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ACOUSTIC RADIATION OF A PLATE EXCITED BY TURBULENT FLUCTUATIONS OF PRESSURE AND SHEARING STRESS

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1. INTRODUCTION

On the surface streamlined by turbulent fluid or gas flow there is observed the field of shearing stress fluctuations, random in space and time, apart from pressure fluctuations. The shearing stress fluctuations exciting the streamlined elastic surface cause its vibration and subsequent acoustic radiation. The importance of this additional acoustic radiation, as far as can be said from publications, has not been evaluated up till now. This is explained by the fact that until recently the information on the space-time structure of the turbulent fluctuation field of shearing stress which is necessary for such evaluation, could be hardly found in the literature. The references [1,2] present the experimental data on space correlation scales and phase velocity of this field, random in space and time, which can be used for evaluation of the acoustic radiation of an arbitrary continuum elasto-inertial system. It is believed worthwhile first to evaluate the acoustic radiation of the simplest continuum elasto-inertial system under dynamic loading of this kind. An infinite homogeneous thin plate is one of the simplest calculation models and its examination permits to reveal the main regularities and effects in the acoustic radiation of thin-wall structures.

2. INVESTIGATION RESULTS

We consider an infinite homogeneous plate of linear visco-elastic material separating two half-spaces filled with media having identical values of the sound wave velocity (c_0) and density (ρ_0). The plate is excited by a one-dimensional system of distributed longitudinal forces, random in space and time, described by a centered distribution function, stationary in time and homogeneous in space. The longitudinal forces are uniformly distributed over the plate thickness.

Within such assumptions the spectral density of the sound pressure associated with sound waves propagating in the medium is presented as follows [3]:

$$\Phi_p(\omega) = (\omega\rho_0)^2 \int_{-k_0}^{k_0} \Phi_\tau(k,\omega)|X(k,\omega)|^2 dk, \qquad (1)$$

where $k_0 = \omega/c_0$.

The integrand represents the product of two functions. The first one is the frequency-wave spectrum

$$\Phi_\tau(k,\omega) = \frac{\Lambda\Phi_\tau(\omega)}{\pi\left[1+(k\Lambda + k_\tau\Lambda)^2\right]}. \qquad (2)$$

Here $\Lambda = \Lambda(\omega)$ is the space correlation scale of spectral components, $k_\tau = \omega/U_p$ is the convective wave number, U_p is the phase velocity, $\Phi_\tau(\omega)$ is the spectral density of the field of shearing stress turbulent fluctuations, which are evaluated from the experimental material of [1] and [2]. It has a single maximum in the vicinity of $k = -k_\tau$ which subsides as the correlation space scale decreases. This maximum occurs in the domain of integration $(|k| \le k_0)$ only in the case of $k_\tau \le k_0$, i.e. $U_p/c_0 = M_p \ge 1$.

The second factor in the product is the transfer function $|X|^2$ [3] which is characterized by two distinct maxima (in the vicinity of $|k| = k_1$ and $|k| = k_0$). Here $k_1 = \omega/c_1$, c_1 is the longitudinal wave propagation velocity in the plate. The longitudinal wave velocity in metal plates is always considerably higher than the sound velocity in the surrounding air. The maximum in the vicinity of $|k| = k_1$ always occurs in the domain of integration in this case.

For an aluminum alloy plate with the loss coefficient $\eta = 0$, the quantity $|X|^2_{|k|=k_1} / |X|^2_{|k|=k_0} \approx 10^3$, i.e. the maximum in the vicinity of $|k| = k_1$ is predominant. This ratio decreases as the dissipation in the plate increases because the maximum in the vicinity of $|k| = k_0$ practically does not depend on η but the maximum in the vicinity of $|k| = k_1$ subsides as η increases, beginning with its certain characteristic value depending on the frequency. In most practical situations the maximum in the vicinity of $|k| = k_1$ is considerably larger than the maximum in the vicinity of $|k| = k_0$.

The dependence of the integrand of Eq.(1) on the wave number is determined mainly by the behavior of the transfer function. For $k_1\Lambda << \eta^{-1}$ the frequency-wave spectrum $\Phi_\tau(k,\omega)$ can be treated as a slowly varying function of the parameter k in comparison with function $|X(k,\omega)|^2$ This makes it possible to estimate the integral (1) as $\eta \to 0$ by standard asymptotic methods and to represent the dimensionless spectral density of the sound pressure in the form:

$$F_p = \frac{\Phi_p(\omega)}{\Phi_\tau(\omega)} \approx \left[\frac{k_1\Lambda}{1+\left(k_\tau\Lambda + k_1\Lambda\right)^2} + \frac{k_1\Lambda}{1+\left(k_\tau\Lambda - k_1\Lambda\right)^2} \right] I(k_1,\omega). \quad (3)$$

Here $I(k_1,\omega)$ is a function of the plate parameters and acoustic medium; it does not depend on the structure of the forcing field (space correlation scales and phase velocity) and is determined by the integral:

$$I(k_1,\omega) = \frac{(\omega\rho_0)^2}{k_1} \int_0^{k_0} \left|X(k,\omega)\right|^2 dk. \quad (4)$$

Equation (3) can be used directly to determine the influence of the space correlation scales and the phase velocity on the sound radiation from a plate excited by turbulent fluctuations of the shearing stress. In the case $k_1 >> k_\tau$, i.e., when the phase velocity of the field of the shearing stress fluctuations is much greater than the longitudinal wave velocity in the plate, one of the amplification effects of acoustic radiation at $k_1\Lambda \approx 1$ follows from Eq.(3). If $k_1 << k_\tau$, i.e., when the phase velocity of the forcing field is much smaller than the longitudinal wave velocity in the plate, another sound radiation amplification effect, corresponding to $k_\tau\Lambda = 1$, follows from Eq.(3) as well as the phase velocity dependence of the sound radiation from the plate. For $k_1 \approx k_\tau$, when $k_1\Lambda >> 1$, Eq.(3) gives a distinct maximum which characterizes an amplification effect analogous to the aerodynamic coincidence effect observed when the plate is excited by turbulent pressure fluctuations. This amplification effect is subsides as $k_1\Lambda$ decreases.

All the above-described amplification effects of the sound radiation from a plate in the field of turbulent shearing stress fluctuations are of the same nature as the sound radiation amplification effects in the field of turbulent pressure fluctuations [4], the only difference being that they are associated with the maximum intensity of the field of forces acting on the plate in the vicinity of k_1, rather than in the vicinity of k_0.

For a comparison of the acoustic radiation of a plate in the fields of turbulent shearing stress fluctuations and turbulent pressure fluctuations we make use of the values $\Phi_\tau(\omega)$, Λ_1, U_τ, obtained in [1,2] and calculated for the same boundary layer parameters as for the pressure fluctuations [5] the comparison of 1/3-octave band sound pressure levels in the field of a plate excited by turbulent pressure fluctuations L_{pq} *at* $\eta = 10^{-2}$ (1), shearing stress fluctuations $L_{p\tau}$ *at* $\eta = 10^{-4}$ (2) *and* $\eta = 10^{-2}$ (3) are shown in Fig.1. These results allow to conclude, that the acoustic radiation of the plate in the turbulent boundary layer is determined by the pressure fluctuation field.

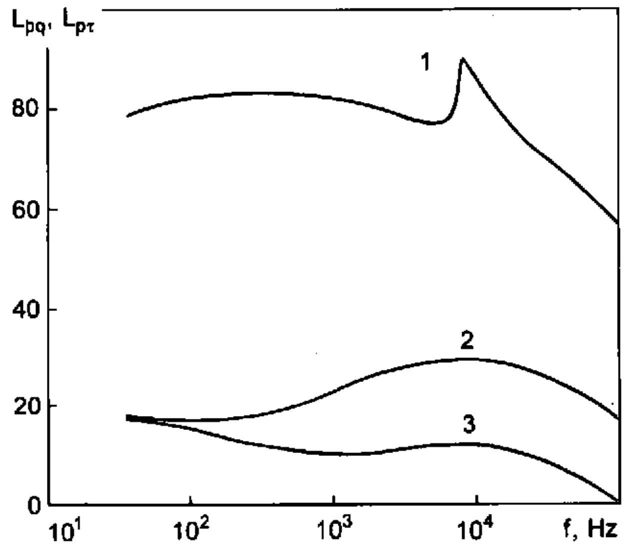

Fig. 1.

3. CONCLUSION

The main physical phenomena determining the acoustic radiation of a plate excited by wall turbulent shearing stress fluctuations are studied. Comparison between the acoustic radiation of a plate in the field of wall pressure fluctuations and in the field of shearing stress of the turbulent boundary layer is made. The dominating role of pressure fluctuations in the acoustic radiation of a plate excited by the turbulent boundary layer is established.

4. REFERENCES

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