SELF-OSCILLATORY DEVICE FOR VIBRATION TESTS

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UDC 620.178.3.05–52

In practical vibration tests of components and units of machines it is fairly often necessary to test objects whose resonance frequencies lie in the range 20-30 Hz. In this range also lie the resonance frequencies of the elastic suspensions of most industrially produced oscillators, and these operate therefore in an unfavorable regime.

The present article suggests a method of controlling the resonance frequency of a mechanical oscillating system ensuring the diversity spacing of the resonance frequencies of the oscillator and of the tested structure, and it examines a self-oscillatory device which puts this method into practice.

This method [1] consists in arranging, together with feedback for speed ensuring the excitation of free vibrations, additional feedback for displacement and acceleration changing the dynamic parameters of the tested structure.

To devise the differential equations permitting investigations by the suggested method to be put into practice, we will examine the principle of operation of a self-oscillatory system [2] whose block diagram is shown in Fig. 1. It consists of: the vibrator V with the tested structure TS mounted on its platform; the chopper Ch; the matching amplifier MA; the phase shifters FS1, FS2, FS3; the derivator D; the integrator I; the amplitude controls AC1, AC3; the band-pass frequency filter F, the summator S; the power amplifier PA.

The self-oscillatory system can be subdivided into the principal self-oscillatory circuit containing the chopper Ch, the matching amplifier MA, the phase shifter FS1, the filter F, the summator S, the power amplifier PA, the oscillator V with the tested structure TS; the feedback circuit for displacement including the integrator I, the phase shifter FS3, the amplitude control AC3; the feedback circuit for acceleration containing the derivator D, the phase shifter FS2, and the amplitude control AC1.

When the conditions of phase and amplitude balance are fulfilled, free oscillations are excited in the principal circuit, and their frequency is determined by the parameters of the tested structure and by the amount of feedbacks for displacement and acceleration. When the resonance frequency of the tested structure differs considerably from the resonance frequency of the elastic suspension of the oscillator, then there is no need for diversity spacing of the resonance frequencies, and the amplitudes of the feedback signals for displacement and acceleration are set equal to zero.

We will examine the case when the resonance frequencies of the tested structure and of the oscillator coincide, and for their diversity spacing the feedbacks for acceleration and displacement are used. In constructing the differential equations describing the dynamics of the self-oscillatory system, we regard the oscillator and the tested structure as a system with two degrees of freedom and with position correlation [3]. Since the self-oscillatory system has crossed feedback, the system of differential equations describing the motion of the tested structure and of the oscillator has the following form:

$$m_1\ddot{x}_1 + h_1\dot{x}_1 + c_1x_1 - c_1x_2 = 0; \quad m_2\ddot{x}_2 + h_2\dot{x}_2 + c_2x_2 - c_1x_2 - c_1x_1 = F_1(\ddot{x}_1) + F_2(\dot{x}_1)\dot{x}_1 + F_3(x_1), \tag{1}$$

where m_1, h_1, c_1, x_1 are the mass, the resistance coefficient, the rigidity, and the coordinate of motion of the structure, respectively; m_2, h_2, c_2, x_2 are the same for the elastic suspension of the oscillator; $F_1(\ddot{x})$, $F_2(\dot{x})$, $F_3(x)$ are the forces corresponding to the feedbacks for acceleration, speed, and displacement, respectively.

To determine the natural frequency of a system with two degrees of freedom and their dependence on the parameters of the feedback, we use the method of Nyquist regeneration diagrams. We assume that the excitation regime is gentle and that $F_2(x) = [s-F_4(x_1^2)]k$ [4],

Institute of Engineering, Academy of Sciences of the Ukrainian SSR, Kharkov. Translated from Problemy Prochnosti, No. 8, pp. 86-88, August, 1985. Original article submitted April 29, 1983.

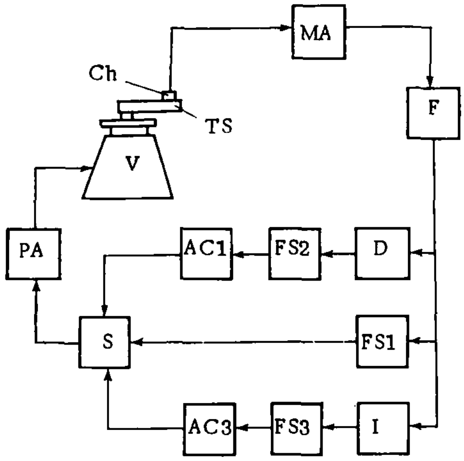

Fig. 1. Block diagram of the self-oscillatory device.

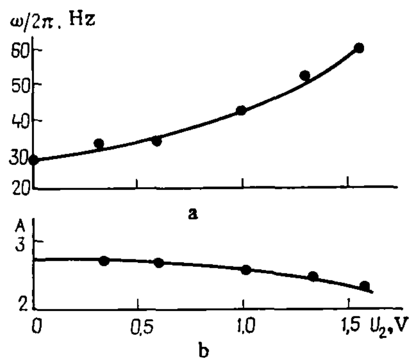

Fig. 2. Dependence of the natural frequency of the tested structure (a) and of the amplitude of the free oscillations (b) on the amount of feedback.

where k is the transmission coefficient of the feedback without matching amplifier (MA), a nonlinear element. Imagining the principal self-oscillatory circuit to be open at the place where the chopper is joined to the tested structure, transmitting to the input the external disturbance $u = u_0 e^{j\omega t}$ and representing x_1 and x_2 in the complex form $x_1 = x_1 e^{j\omega t}$, $x_2 = x_2 e^{j\omega t}$, we determine the complex transmission coefficient of the open system:

$$W(j\omega) = \frac{x_1}{u};$$

$$W(j\omega) = \frac{j\omega\omega_{01}^2 \left[s - F_u\left(-\omega^2 x_1^2\right)\right] k}{(\omega_{0\Sigma}^2 - \omega^2)(\omega_{01}^2 - \omega^2) - 4\delta_1\delta_2\omega^2 - \alpha + \omega_{01}^2 \frac{\Delta m}{m_2}\omega^2 + j2\omega\left[\delta_1(\omega_{0\Sigma}^2 - \omega^2) + \delta_2(\omega_{01}^2 - \omega^2)\right]}. \quad (2)$$

We calculate the values of the possible self-oscillatory frequencies from the condition of balance of the phases:

$$\left.\begin{aligned} & I_m W(j\omega) = 0; \\ & \omega^4 - \left(\omega_{0\Sigma}^2 + \omega_{01}^2 \frac{\Delta m}{m_2} + \omega_{01}^2 + 4\delta_1\delta_2\omega_{01}^2\right)\omega^2 \times \\ & \times \frac{c_1 + \Delta c}{m_2} + \omega_{0\Sigma}^2\omega_{01}^2 = 0; \\ & \Delta m = \frac{F_1(\dot{x}_1)}{\ddot{x}_1}; \quad \Delta c = \frac{F_2(x_1)}{x_1}, \end{aligned}\right\} \quad (3)$$

where $\omega_{01}^2 = \frac{c_1}{m_1}$; $\omega_{0\Sigma}^2 = \frac{c_1 + c_2}{m_2}$; $\delta_1 = \frac{h_1}{2m_1}$; $\delta_2 = \frac{h_2}{2m_2}$.

Equation (3) represents a parabola whose apex is shifted relative to the origin of coordinates. The ordinate of the apex of the parabola determines the ratio between the natural frequencies of the system, the abscissa determines their values.

The ordinate of the apex, which we denote y_0, is determined by the following expression:

$$y_0 = \omega_{0\Sigma}^2 \omega_{01}^2 - \frac{c_1 + \Delta c}{m_2} - \frac{[\omega_{01}^2(\pm \Delta m) - \omega_{0\Sigma}^2 - \omega_{01}^2 - 4\delta_1\delta_2\omega_{01}^2]^2}{4}. \tag{4}$$

It follows from (4) that when the feedback for displacement is positive and the feedback for acceleration is negative, the difference between the natural frequencies of a system with two degrees of freedom increases, and conversely, when the feedback for displacement is negative and the feedback for acceleration is positive, the difference between the natural frequencies becomes smaller.

In the self-oscillatory system under examination, the feedback signals are represented by electric voltages which are summed in the summator. Let us examine the potential diagram at the summator input. Here, $\dot{u}_1$ corresponds to the feedback for acceleration, $\dot{u}_2$ to the feedback for speed, $\dot{u}_3$ to the feedback for displacement.

It follows from expression (4) that simultaneously using the feedbacks for displacement and acceleration is inadvisable because the voltages proportional to displacement and acceleration compensate each other. Therefore it is better if, basing ourselves on the traditional method of controlling the parameters of oscillatory effects in harmonic loading, we regulate the natural frequencies of the tested objects in the range of low frequencies by using feedback for displacement, and in the range of high frequencies feedback for acceleration.

The results of the experimental verification of the method of regulating the natural frequency are presented in Fig. 2 in the form of dependences of the natural frequency of the tested structure and of the amplitude of the free oscillations on the amount of feedback for acceleration. By changing the amount of feedback we succeeded in shifting the natural frequency of the tested structure from 29 to 60 Hz, and with the resonance frequency of the oscillator VÉDS-400A, this ensured normal operation of the self-oscillatory system. We found that the amplitude of the free oscillations decreased, but this can be avoided by using automatic fine tuning of the phase shift in the feedback circuit and stabilization of the amplitude of the free oscillations.

LITERATURE CITED

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