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DIFFRACTION CORRECTION OF FREQUENCY RESPONSE FOR LOUDSPEAKER IN RECTANGULAR BAFFLE

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The problem of diffraction correction of frequency response of loudspeaker in finite baffle was considered by H. OLSON [2] in thirties of XX century. He found experimentally the frequency responses of corrections caused by interference of direct and diffracted waves. He predicted necessity of eccentric placing of loudspeaker in the baffle in order to avoid a deep dip in frequency response for frequency higher as twice as for lower limiting frequency of the baffle. However, the problem was never solved theoretically except the simplified case of loudspeaker centrally placed in circular baffle. In the paper a theory of diffraction on the baffle edge of the wave radiated by a point source eccentrically placed in the rectangular baffle is presented. The results of calculations of the diffraction corrections for various configurations of the source and the baffle are presented as well. The statistical dependence between irregularity of the frequency response of the diffraction correction above the lower limiting frequency of the baffle and standard deviation of the diffraction path is shown. The conclusions can be useful for design process of the baffles.

Key words: rectangular baffle, frequency response of loudspeaker, diffraction correction.

1. Introduction

The simplest way for practical realization of idealized model of loudspeaker in infinite baffle is application of the baffle of finite size. If the baffle is sufficiently large, the waves radiated by the rear side of loudspeaker diaphragm, which are in antiphase with respect to waves radiated by the front side of diaphragm, diffract around the edge of the baffle and interfere below the frequency range of loudspeaker. When the way of diffraction is equal to half of wavelength, the waves radiated by the rear and front sides of the diaphragm interfere in phase and the pressure of resultant wave increases. The frequency corresponding with this wavelength is the lower limiting frequency of the baffle. Below this frequency the frequency response of loudspeaker in the finite baffle decreases, independent on the loudspeaker quality. Then, it is senseless to use the better loudspeaker than resulting from the lower limiting frequency of the baffle. For a given loudspeaker it is possible to calculate necessary dimensions of the baffle in order to avoid worsening of the properties of the entire device.

2. Modelling

The loudspeaker is considered as two point sources radiating with opposite phases in both sides of the infinitely thin baffle. The simplest model is circular baffle of radius a with the loudspeaker in the centre. The resultant acoustic pressure will be calculated in the far field $r \gg a$. The wave radiated by the rear side of the diaphragm diffract around the baffle and interferes with the wave radiated by the front side. The difference of ways of both waves is equal to a. The pressure at the observation point is given by the following equation:

$$p_w = p_{\text{direct}} + p_{\text{diffracted}} = \frac{Q}{4\pi r} e^{-jkr} - \frac{Q}{4\pi r} e^{-jk(r+a)} = \frac{Q}{4\pi r} e^{-jkr} \left(1 - e^{-jka}\right), \tag{1}$$

where Q – strength of the source, k – wavenumber. Its amplitude is equal to [3]:

$$p_{wm} = |p_w| = \frac{Q}{2\pi r} \left| \sin \frac{ka}{2} \right|. \tag{2}$$

The level of this pressure ΔL_p, in decibels, as the function of dimensionless parameter ka is presented in Fig. 2. This level is equal to a correction which should be added to the frequency response of the loudspeaker in infinite baffle. The lower limiting frequency of the baffle, corresponding the difference of the ways of both waves equal to the half of wavelength $(a = \lambda/2)$ is equal to $f_g = c/2a$. For this frequency the correction has maximum equal to 6 dB. Below this frequency the value of correction decreases with the slope of 6 dB/oct. If the resonant frequency of the loudspeaker is equal to lower limiting frequency of the baffle, the frequency response of the device has the slope 18 dB/oct instead of 12 dB/oct as for loudspeaker in the infinite baffle. It is senseless to use better loudspeaker, with resonant frequency significantly lower than lower limiting frequency of the baffle. Because above $ka = 1$ the frequency response has a peak caused by diffraction, the loudspeaker should have the quality Q_{TS} significantly lower than 0.707 (maximally flat frequency response in infinite baffle) in order to compensate this peak. For frequency twice greater than lower limiting frequency of the baffle the both waves: direct and diffracted interfere in the antiphase and the total acoustic pressure is equal to zero and its level has the value $-\infty$. This effect repeats with the period $ka = 2\pi$.

In the practice the rectangular baffle is applied rather than the circular one. In the paper such baffle is considered. Let the shorter side of the rectangle is equal to $2a$, and the longer one – $2b$. Let us assign $B = b/a$ $(B \geq 1)$, $\xi_0 = x_0/a$, $y_0 = \eta_0/a$ and the origin of the coordinate system is placed in the center of the rectangle. The coordinates of the loudspeaker are x_0, y_0 (Fig. 1).

The waves radiated by the rear side of the loudspeaker diaphragm have different paths of diffraction around the baffle and they interfere with direct wave in different

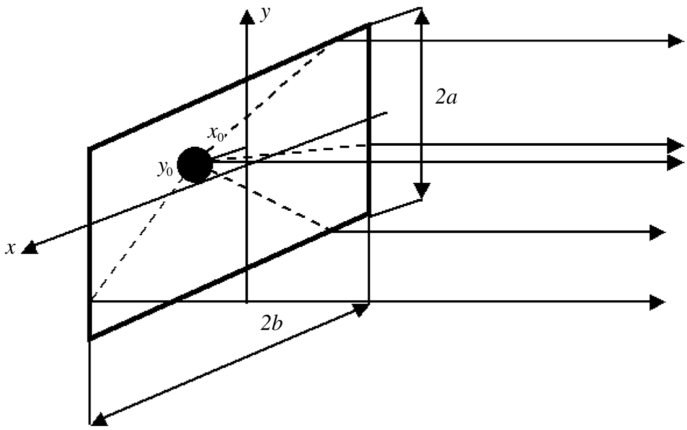

Fig. 1. The sketch for calculation of diffraction correction of loudspeaker in finite rectangular baffle.

phases. It causes that the diffractional correction as the function of frequency is more uniform as for square baffle. The acoustic pressure in the far field can be calculated from the following equation:

$$\begin{aligned} p_w = & \frac{Q}{4\pi r} e^{-jkr} \left\{ 1 - \frac{1}{4(B+1)} \left[\int_{-1}^{1} e^{-jka\sqrt{(B-\xi_0)^2+(u-\eta_0)^2}} \mathrm{d}u \right. \right. \\ & + \int_{-B}^{B} e^{-jka\sqrt{(u-\xi_0)^2+(1-\eta_0)^2}} \mathrm{d}u + \int_{-1}^{1} e^{-jka\sqrt{(B+\xi_0)^2+(u-\eta_0)^2}} \mathrm{d}u \\ & \left. \left. + \int_{-B}^{B} e^{-jka\sqrt{(u-\xi_0)^2+(1+\eta_0)^2}} \mathrm{d}u \right] \right\}. \end{aligned} \tag{3}$$

The diffractional correction as the function of frequency for the square baffle with loudspeaker in the center is presented in the Fig. 2. The side of the square is equal to $2a$, and the average value of the diffraction path is equal to $a_{\text{av}} = 1.148a$. The lower limiting frequency is equal to:

$$f_g = \frac{c}{2a_{\text{av}}} \approx \frac{c}{2.3a}\,. \tag{4}$$

The average path of diffraction is very convenient parameter. Its values for various configurations of loudspeakers and baffles are presented in the Table 1. The deep dip appears for frequency equal to $2f_g$ for loudspeaker in the square baffle, however the depth is not infinite as for square baffle, but it is equal to -13 dB. Further smoothing of the correction as the function of frequency can be obtained by application of rectangular baffle instead of square one and by eccentric position of the loudspeaker.

The corrections as the functions of frequency for loudspeaker placed in the center of rectangular baffles of various proportions of sides are presented in Fig. 3. The

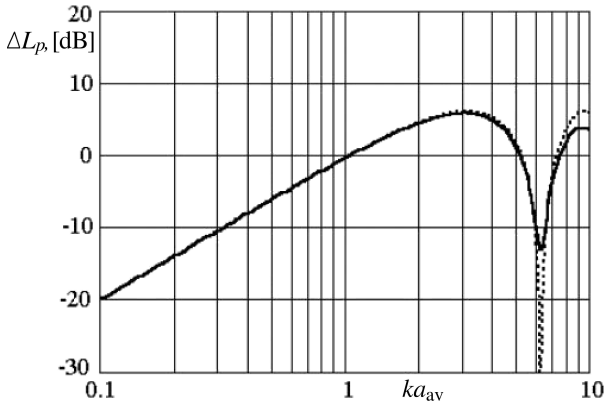

Fig. 2. Diffractional correction of the loudspeaker in the square baffle as the function of the normalized parameter ka_{av}. For comparison the correction of loudspeaker in the center of circular baffle of radius a $(a_{\mathrm{av}} = a)$ is presented (dotted line).

Table 1. Diffractional parameters of the rectangular baffles.

B	ξ_0	η_0	a_{av}/a	σ_a/a	σ_L [dB]
1.0	0	0	1.148	0.126	4.17
1.2	0	0	1.260	0.159	3.871
1.5	0	0	1.422	0.249	3.061
1.7	0	0	1.526	0.318	2.671
2.0	0	0	1.679	0.424	2.410
1.0	0.3	0.2	1.177	0.281	2.369
1.2	0.3	0.2	1.287	0.297	2.461
1.5	0.3	0.2	1.445	0.353	2.376
1.7	0.3	0.2	1.548	0.403	2.225
2.0	0.3	0.2	1.700	0.490	1.977
1.0	0.5	0.3	1.227	0.418	1.719
1.2	0.5	0.3	1.330	0.431	1.748
1.5	0.5	0.3	1.484	0.471	1.899
1.7	0.5	0.3	1.584	0.509	1.933
2.0	0.5	0.3	1.733	0.579	1.838

corrections for loudspeakers placed eccentrically in rectangular baffles are presented in Fig. 4.

If the value of $B = b/a$ increases, the lower limiting frequency of the baffle decreases, because the value of average path of diffraction increases. The irregularity of the correction decreases, because of standard deviation of diffractional paths around

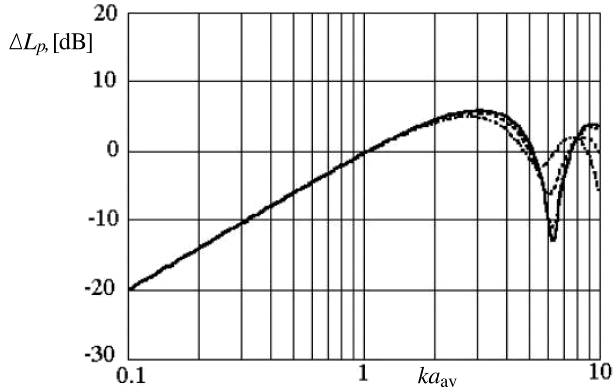

Fig. 3. Diffractional correction as the function of normalized wave parameter ka_{av} for loudspeaker placed in the center of rectangular baffles with $B = 1$ (square, continous line), $B = 1.2$ (dotted line), $B = 1.5$ (dashed line) and $B = 2$ (dashed-dotted line).

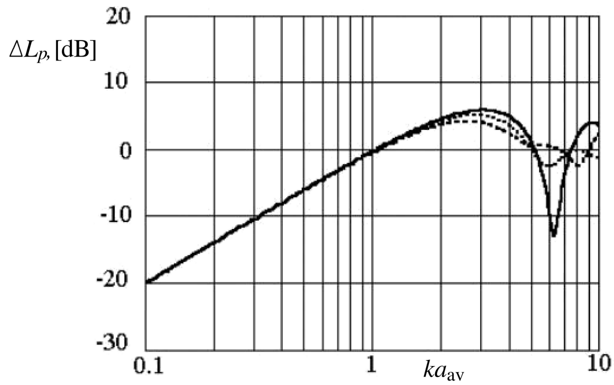

Fig. 4. The diffractional corrections for loudspeakers placed eccentrically in the rectangular baffles: $B = 1.2$, $\xi_0 = 0.3$, $\eta_0 = 0.2$ (dotted line), $B = 2$, $\xi_0 = 0.5$, $\eta_0 = 0.3$ (dashed line). For comparison – the correction of loudspeaker in the the square baffle (continous line).

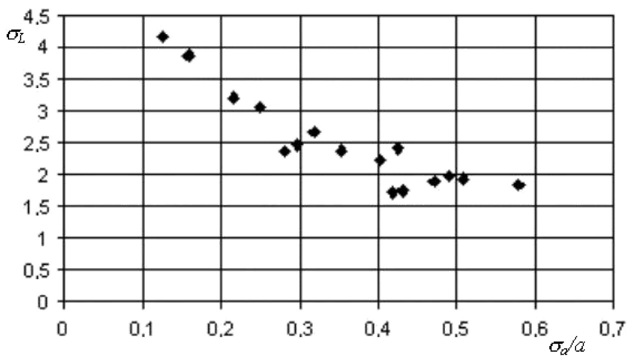

Fig. 5. Dependence between the standard deviation of the diffractional correction in the range $1 < ka_{\mathrm{av}} < 10$ and normalized standard deviation of the diffractional path around the baffle.

their average value increases. In the Table 1 the values of average path of diffraction, their standard deviations as well as standard deviations of the corrections in normalized logarithmic scale in the range $1 < ka_{\mathrm{av}} < 10$ are presented. The dependence between the standard deviation σ_L of the diffractional corrections and the normalized standard deviation σ_a/a of the diffraction path is presented in Fig. 5.

3. Conclusions

The tendency of decreasing of the irregularity of correction when the assymetry of the baffle and eccentricity of loudspeaker position increases can be observed. For higher values of normalized standard deviation of diffractional path this tendency decreases. For normalized baffle [1] used for measurements of loudspeakers the average value of diffraction path is equal to $a_{\mathrm{av}} = 86.4$ cm, its standard deviation is equal to $\sigma_a = 14.6$ cm, the lower limiting frequency $f_g = 190$ Hz and the standard deviation of diffractional correction is $\sigma_L = 3.2$ dB. The value of this correction for limiting frequency is equal to $+5.5$ dB, and for frequency two times greater this value equals -6.7 dB. The normalized baffle has rather poor properties – high lower limiting frequency and great irregularity of diffractional correction.

References

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