Methods for controlling the vibration state of technical facilities

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Abstract. The article considers the features of the dynamics of systems with several degrees of freedom with the introduction of additional constraints. As an example, the authors consider the computational scheme of a locomotive traction engine with an axial overhung support. Different cases of the combination of perturbations were analyzed and the conditions for dynamic damping were determined. The specificity of the tasks to be solved was in the necessity to determine the conditions while choosing system parameters that would minimize the occurrence of cross-couplings. These conditions were determined and implemented through the introduction of additional inertial elements into the system structure. With an appropriate choice of system parameters, the vibration platform can be invariant with respect to the deviation to the kinematic effect x_j(t). The necessary conditions that can be obtained by parallel inclusion of inertial and elastic elements in systems with low friction were considered.

1. Introduction
Transport technical devices, in terms of solving problems of protection against vibration and shock, are complex objects. The theory and practice of transport dynamics, the protection of machinery, equipment, instruments is considered in a fairly large number of works of domestic and foreign authors. At different times, various aspects of this problem were regarded, related to the refinement of mathematical models, the introduction of new constraints, including the use of external energy sources, the use of automation elements and approaches based on the methods of the theory of automatic control, including direct control using computer technology. From the consideration of individual dynamic phenomena and processes, a definite tendency emerged towards the study of the vibrational states of facilities, the formation and study of vibrational fields and methods of controlling complex dynamic states, which presupposes the further development of systemic methodological and scientific-methodological viewpoints.

The authors consider the features of the dynamics of systems with several degrees of freedom with the introduction of additional constraints. As an example, the authors consider the computational scheme of a locomotive traction engine with an axial overhung support [1, 2]. The basic computational
scheme of the drive has the form of a two-dimensional model (Figure 1), which, in turn, can be interpreted by the structural diagrams (Fig. 2 and 3).

![Figure 1. Basic calculated two-dimensional model.](image1)

2. Construction of the model

Additional constraints can be introduced by “connecting” the corresponding links with transfer functions $L_1 p^2$ and $L_2 p^2$ that are parallel to links $c_1$ and $c_2$. Necessary transfer functions with power and kinematic perturbations were subsequently determined. A number of certificates for utility models were obtained for the constructive and engineering implementations of additional constraints.

![Figure 2. Structural diagram of the basic model.](image2)

![Figure 3. Structural diagram of the calculated model in the coordinate system.](image3)
Some approaches to the rational designing of an axial overhung support were considered (certificate No. 29504 dated May 20, 2003. Bull. No. 14 dated May 20, 2003), which was associated with the introduction of additional constraints into the interaction scheme. It was shown that the dynamic damping of oscillations significantly depended on the geometric and mass-inertial properties of the systems [3-7]. Frequency values can vary, creating certain zones to achieve oscillation damping effects. The spectrum of possibilities also depended on the nature of the introduction of additional constraints, bearing in mind the combinatorics of their distribution by degrees of mobility. In some cases, modes of dynamic oscillation damping in the coordinates might occur [1, 8].

More complex three-dimensional objects of protection and some practical developments in terms of algorithmic and software research were also considered [1, 9-16].

The problems of spatial vibration isolation and vibration protection were often encountered in practice and were characteristic, in particular, for transport systems, equipment protection, and creation of comfortable conditions for a human operator. The computational scheme of the spatial vibration protection platform is shown in Fig. 4. The dynamic properties of the system were investigated, the expressions for determining partial frequencies and relations determining the conditions for vibrations' decoupling, frequency characteristics were obtained.

![Figure 4. Computational scheme of the vibration protection platform.](image)

The introduction of inertial elements led to the occurrence of additional modes of dynamic oscillation damping during kinematic impacts. It was shown that the conditions for dynamic damping did not depend directly on the inertial characteristics of the protected part of the system, which made it possible to use it as the filter for the protection from the vibrations of facilities with the different mass-inertia parameters. The generalized mathematical model of the system is represented by expression (1), and its structural diagram and the detailed components are shown in Figure 5, in this case:

\[
Au + Cu = B\dot{z} + Cz
\]

where

\[
u = (z_1, z_2, z_3), \quad \xi = (\xi_1, \xi_2, \xi_3), \quad E_{11}(p)Z_1 + E_{12}(p)Z_2 + E_{13}(p)Z_3 = \]

\[
E_{21}(p)Z_1 + E_{22}(p)Z_2 + E_{23}(p)Z_3 = \]

\[
E_{31}(p)Z_1 + E_{32}(p)Z_2 + E_{33}(p)Z_3 = \]

\[
F_{i,j}(p) = a_{i,j}(p) + b_{i,j}, \quad F_i(p) = b_i(p) + c_i, \quad (i, j = 1, 2, 3) \text{ are real polynomials}, \quad Z_1, Z_2, Z_3 \text{ is the}
\]
Laplacian image of generalized coordinates, Σ1, Σ2, Σ3 is the Laplacian image of perturbations.

Figure 5. Generalized structural diagram (a) and its detailed components (b).

Let us note that the terms \( a_{ij}p^2 \), \( b_{ij}p^2 \) reflect the introduction of the additional constraints, which create the extra forces, which depend on the accelerations of relative motion.

In certain cases computational scheme can be represented by different versions. Using conditions of symmetry or proximity to them, it is possible to simplify the initial model and to determine the basic parameters of dynamic state. The expressions (2) and (3) are used for determining the partial frequencies of the system from the coordinates \( x_1, x_2 \) and \( x \) and \( \phi \) :

with the generalized coordinates \( x_1, x_2 \)

\[
n_1 = \sqrt{c_1 / [(mL_1^2 + J)(l_1 + l_2)^3 + L_1]} \quad n_2 = \sqrt{c_2 / [(mL_2^2 + J)(l_1 + l_2)^3 + L_2]} \]

(2)

with the coordinates \( x \) and \( \phi \)

\[
n_1 = \sqrt{(c_1 + c_2)(m + L_1 + L_2)} \quad n_2 = \sqrt{(c_1L_1^2 + c_2L_2^2)(J + L_1^2L_2 + L_2^2L_1)}
\]

(3)

The change in the values of partial frequencies depends on reduced mass. It is possible to note that an increase in the reduced mass leads to noticeable reduction in the natural and partial vibration frequencies. However, the authors also encountered special features: system “cutoff” effects were observed.

3. Conclusion

Different cases of the combination of perturbations were analyzed and the conditions for dynamic damping were determined. The specificity of the tasks to be solved was in the necessity to determine the conditions while choosing system parameters that would minimize the occurrence of cross-couplings. These conditions were determined and implemented through the introduction of additional inertial elements into the system structure. With an appropriate choice of system parameters, the vibration platform can be invariant with respect to the deviation to the kinematic effect \( x_j(t) \). The necessary conditions that can be obtained by parallel inclusion of inertial and elastic elements in systems with low friction are considered.
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