment.

The direct sound energy is in inverse proportion to the distance to the sound source. This may be written as:

$$E_t = \frac{1}{r^2} \quad \text{or} \quad E_t = \frac{A}{r_{mk}}. \tag{1}$$

The diffusive energy to be found may be expressed as follows:

$$E_x = E_{df} = \frac{A}{r_x^2}. \tag{2}$$

The ratio between the direct sound energy and the diffusive sound energy will be expressed in terms of the boominess radius:

$$\frac{E_t}{E_{df}} = \frac{r_x^2}{r_m^2}. \tag{3}$$

It follows that

$$r_x^2 = \frac{E_t}{E_{df}} r_{mk}^2. \tag{4}$$

The difference between the direct sound energy and the diffusive sound energy will be written as

$$E_t - E_{df} = 10 \lg \frac{r_x^2}{r_{mk}^2}. \tag{5}$$

Then

$$\frac{r_x}{r_{mk}} = 10^{\frac{E_t - E_{df}}{20}}. \tag{6}$$

The following formula will be used for the final determination of the boominess radius:

$$r_x = r_{mk} 10^{\frac{E_t - E_{df}}{20}}. \tag{7}$$

The boominess radius calculated by this formula means that the direct sound energy will equal the diffusive sound energy within the area of this radius, provided the sound field structure will remain the same as in the point being measured. This, in its turn, means that the diffusive sound energy varies at the points assessed. Estimation of the diffusive sound field represents the most difficult problem of this method.

## 4. Assessment of the diffusive sound field

When an impulse sound source is used and the boominess radius is to be determined, there arises a difficult task of diffusive sound field assessment. This field becomes settled only after a certain period of time when the sound source ceases operating. Consequently, the diffusive sound field will never occur in the initial stage of attenuation. It will only appear after a period of time, which strongly depends on the acoustic properties of the hall. Therefore the most important thing is to establish the moment of beginning of the diffusive sound field. The direct sound energy and the diffusive sound energy will vary at different spots of the hall. The direct sound will be very strong near the sound source, its energy varying in inverse proportion to the square of the distance. The distance increase will also cause changes in the diffusive sound energy.

The diffusive sound energy may only be assessed on the basis of an integral sound field attenuation curve. Fig 2 shows the attenuation of the sound field within the first 600 ms in a hall of volume 22,700 m³, depending on the distance to the sound source.

The graph shows that there are three field attenuation intervals when the distance to the sound source is 1 m: initial, very fast, determined by the direct sound, with the duration of about 30 ms only; slower, determined by the early reflections, with the duration of 30-110 ms; and relatively slow, determined by the late reflections and starting from 110 ms. As the distance from the sound source increases, the influence of the direct sound over the field attenuation is less marked and similar attenuation is ob-

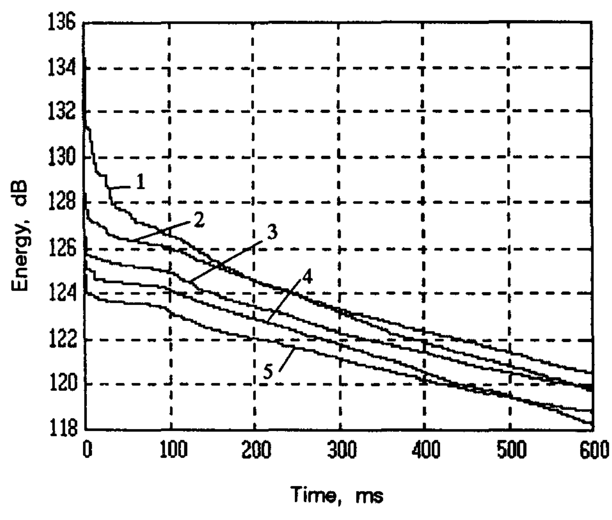


Fig 2. The attenuation of the sound energy in the hall depending on the sound source distance. 1 - 1 m; 2 - 2.5 m; 3 - 5 m; 5 - 10 m

served in the time interval to 100 ms. As the time increases to 600 ms, the character of the field attenuation is almost unchanged despite the microphone's becoming more remote from the sound source. This brings up the question: Whether one may hold that there exists a diffusive sound field in this interval? May be it settles down later? For this purpose, one must know the character of the field attenuation in its late period. The results of the examination are presented in Fig 3.

Entirely different results are obtained in this case. Up to 700 ms, the field attenuation character was almost the same in all instances. However, the sound field attenuation is quite different as the time is longer. Two areas may be recognized here: the first, when the distance to the sound source is from 2.5 m to 7.5 m; the second, when the distance to the sound source is very small (1 m) or very large (10 m and more). The analysis of the first area shows that the field attenuation character is almost unchanged after 1000 ms and the attenuation is very slow. This is determined by the air volume resonances, i.e. the acoustic defects of the hall. Thus, one cannot assert that there exists a diffusive sound field in this time interval.

In the second area, one also sees the same field attenuation character up to 2000 ms, but there appear differences as the time is longer. Thus, the notion of the diffusive sound field may now be applied to the broader interval of time and the field is only slightly dependent on the distance to the sound source. When this distance exceeds 10 m (e.g., 20 or 30 m), the field attenuation approximates the straight line.

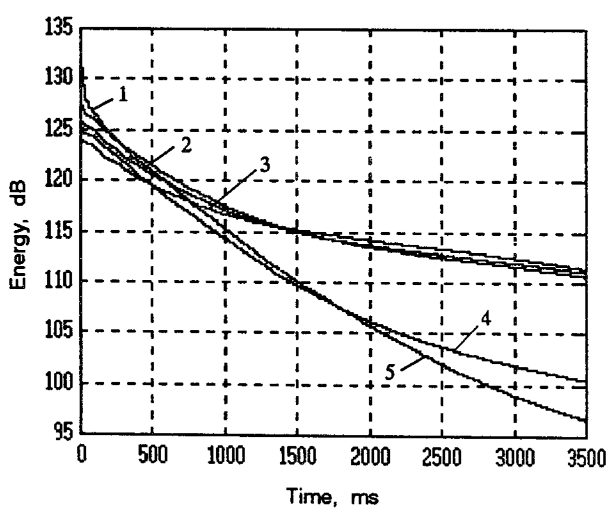


Fig 3. The attenuation of the sound energy in the hall depending on the sound source distance. 1 - 7.5 m; 2 - 5 m; 3 - 2.5 m; 5 - 10 m

The analysis of these results allows to arrive at the conclusion that the diffusive sound field is formed in the time interval from 500 to 1000 ms. The investigations show that this time interval depends on the volume and acoustic properties of the hall.

## 5. Results

### 5.1. Interdependence of the boominess radius and the sound source distance

The investigations of the boominess radius were conducted in the Vilnius Archcathedral. The volume of the cathedral is 22,700 m³, length 57 m, width 24 m, and maximum height 19.8 m. The results of the examination are presented in Fig 4.

The reverberation time for the boominess radius calculated from the formula was taken from the measurement results. The reverberation time changed little with the increase in the sound source distance, therefore in this case the boominess radius is almost independent of the distance to the source, whereas the radius calculated by this method increases with the increase in the source distance, but up to 7.5 m only. Further, the influence of the distance is slight and the boominess radius varies from 6 m to 8 m.

Investigations show that the values of the boominess radius are strongly dependent on the position of point 1 on the sound field attenuation curve, i.e. from the beginning of the diffusive sound field being assessed. When the microphone is at a 1 m distance from the sound source, the start time t1 and the end time $t_2$ may be established for the diffusive sound field, accepting the sound field attenuation from -15 to -20 dB. This corresponds to the time interval from 516 ms to 975 ms. When the distance to the source is increased to 2.5 m., the starting and the ending of the diffusive sound field being assessed corresponds to the sound field at-

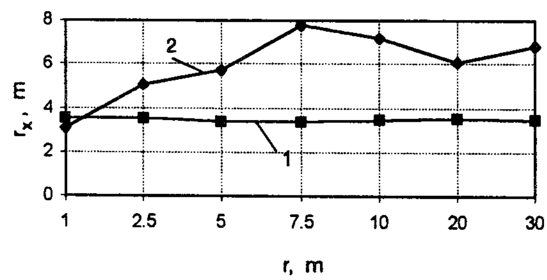


Fig 4. Dependence of the boominess radius on the sound source distance. 1 - calculated from the theoretical formula; 2 - measured with the employment of this method

tenuation from -10 to -13 dB. This makes up the time interval from -10 dB to -13 dB. As the distance is further increased, the diffusive field under investigation may be approximated along the sound field attenuation from -7 dB to -10 dB. This corresponds to the time interval from 500 ms to 1000 ms approximately, confirming the above statements. Investigations show that the starting and ending of the diffusive sound field may acquire other values with the change in the volume and absorption of the hall.

## Conclusions

1. The standard reverberation time and the volume of the hall cannot represent the only criteria determining the boominess radius.

2. When the boominess radius is established from the integral sound field growth and attenuation curve, its values are determined by the time of beginning of the diffusive sound field.

3. The boominess radius is a variable for the same measurement point and it depends on the moment of evaluation of the diffusive sound energy.

4. The boominess radius depends on the distance to the sound source. It increases as the distance is increased to a certain limit, and later no change is observed.

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**NAUJAS AIDUMO RADIUSO NUSTATYMO METODAS**

**V. Stauskis**


S a n t r a u k a

Siūlomas naujas aidumo radiuso nustatymo metodas, naudojant eksperimentu gautas integralines garso lauko augimo ir slopimo kreives.

Aidumo radiusas, arba kritinė distancija, iki šiol buvo skaičiuojamas tik pagal teorinę formulę, kurioje figūruoja tik salės tūris ir reverberacijos laikas. Apskaičiuotas reverberacijos laikas tos pačios salės taškuose visada yra pastovus dydis. Išmatuotas reverberacijos laikas įvairiuose salės taškuose jau yra skirtingas, tačiau rezultatai skiriasi nedaug, todėl ir aidumo radiusas turi būti beveik vienodas įvairiuose salės taškuose. Šiame darbe daroma prielaida, kad reverberacijos laikas negali būti vieninteliu kriterijumi, kuris nusako aidumo radiusą.

Metodo pagrindas yra integralinės garso lauko augimo ir slopimo kreivės, pagal kurias nustatomos tiesioginio garso ir difuzinio garso energijos. Problema yra sužinoti laiką, nuo kurio prasideda difuzinis garso laukas. Tyrimais nustatyta, kad difuzinio garso lauko pradžios laikas labai priklauso nuo atstumo iki garso šaltinio. Arti garso šaltinio difuzinio garso lauko pradžios laikas gali būti taške, prie kurio garso energija nuslopsta 15 dB, o pabaigos laikas - taške, prie kurio energija nuslopsta iki 20 dB. Nustatyta, kad toli nuo garso šaltinio difuzinis garso laukas gali būti įvertinamas parenkant lauko slopimą nuo -7 iki -10 dB. Toks slopimas pagal lygį užima laiko intervalą apytikriai nuo 500 iki 1000 ms. Laikoma, kad tokiame laiko intervale jau nusistovi difuzinis garso laukas. Šis intervalas priklauso nuo salės tūrio ir jos absorbcijos. Žinodami difuzinio garso lauko pradžios ir pabaigos laikus, juos aproksimuojame tiese. Garso lauko slopimo integralinėje kreivėje ieškome taško, prie kurio ši kreivė nuo aproksimuojančios tiesės nukrypsta 0,1 dB. Laikome, kad šis taškas ir charakterizuos difuzinio garso lauko energiją. Tiesioginio garso lauko energiją surandame iš garso lauko augimo integralinės kreivės. Pagal pateiktą formulę apskaičiuotas aidumo radiusas ir jo priklausomybė nuo atstumo iki garso šaltinio.

Tyrimai rodo, kad aidumo radiusas beveik nepriklauso nuo atstumo iki garso šaltinio, jeigu jis apskaičiuotas pagal kitų autorių siūlomą formulę. Iš eksperimento duomenų nustatant aidumo radiusą pagal šį metodą aidumo radiusas turi didesnes absoliučias reikšmes, negu apskaičiuotosios, ir jis pastebimai didėja, didėjant atstumui iki garso šaltinio, tačiau tik iki 7,5 m. Toliau didėjant atstumui iki šaltinio aidumo radiusas kinta nedaug.


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