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ANALYSIS OF THE ACOUSTIC FIELD ENERGY DISTRIBUTION IN A RECTANGULAR HALL FOR MANY SOUND SOURCES*

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This paper presents conclusions regarding the relations of the energy distribution of the field of reflected waves for a simultaneous action of many sources with such parameters as: the dimensions of the hall, the proportion of the dimensions of the floor, and the position of the most powerful sound sources.

1. Introduction

The difficulty in analyzing the acoustic field in enclosures by the wave method and the insufficient results of analysis by the statistical method have caused scientists to seek simpler and more accurate methods. Recent years have brought development of the numerical approach in the geometrical methods: "the ray tracing method" [1, 2] and "the image source method" [3, 4, 7]. Papers [5, 6, 8] presented a geometrical–numerical method of investigation of the acoustic field energy distribution in a rectangular room. This method uses an array of image sources determined by a computer. The powers of the image sources are relatively lower than the power of a real source, depending on the value of the absorption coefficient of the walls and on the distance from the observation points. In addition to simplifying assumptions related to the present implementation of the geometrical–numerical method [8], in analyzing the field with many sources acting simultaneously it was assumed that the energies of waves from all the sources sum up at the observation point. The programme is so designed that the energy of the direct waves, the reflected waves as well as the total energy are calculated for each sound source and each observation point. The algorithm does not impose any restrictions on the order of reflection. In practice, some restrictions are necessary due to time limit and calculation cost.

The input data are: the dimensions of the hall, the absorption coefficients of the walls, the number of sources, the number of observation points, the power

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of the sources and the energy attenuation constant in the air. The results are obtained in the form of two tables: the sound pressure levels of direct and reflected waves from individual sources at successive observation points and the sound pressure levels of direct, reflected and resultant waves from all the sources at the successive observation points.

The present algorithm can be used in twofold manner. First of all, it can be used for analysis of the energy distribution in a hall, i.e. for seeking some general regularities of the acoustic field for variations in particular parameters. Another possibility is making computations for specific real cases, for example, seeking the most efficient means of noise reduction in a given area or point. The same computations can be made for the design of industrial halls, provided that it is defined what acoustic conditions are the most desired from the point of view of noise control. If one is interested in the acoustic conditions in the entire hall rather than at a specific "work post", for a uniform distribution of sources, the calculations can be limited to include the field of reflected waves only. The field of direct waves is related only to the distance of sources from observation points, i.e. it does not depend on regularities which result from variations of the other parameters of the system. Obviously, the energy of the resultant field as a sum of the direct field energy and of the energy of reflected waves will vary in a slightly different manner than the energy of reflected waves. However, it seems that this difference is not significant in the investigations of the general regularities of the sound field.

2. Discussion of the results

In the investigation of the dependence of the energy distribution on the acoustic system parameters it is possible to seek regularities but it is difficult to compare individual cases, since (apart from the criterion of minimum energy level) no good comparative criteria exist.

The effect of the following parameters on the energy distribution was analyzed: the size of the hall, the proportions of the floor dimensions (for approximately the same floor area) and the position of the most powerful sources for a constant density of sources, i.e. a constant floor area per one sound source (i.e. a machine) and a constant hall height $h = 7.8$ m. The dimensions of halls, the values of absorption coefficients of walls and also other data are close to the real values, e.g. sources and observation points are at a height of 1.5 m above the floor.

2.1. *The effect of the hall size*

Fig. 1 shows the arrangement of sources of equal power ($L_N = 101$ dB) and observation points in one of the examples for which the computations were made. The other two examples involve computations in halls with a floor

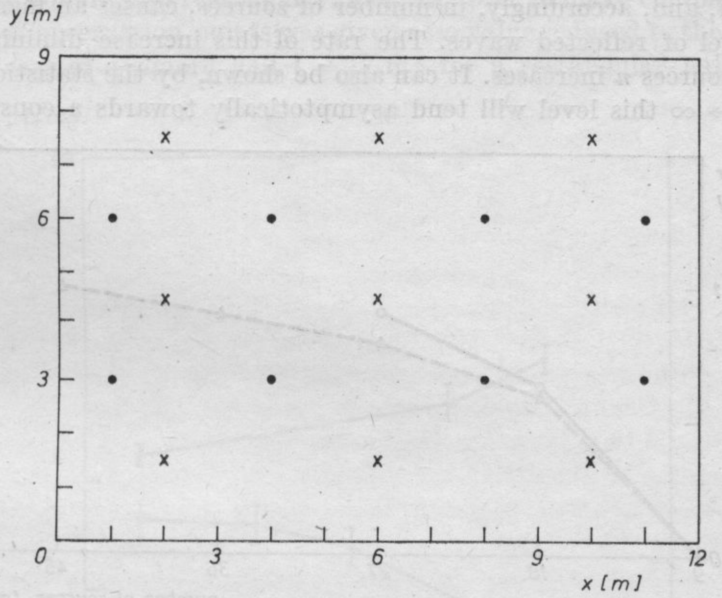

Fig. 1. The projection of the floor of the hall with dimensions 9 × 12 m with plotted positions of sources (x) and observation points (●); the height of the hall $h = 7.8$ m

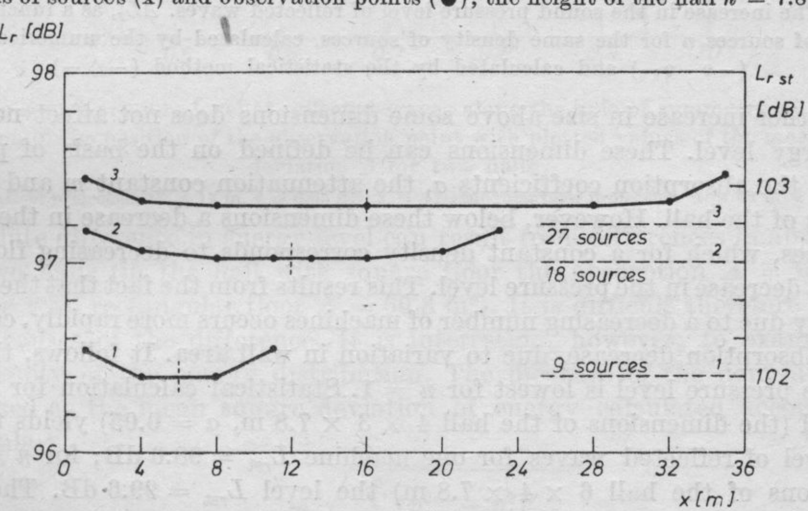

Fig. 2. The sound pressure level of reflected waves along the x axis as a function of the distance of the observation point from the wall, $x = 0$

1 – a hall with dimensions 9 × 12 × 7.8 m, *2* – a hall with dimensions 9 × 36 × 7.8 m; on the left calculation results by the numerical method, on the right those by the statistical method, the density of sources $G = 12$ m²/machine

area twice as large and three times as large, respectively, but with the same density of identical sources ($G = 12$ m²/machine). Fig. 2 shows the results of numerical calculations and those of statistical calculations. For a constant density of sources and a constant hall height an increase in hall size, i.e. also in floor area, and, accordingly, in number of sources, causes an increase in the pressure level of reflected waves. The rate of this increase diminishes as the number of sources n increases. It can also be shown, by the statistical method, that for $n \to \infty$ this level will tend asymptotically towards a constant value.

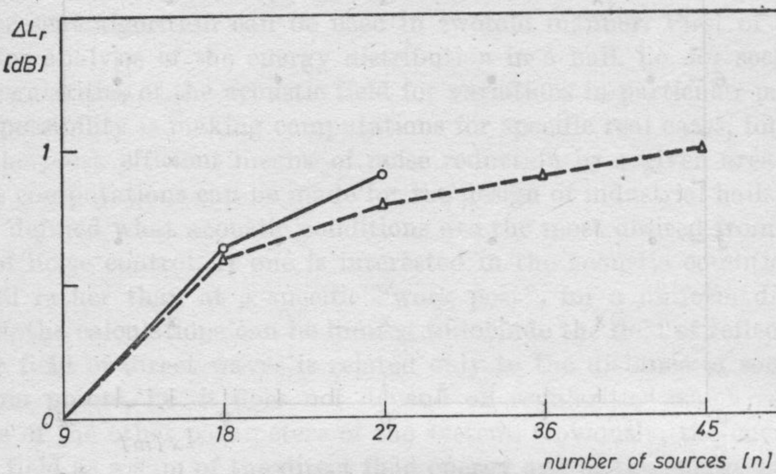

Fig. 3. The increase in the sound pressure level of reflected waves. ΔL_r, as a function of the number of sources n for the same density of sources, calculated by the numerical method (–o–o–) and calculated by the statistical method (–△–)

Any further increase in size above some dimensions does not affect noticeably the energy level. These dimensions can be defined on the basis of power of sources, the absorption coefficients a, the attenuation constant m and the proportions of the hall. However, below these dimensions a decrease in the number of sources, which for a constant density corresponds to decreasing floor area, causes a decrease in the pressure level. This results from the fact that the increase in energy due to a decreasing number of machines occurs more rapidly, compared to the absorption decrease, due to variation in wall area. It follows, therefore, that the pressure level is lowest for $n = 1$. Statistical calculation for the data assumed (the dimensions of the hall $4 \times 3 \times 7.8$ m, $a = 0.05$) yields the pressure level of reflected waves for one machine $L_{rst} = 98.6$ dB; for $n = 2$ (the dimensions of the hall $6 \times 4 \times 7.8$ m) the level $L_{rst} = 99.6$ dB. The results for larger n are given in Fig. 2.

2.2 *The effect of the proportion of dimensions of the floor*

The following quantities are invariable in the computations: the density of sources of equal power ($L_N = 101$ dB), the floor area (the number of sources), the absorption coefficients $a = 0.05$ and the energy attenuation constant in the air $m = 0.004$. The proportions of the dimensions of the floor varied, however, from 1:1 to 1:2 to 1:3.6. In view of slight differences in the energy distribution between the first and second cases, only the first and third cases were considered, i.e. halls with square and rectangular floor. In order to make comparison easier the position of observation points was given as a value reduced to the hall length x/l; in the case of a square hall $l = 17$ m; for a rectangular hall $l = 32$ m.

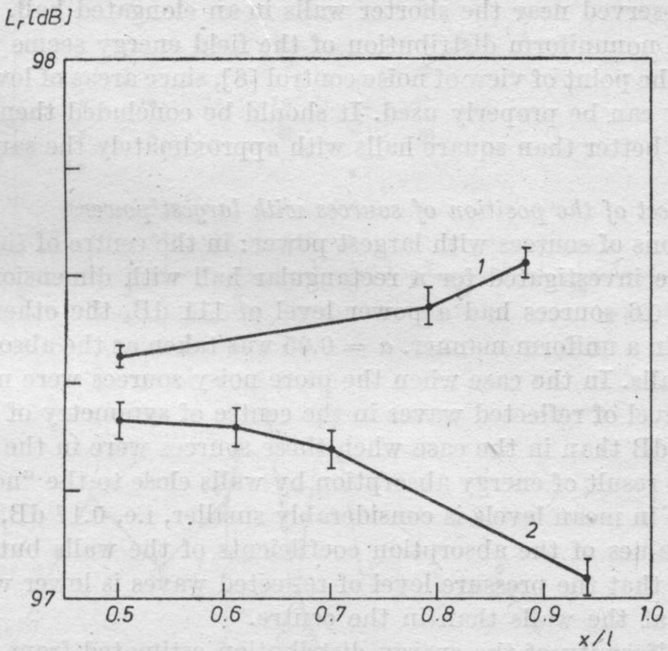

Fig. 4. The sound pressure level of reflected waves along the axis of symmetry of the floor as a function of the position of the observation point with plotted values of the mean square deviation δ for two halls

1 – a square floor projection 17 × 17 m, $\delta = 0.05$ dB; *2* – a rectangular floor projection 9 × 32 m, $\delta = 0.07$ dB

The absolute difference in energy level can result from differences in absorption in the two halls (in the hall with square floor the absorption $A = 55.4$ m²), in the one with rectangular floor $A = 60.8$ m²). It is difficult therefore to analyze the causes of the difference. It is interesting, however, to examine the nonuniformity of the energy distribution. The measure of the nonuniformity was defined as the mean square deviation of energy calculated according to the formula

$$\delta = \sqrt{\frac{\sum_{i=1}^{n}(p_{\text{av}}^2 - p_i^2)^2}{n}},$$

where p_{av}^2 – the value of mean square sound pressure for all points, p_i^2 – the value of mean square sound pressure at the ith observation point, n – the number of observation points.

The deviation is 0.5 % for a hall with square floor, 0.8 % for a rectangular hall with the constant coefficient $a = 0.05$ for all walls and 0.86 % and 1.12 %, respectively, for the absorption coefficient of the ceiling $a = 0.8$ and $a = 0.05$

for the walls. Therefore, the nonuniformity of energy distribution is smaller in a square hall than in a rectangular one and obviously increases for different absorption coefficients of the surface area. A noticeable decrease in the energy level can be observed near the shorter walls in an elongated hall. For constant energy a more nonuniform distribution of the field energy seems to be advantageous from the point of view of noise control [8], since areas of lower or greater energy density can be properly used. It should be concluded then that rectangular halls are better than square halls with approximately the same floor area.

2.3 *The effect of the position of sources with largest power*

Two positions of sources with largest power: in the centre of the hall and at the walls, were investigated for a rectangular hall with dimensions $9 \times 18 \times \times 7.8$ m. 4 of 16 sources had a power level of 111 dB, the other had 96 dB, all positioned in a uniform manner. $\alpha = 0.05$ was taken as the absorption coefficient of the walls. In the case when the more noisy sources were near the walls the pressure level of reflected waves in the centre of symmetry of the floor was lower by 1.52 dB than in the case when these sources were in the centre of the floor. This is a result of energy absorption by walls close to the "noisy" sources. The difference in mean levels is considerably smaller, i.e. 0.17 dB, which is due to very low values of the absorption coefficients of the walls but still permits the statement that the pressure level of reflected waves is lower when the loud machines are at the walls than in the centre.

The nonuniformity of the energy distribution estimated from values of the mean square deviation of energy is greater when more powerful machines are in the centre of the hall. The mean square deviations are respectively 7.1 and 6.6%. However, in the case when the ceiling is covered with a highly absorbent material ($\alpha = 0.8$) a greater nonuniformity occurs when the "noisy" sources are near the walls (the mean square deviations being 4.6 and 4.4%, respectively). For different absorption coefficients of the walls the energy distribution due to the arrangement of sources of different power varies essentially due to the arrangement of sound absorbing materials (Fig. 5b, c).

Increased value of the absorption coefficient of the walls at which the "louder" sources are placed considerably decreases the pressure level of reflected waves [8]. This may lead to another conclusion that in the case when materials of different values of the absorption coefficient of the walls are used it is better to set the "loud" machines at the walls rather than in the centre of the hall because of a lower noise level and greater nonuniformity of the energy distribution. However, for low values of the absorption coefficient of the walls the criterion of the nonuniformity of the energy distribution seems more essential, and it follows, therefore, that it is better to set the more powerful machines in the centre of the hall. Some discrepancy in estimations suggests that computations should be made for specific cases and that machines should be set according to the results of these computations.

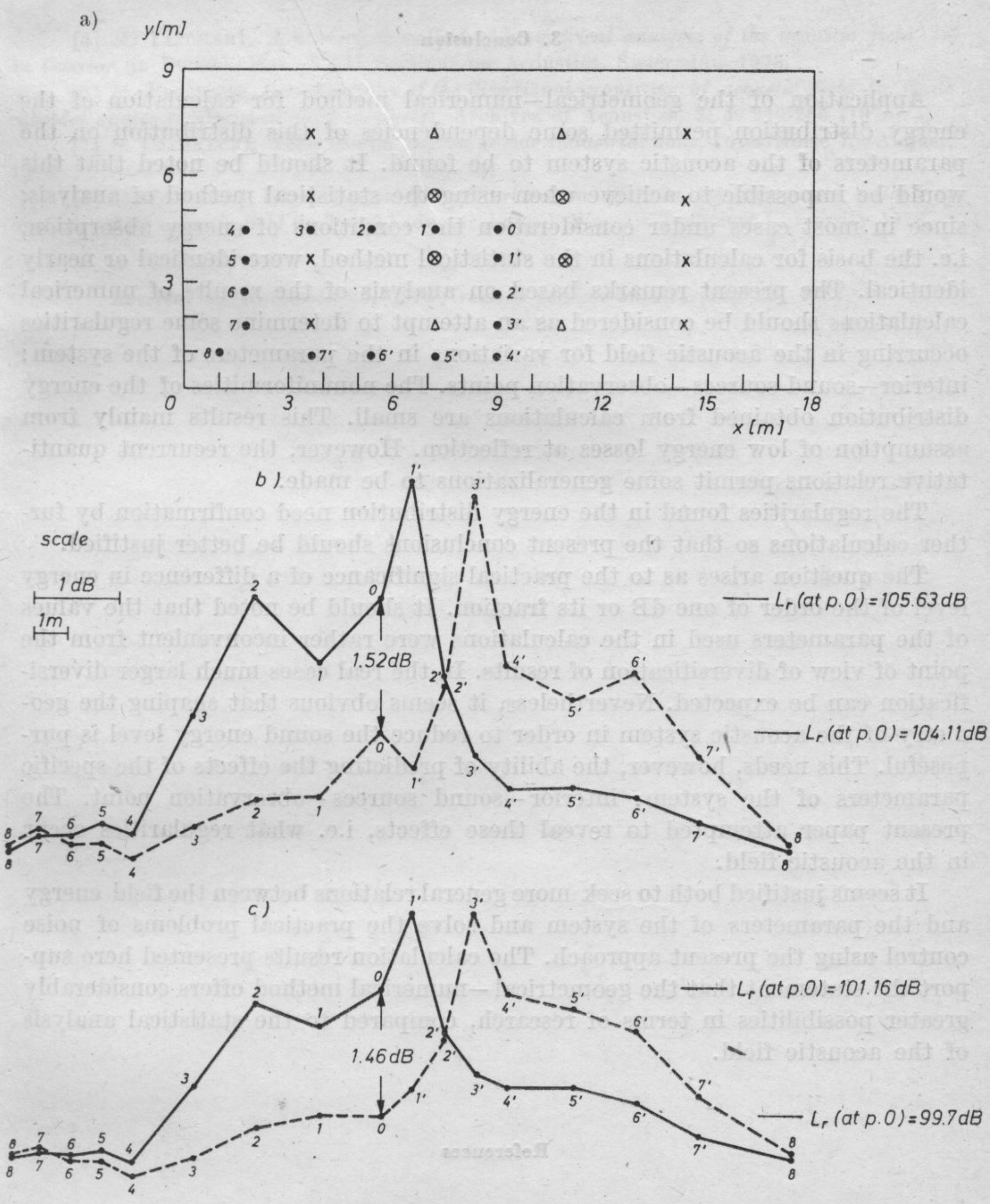

Fig. 5. a) A floor projection with plotted positions of sources of different power levels of 111 dB (△), 108 dB(⊗) and 96 dB (x) and positions of observation points (●); b) The sound pressure level of reflected waves in successive observation points (numbered as in Fig. 5a) as a function of the distance along the x axis or y axis for the same value of the absorption coefficient $a = 0.05$; —— "noisy" sources in the middle, — — — — "noisy" sources near the walls; c) as in b) but for different values of the absorption coefficient; $a = 0.08$ for the ceiling and $a = 0.05$ for the walls

3. Conclusion

Application of the geometrical–numerical method for calculation of the energy distribution permitted some dependencies of this distribution on the parameters of the acoustic system to be found. It should be noted that this would be impossible to achieve when using the statistical method of analysis, since in most cases under consideration the conditions of energy absorption, i.e. the basis for calculations in the statistical method, were identical or nearly identical. The present remarks based on analysis of the results of numerical calculations should be considered as an attempt to determine some regularities occurring in the acoustic field for variations in the parameters of the system: interior–sound sources–observation points. The nonuniformities of the energy distribution obtained from calculations are small. This results mainly from assumption of low energy losses at reflection. However, the recurrent quantitative relations permit some generalizations to be made.

The regularities found in the energy distribution need confirmation by further calculations so that the present conclusions should be better justified.

The question arises as to the practical significance of a difference in energy level of the order of one dB or its fraction. It should be noted that the values of the parameters used in the calculations were rather inconvenient from the point of view of diversification of results. In the real cases much larger diversification can be expected. Nevertheless, it seems obvious that shaping the geometry of the acoustic system in order to reduce the sound energy level is purposeful. This needs, however, the ability of predicting the effects of the specific parameters of the system: interior–sound sources–observation point. The present paper attempted to reveal these effects, i.e. what regularities occur in the acoustic field.

It seems justified both to seek more general relations between the field energy and the parameters of the system and solve the practical problems of noise control using the present approach. The calculation results presented here support the statement that the geometrical–numerical method offers considerably greater possibilities in terms of research, compared to the statistical analysis of the acoustic field.

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