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THE HIGH-FREQUENCY VIBRATION AND SOUND RADIATION OF A HOMOGENEOUS PLATE WITH INTERNAL LOSSES

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ABSTRACT

The high-frequency forced vibrations of a homogeneous plate that contacts with acoustic media are investigated. The roots values of the dispersion equation of the plate bending vibration with account for the shear and rotary inertia of it cross section and for internal losses were analyzed. It is showed the frequency range where this equation has not a single but three pairs of real roots appears just when losses are equal to zero. The waves caused by the plate - media cooperation don't disappear but transmit along the plate with decreasing that is proportional to the loss value when the internal losses are counted. A physical meaning of wave transforming at some frequency ranges when the fast decreasing waves transform to the nonuniform waves is explained. The process of the acoustic pressure forming near the plate by elastic waves is investigated at the case when the pressure is a sum of the steepest path integral and the line integral around the dispersion equation poles that are at the physical Riman sheet. The four areas of the main influence of a continuos spectra and a discrete wave spectra are established.

INTRODUCTION

The vibration motion of submerged plate largely depends on frequency of vibration. The near plate acoustic field has been investigated by Romanov and Ivanov [1]. Mindlin, Stuart and other authors [2] -[6] have been investigated high-frequency vibration and sound radiation of submerged plates above the coincidence frequency.

This paper considers the high-frequency forced vibration and sound radiation of the plate with internal losses. The plate contacts with acoustic media by one of two or by both surfaces.

1. THEORETICAL FORMULATION

The infinite plate is time-harmonic excited by a line (at $x = x_0$) force $F = F_0\delta(x - x_0)$.The plate bending vibration theory accounts for shear and rotary inertia of the plate.

The dispersion equation of the plate bending vibration is

$$h(\chi) = [\chi^4 - \chi^2(1 - i\eta)d_1 + (1 - 2i\eta)d_2 - (1 - i\eta)\beta^2]\sqrt{\chi^2 - 1} - \\ -b\beta^3(1 - i\eta)[1 + \chi^2 d_3 - (1 - i\eta)d_4] = 0, \tag{1}$$

where

χ- dimensionless wave number, η-the internal loss factor ,

β- dimensionless frequency, $\beta = f_0 /$;

d_1, d_2, d_3, d_4,- dimensionless parameters, dependent from properties of a plate material and acoustic media;

$$d_1 = [k_l^2 + k_s / k_1)^2]/k_0^2; \; d_2 = k_l^2 k_s^2 / k_1^2 k_0^4; \; d_3 = k_0^2 a; \; d_4 = k_l^2 a; \\ b = \rho_0 c_l / 2\rho c_0 \sqrt{3}; \tag{2}$$

k_l, k_s- wave numbers of the plate longitudinal and shear vibration without the account of losses of energy;

k_0 - acoustic media wave number; ρ and ρ_0 - density of the plate material and of acoustic media;

c and c_0 - speed of longitudinal waves in a plate and sound speed in acoustic media;

k_1- root of the equation:

$$4\sqrt{(1 - k_1^2\alpha)(1 - k_1^2)} = (2 - k_1^2)^2; \; \alpha = (1 - 2\sigma)/2(1 - \sigma); \; a = h^2 / \sigma k_1(1 - \sigma); \tag{3}$$

h - thickness of the plate, σ - Poisson 's ratio;

The equation (1) has 10 complex roots, one pair from which ($\chi_1 = a_0 - i_0$; $\chi_2 = -a_0 + i_0$) is real, and from other four pairs of complex roots two pair characterize interaction of the plate and media and two others correspond to non-uniform (distortion) waves in the plate vibrating in vacuum.

Vibration of a steel plate in water (b=0.26) and on it surface (b=0.13) is analyzed at frequencies until (β= 0.25). When loss factor varied from 0 to 0.2

accounting for shear and rotating inertia of the plate cross section results in appreciable changing of roots values only when $\beta < 4$. This influence is maximum at the frequency of coincidence ξ_0. Here (with $\eta = 0.2$) the increasing of b_0 is approximately 1,5 times, and it is observed also increasing of a_0 and a_1 and reduction of b_2 by size 6 - 12%. If the of accounting of Timoshenko-Mindlin plate theory with absence of internal losses practically do not change the size of b_1, but with $\eta = 0.2$ at frequency $\beta = 1$ increasing of its attitude is approximately 20 % . It was shown, similar to paper [1] that with $\eta = 0$ and $b = 0.13$ in a range $1.4 < \beta < 14.3$, the dispersion equation has not one, but three pairs of real roots. With unzero attitudes of η the waves, caused by interaction of the plate and media ($\chi_{3,4,5,6}$), do not disappear (as when $\eta = 0$), but are distributed along a plate with attenuation and they don't differ, on the nature, from similar waves, noticed behind borders range of frequencies. A degree of their attenuation is proportional to value of η. In a case of one side and bilateral contact of a steel plate with water, that vibrating at frequencies $\beta < 0.37$. the waves ($\chi_{7,8,9,10}$) with large attenuation from a line of excitation degenerate to non-uniform wave ($a_2 = 0$).

The energy that accepts by the plate becomes less the energy of radiation and internal friction. Wave process, caused by components $\chi_{7,8,9,10}$, is located directly at lines of action of force. The acoustic pressure in a point with coordinates R and Θ ($R = \sqrt{x^2 + z^2}, \Theta = arctg(z/x)$) is:

$$P(R,\theta) = F_0 b \beta^3 k_0 [\left| \frac{g(\chi) \exp(ik_0 R)}{h(\chi)\sqrt{-ik_0 R \cos\theta}} \right| + 2\pi i \sum \operatorname{Re} s_{\chi_n}(q)]; \quad (4)$$

where:

$$g(\chi) = 1 - d_3 \chi^2 - (1 - i\eta) d_4; \; g = g(\chi) / h(\chi) \sqrt{\chi^2 - 1}; \quad (5)$$

$$\operatorname{Re} s_{\chi_n}(q) = \exp[-R \sin\theta k_0 \operatorname{Re}\sqrt{\chi_n{}^2 - 1} + k_0 R \cos\theta \operatorname{Im}(\chi_n)] \times \left| \frac{g(\chi_n)}{\left.\frac{\partial h(\chi)}{\partial \chi}\right|_{\chi_n}} \right| \quad (6)$$

First component reflects the contribution of continuous wave spectrum of radiating $|\operatorname{Re}\chi| \le 1$ components of the plate vibration, and second component - discrete spectrum, i.e. the contribution of separate waves, having the greatest amplitudes and mathematically appropriating to roots of the dispersion equation.

2. RESULTS AND DISCUSSION

The typical dependencies of high frequency sound radiation components from $\bar{x} = x k_0 / 2\pi$ are shown on Fig 1. Levels of acoustic pressure in direct affinity from a plane $x = 0$ are defined basically, by the pair of non-uniform quickly attenuated waves ($\chi_{7,8,9,10}$) An area of it prevailing influence appears rather small. The pressure levels are decreasing more than two orders with removal from a line of the plate excitation on distance, equal to half of length of a sound wave. A relative role of the pair of the quickly attenuated waves in formation of acoustic fields weakens with increase of coordinate $\bar{z}$. This is connected with the increasing of influence on total levels of acoustic pressure of a continuous spectrum of radiating plate vibration components. So, if $\bar{z}$=1 the area of the prevailing contribution of the pair of waves $\chi_{7,8,9,10}$ at frequency β=0.5 is limited by the range attitudes $0 \leq x \geq 0.125$. At the same frequency when $\bar{z}$=5 this area is limited from above by meaning $\bar{x} \cong 0.08$. With particular meanings of z with increasing of frequency the area borders of prevailing influence of waves $\chi_{7,8,9,10}$ move to a line of exciting force. The area of prevailing influence of the continuous spectrum on radiated a acoustic field in a saddle - point representation extends in the direction of x-axes with increasing of z_0. For distances $\bar{z}$=1 and 5 when β=0.5 it lays between meanings equal approximately 0,125 - 10 and 0,08 - 100 accordingly. The spatial diagram of the contribution of a continuous spectrum of radiating components includes the maximum of acoustic pressure, the level of which decreases with the growth of shortest distance up to the line of excitation. Coordinates of the maximum concurrence with coordinates of the ray, outgoing from an excitation line under a corner arcsin ($\mathrm{Re}\chi_{3,4,5,6}$), equal approximately 55.4° with β=0.5. Just under this corner begin to radiate a physical pair of non-uniform slowly attenuated waves $\chi_{3,4,5,6}$. These waves do not take part In formation of a continuous spectrum maximumes, but it's occurrence is connected with increasing of radiating ability of wave component that propagate speeds are close to the speeds of their distributions.

Area of the primary influence of the pair of waves $\chi_{3,4,5,6}$ has appeared very small. It is limited to distances from plates about the length of a sound wave in media and narrow angular contiguous to a corner it "follows". With β=0.5 and $\bar{z}$=1 the primary influence of considered pair of waves is limited by distances from a line of excitation $10<x<12$. With further increasing X (with Z=1) the basic contribution in the acoustic field of a plate begins to exhibit in the pair of uniform waves $\chi_{1,2}$. Their influence, as well as in case of low-frequency fluctuations of a plate, is concentrated in the subsurface layer of acoustic media. The thickness of this layer increases with removal from a line of excitation. So, with β=0.5 and meanings $\bar{x}$, equal to 12 and 60, the contributions of homogeneous waves is more than the contribution of other wave components with meanings $\bar{z}$, smaller than 1 and 3. With downturn of vibration frequency (when β<1) the relative meanings of borders ($\bar{x}$,$\bar{z}$) of prevailing influences of uniform waves do not undergo of the basic changes.

The analysis of wave structure of the plate radiation has shown, that at frequencies $\beta<1$ the resonant radiating peak exists when $\chi = \chi_{3,4,5,6}$. An acuteness (narrow) of peak is defined by the of internal losses. The greatest radiation in area of wave resonance exists with absence of losses in a plate.

CONCLUSION

The high -frequency vibration and the near - field sound radiation from infinite plate has been examined.

It was shown that the waves caused by the plate - media cooperation don't disappear but transmit along the plate with decreasing that is proportional to the internal losses. The four areas of the main influence of a continuous spectra and a discrete wave spectra are established.

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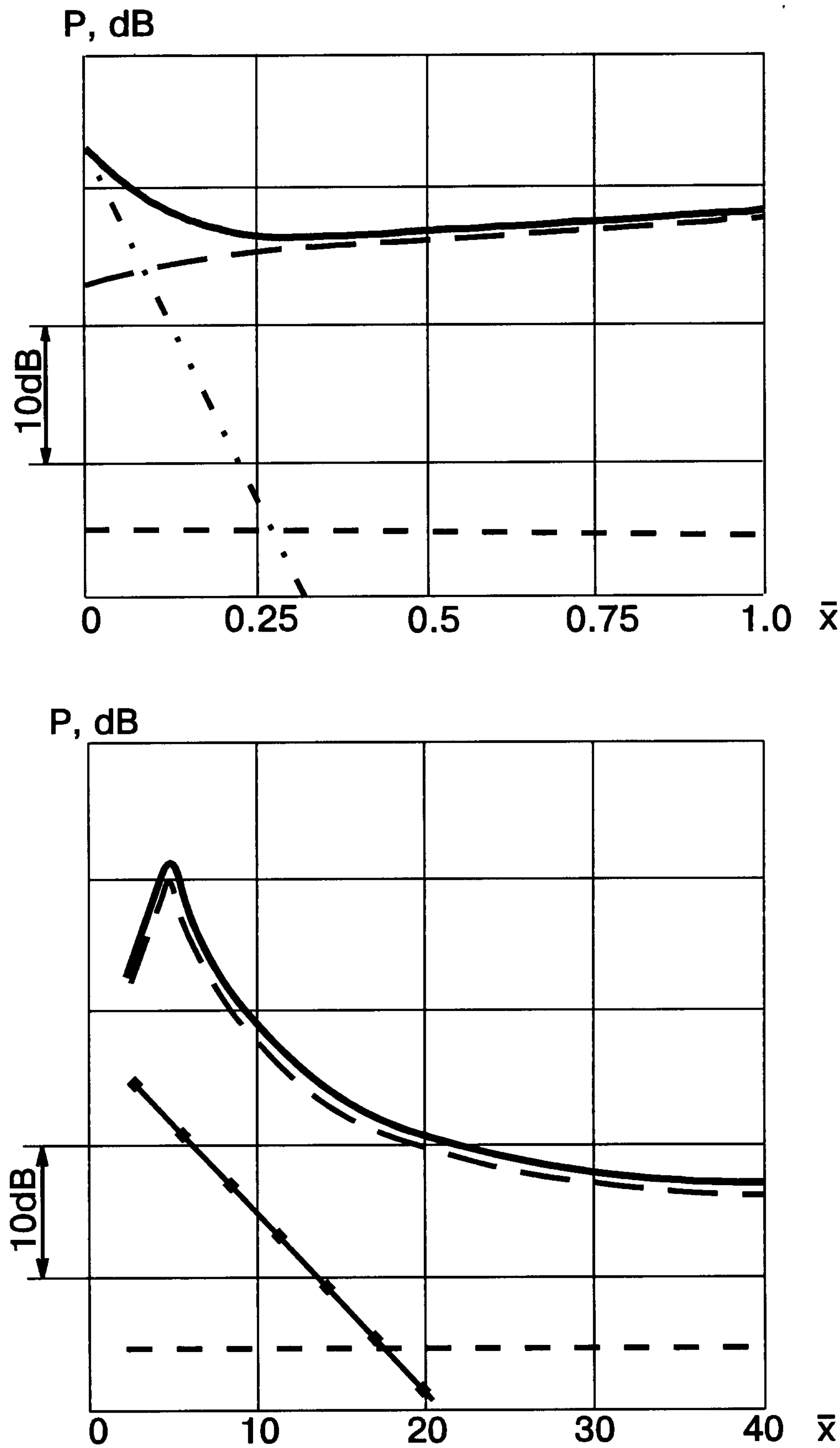

Fig. 1 Components of sound pressure field P_{Σ}(——) near the steel plate (z=1; β =0.5) vibrating on water surface, caused bu: continuos spectrum (— —), $x_{1,2}$ (- - -); $x_{3,4,5,6}$ (—■—); $x_{7,8,9,10}$(· · — ·).