Mathematical Description and Modeling of the Vibration Isolation Device with Neodymium Compensator Stiffness

E G Gurova
Mechatronics and automation department, Novosibirsk State Technical University, Av. K. Marx, 20, Novosibirsk, 630073, Russia
E-mail: lena319@mail.ru

Abstract In this article a mathematical description of the block diagram of the vibration isolation device with stiffness compensator is given. The vibration isolation system simulation performed with different functional elements, during which operation waveforms obtained with neodymium device compensator of the stiffness. Research & Development is under the scholarship of the President of Russian Federation, order No 184 from 10th of March 2015.

Introduction
To obtain the properties of the vibration isolation devise with neodymium compensator of the stiffness expediently investigate its mathematical model on theory stage. The equation of the movement of the mass, which is connected with basis of the vibration isolation device with compensator of the stiffness (without adjusting system), has been obtained from mathematical model of the device. In [1, 2, 3] the equation of the vibration isolation device with compensator of the stiffness (linear and nonlinear) has been obtained also. High requirements for precision and reliability of the operation of the mechanical transport system are fundamental issue of the development. The stability of the device and separated parts operation is impacted by dynamic loads during of the exploitations. The sources of these disturbances can be electromechanical devices [4, 5]: drives, actuating devices (fans, propellers) and etc.

In case of the using of the vibration isolation devices of the nonlinear compensators, the investigation must be performed with the nonlinear systems analysis methods.

Calculation and simulations
Differential equation is described the behavior of the mass on elastic suspension, with spring and nonlinear stiffness compensator has a view:

\[ m x'' + c x - F_c(x) + F_{sp} = F(t), \] (1)

where
- \( m \) is mass of the object;
- \( x \) is movement of the object;
- \( c \) is rigidity of the elastic element;
- \( F_c(x) \) is function, which is described the characteristic of the compensator;
- \( k_{cp}(x) \) is coefficient of the control system, depended from movement of the oscillations center of the anchor;

\( F(t) \) is the function, which is described the characteristic of the load.
\( F(t) \) is disturbing force.

With basis of the equilibrium equation (1) we can make cinematic scheme of the device with compensator of the stiffness and control system [6, 7, 9]. The view of the scheme is shown on figure 1.

\[
F(t) \downarrow \\
F_s \uparrow \\
m \uparrow \\
F_c(x) \cdot k(x) \downarrow \\

S \quad \text{SP} \quad \text{C} \quad \text{CS} \quad \text{MS} \quad x
\]

**Figure 1.** Cinematic scheme of the vibration isolation suspension with the stiffness compensator and control system

The equation of the traction characteristic of the supermagnet compensator [10, 13] can be represented as:

\[
F(x) = F_1 + F_2 = \frac{\pi \mu_0}{4} \left( \frac{2B_0}{\mu_0} \right)^2 R^4 \left( \frac{1}{(x)^2} + \frac{1}{(x+2h)^2} - \frac{2}{(x+h)^2} \right) - \frac{\pi \mu_0}{4} \left( \frac{2B_0}{\mu_0} \right)^2 R^4 \left( \frac{1}{(b-x)^2} + \frac{1}{(b-x+2h)^2} - \frac{2}{(b-x+h)^2} \right),
\]

where \( \mu_0 = 4\pi \cdot 10^{-7} \) is permeability, \( H/m \);
\( \delta \) is max distance between magnets, \( m \);
\( B_0 \) is residual magnetic induction of the magnet, \( T \);
\( R \) is radii of the magnet, \( m \);
\( h \) is height of the magnet, \( m \);
\( x \) is shift from the center, \( m \).

For compilation and theoretical investigation of the models of the vibration isolation devices is much convenient to use the method, which is used in theory of the automatic control (representation of systems as structural schemes and its modelling [7, 9]).

When compiling a design scheme in the program Simulink adhere to some rules:
- each unit has only input value and one output value (in system of the automatic control the value usually are named variables);
- all units are single directed, i.e. input variable impacts on output variable, but output variable on input variable does not;
• the units are described by transfers function instead of differential equations. The transfer function is the ratio of the Laplace image of the output signal and input signal with zero initial conditions.

On the figures 2 and 3 the mathematical model of the oscillation system without stiffness compensator and oscillogram of resulting shifts of protected object, consequently, are shown.

![Mathematical model](image1)

**Figure 2.** The mathematical model of the oscillation system with rigid element and without stiffness compensator

![Oscillogram](image2)

**Figure 3.** Oscillogram of the oscillation system operation without stiffness compensator

The simulation has been shown that system has non sustainability oscillations. Inside of the system there are established oscillations of the different frequencies and amplitudes, and max amplitude is achieved 3 sm. These oscillations are an unsatisfactory indicator of the vibration isolation system.

To realize full model of the vibration isolation device the connection of the stiffness compensator is necessary [7, 11]. The view of the vibration isolation suspension model with neodymium compensator of the stiffness is shown on figure 4.
Figure 4. Mathematical model of the vibration isolation device with compensator of the stiffness

This structural scheme allows simulate the behavior of the object under any disturbances $F(t)$, and in the model it is possible to change the stiffness of the basic elastic element $c$ and the compensator $c_k$ and the object mass $m$. However in this model does not take to account the presence of the control system, which is tracking the changes of the static part of the force $F(t)$, i.e., the model allows investigation of the behavior of the system only in stationary regime.

The initial data of the model of the vibration isolation device:
- mass of the object $m = 8$ kg;
- stiffness of the spring $c = 2370$ N/m.

For represented model the input signal is sine wave with parameters:
- amplitude $1.5$ mm;
- frequency $2\pi \cdot 8$ rad/sec;
- another parameters are zero.

As the load the step-signal is used. The load is not connected to vibration isolation system without correcting unit.

The results of the simulation are shown on figure 5.
From results of the simulation we can see that there are conservative oscillations in the system with a sufficiently small amplitude of the order of a thousandth of a millimeter. However, the oscillations presence in the positive displacement region, which indicates that the compensators force acts with a larger value than the elastic force, which caused displacement of the oscillation axis.

To obtain sustainable oscillations of the vibration isolation device and possibility of the correction of its properties [8, 12], we need to include inside the model the control system (figure 6). In this case oscillogram of the resulting shift became a view, is shown of figure 7.
Figure 7. Oscillogram of the vibration isolation device operation with neodymium compensator of the stiffness and control system

The results of the simulation allow us to make the conclusion, that vibration isolation system with neodymium compensator of the stiffness is sustainable with inclusion of the control system.

Results
As result of scientific research, which were led within the framework of development of the vibration isolation devices with the stiffness compensators, a mathematical model is presented, on the basis of which simulation of vibration isolation systems was performed. The basis of the research was software Matlab 6.5 Simulink. The simulation has shown that the system with the stiffness compensator based on neodymium magnets is very effective for decreasing of the vibration oscillation under different load when adjusting system is connected.

Conclusion
The research «Vibration isolation devices with the stiffness compensators based on electromagnets and neodymium magnets» was performed under the scholarship of the President of Russian Federation for young scientists, order No 184 from 10th of March 2015.

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