

# Dynamic Vibration Protection of a Mechanical System with a Finite Number of Degrees of Freedom

Almuratov Shavkat Narpulatovich<sup>1</sup>, Savenko Oksana Viktorovna<sup>2</sup>, Turaev Kakhramon Nortozievich<sup>3</sup>, Toshboeva Nargiza Yuldashovna<sup>4</sup>

<sup>1</sup>(PhD) Dotsent Renaissance Educational University, Uzbekistan

<sup>2,3</sup>Senior Lecturer, Termez State University, Uzbekistan

<sup>4</sup>Senior Lecturer at the University of Business and Science, Uzbekistan

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**Abstract**—*In the conditions of constantly tightening requirements for vibration and noise, shown to modern power plants, the possibilities of passive vibration isolation are provided practically exhausted. As a result, in this situation, active vibration protection systems acquire decisive importance. In the work, the dynamics of two mass active vibration protection systems is developed. Its efficiency and stability areas are solved.*

The most effective way to combat vibration is to reduce the variable forces in the sources and energy transmission chains (internal combustion engines, gear transmissions, electric motors, etc.). But, naturally, when designing sources, the key task is to fulfill the main functional task - to ensure the transfer of energy from the source to the receiver with maximum efficiency while necessarily meeting the requirements for strength and resource characteristics. Vibration activity often recedes into the background. Hence the limitations of this way of combating vibration.

To protect technical and biological objects from vibration excitation in the low-frequency range, a huge number of vibration protection systems have been developed, based on the use of a wide range of shock absorbers. Such vibration protection systems are called passive. However, their use in many cases turns out to be ineffective, for example, when protecting objects from vibration spectra changing over time.

Recently, automated vibration protection systems have found application, which are called active vibration

protection systems. [1,2]. The creation of effective active systems for vibration damping of low-frequency vibration of various mechanisms, excited by the action of variable forces, has been the goal of the work of many researchers over the past several decades. In general, control of such systems can be implemented on the principle of disturbance compensation, compensation of deviation of the controlled variable, or a combination of both these methods.

Experience in creating active vibration damping systems has shown that the most promising in terms of complete reproduction of variable forces, comparative ease of implementation and control, and lack of sensitivity to negative environmental factors are electrodynamic vibration protection systems, in which an electrodynamic vibrator serves as an actuator [3]. A characteristic feature of active systems is the use of active circuits consisting of measuring, amplifying and executive elements. The latter generate a force that allows reducing the dynamic loads acting on the protected object.

In active vibration protection systems, information about the nature of disturbances, their frequency and

amplitude composition is required to create a control action (control). The role of sources of this information is played by electrical vibration converters, which act here as converters of motion parameters (force, acceleration, displacement) into electrical signals (voltage, current). The converters used (displacement sensors, force sensors, accelerometers, etc.) must have a sufficiently wide frequency range (at least five times wider than the frequency range of the measured signal) and a low coefficient of nonlinear distortion. Electrical signals as control actions must be proportional to the disturbing force  $Q(t)$ . When the frequency and amplitude of the external action change, the frequency and amplitude of the current (voltage) should change in a similar way. An oscillatory system with an electrodynamic vibrator can be considered as an object of automatic control and the methods developed in the theory of automatic control can be used to study it [3,4]. When compiling a system of equations describing the dynamics of a mechanical oscillatory system with an electrodynamic force generator, both mechanical motion and electrical processes in the conductor circuit (moving coil) should be taken into account. In electrodynamic devices, the current for creating force arises as a result of the movement of either the conductor itself or its suspension points.

For instance, let us consider a mechanical system consisting of one body. Let us consider the mechanical system shown in pic. 1, the scheme of active vibration protection systems, in which the vibrator body is considered vibration-isolated from the rest of the system. This allows us not to take into account the dynamic reaction force from the vibrator body when constructing a mathematical model. The force  $F$  generated by the vibrator acts on the base. Dissipative elements with rheological properties are included parallel to the elastic connections. A force sensor is installed between the "spacer" plate and the fixed base, converting the force acting on the plate into a control signal.

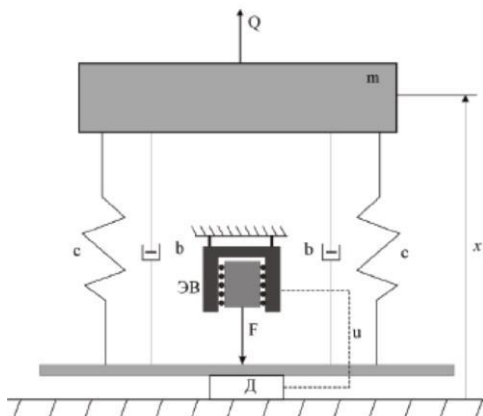


Fig. 1. Active vibration protection systems with one degree of freedom

Electrical signals as control actions must be proportional to the disturbing force  $Q(t)$ . An oscillatory system with an electrodynamic vibrator can be considered as an object of automatic control and applied for its study developed in the theory of geometric servo-connections.

The behavior of this system will be described by equations

$$m\ddot{x} + c_p(x(t) - \int_{-\infty}^t R(t-\tau)x(\tau)d\tau) = Q; \tag{1}$$

$$L \frac{di}{dt} + Ri = U,$$

The first equation of system (1) characterizes the mechanical motion of the mass  $m$ , and the second - the electrodynamic equilibrium in the circuit of the vibrator's moving coil. In these equations,  $x$  is the absolute coordinate of the mass oscillations  $m$ .

$Q = Q(t)$  - external disturbing force,  $i$  - current in the control winding circuit of the electrodynamic vibrator,  $F = F(t)$  - ponderomotive force depending on the winding current (in particular, it occurs in geometric servo link),  $L, R$  - inductance and active resistance of the control winding,  $U$  - voltage on the winding of the moving coil,  $F(i) = B/i$  - Ampere force,  $c_0$  - instantaneous stiffness coefficient and  $R(t-\tau)$  - relaxation core. Control is introduced as negative feedback on the total force acting on the base (sensor D):

$$U = -k_U(F(i) + cx(t) - \int_{-\infty}^t R(t-\tau) \dots)$$

where is the coefficient of proportionality between the voltage on the winding and the force  $kU = k_o k_{yc} > 0$  ( $k_o k_{yc}$  - sensitivity coefficients of the force sensor and amplifier gain). The paper [5,6] presents the results of calculations of active vibration protection of a mechanical system with one degree of freedom. We will conduct a study of models of active vibration protection systems with various connection schemes of an electrodynamic vibrator and application of an external dynamic load. In all cases, the task is to reduce the dynamic load on the foundation. Modeling is performed in the low-frequency range.

Let us consider a model of active vibration protection systems with two degrees of freedom. Let us assume that the task is to actively isolate some elastically fixed mass ( $m_1$ ) in the near-resonance range (relatively low frequencies are considered). An external disturbing force acts on the mass  $Q(t)$ . In order to install the vibrator, additional mass is introduced. ( $m_2$ ), fixed to the insulated mass by means of elastic elements ( $C_2$ ). In parallel to the elastic connections,

dissipative elements with a resistance coefficient are also included  $b_{1,2}$ . Between the “attachment” plate and the fixed base, a force sensor D is installed, converting the force acting on the plate into a control signal (voltage and at the coil terminals). The system is described by the equations:

$$\begin{aligned} m_1 \ddot{x}_1 + c_1 x_1 - c_2 (x_2 - x_1) + b_1 \dot{x}_1 &= Q - F; \\ m_2 \ddot{x}_1 + c_2 x_1 - c_2 (x_2 - x_1) + b_2 \dot{x}_2 &= F; \quad (2) \\ L \frac{di}{dt} + Ri - U + Bl(x_2 - x_1) &= 0. \end{aligned}$$

The first two equations of system (2) characterize the motion of masses  $m_1$  and  $m_2$ , the third - electrodynamic equilibrium in the circuit of the moving coil of the vibrator. In these equations  $x_1$  and  $x_2$  - absolute coordinates of the masses;  $Q = Q(t)$  - external disturbing force;  $i$  - current in the circuit of the control winding of the electrodynamic vibrator;  $F = F(i)$  - ponderomotive force depending on the current in the winding;  $L$ ,  $R$  - inductance and active resistance of the control winding;  $U$  - voltage on the winding of the moving coil.

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