Description of the traction characteristics of the neodymium compensators of the automatic vibration isolations

E G Gurova, Y V Panchenko and M G Gurov
Novosibirsk State Technical University, 20, K. Marx ave., Novosibirsk, 630073, Russia
E-mail: lena319@mail.ru

Abstract. In this paper the method of calculation of neodymium magnets was presented. The calculation of the neodymium magnets characteristics and stiffness correctors of the vibration isolator according to the requirements for vibration isolation devices with stiffness compensators was performed. This research has been performed with the support of the President scholarship for young scientists, order № 184 of Ministry of education and science of the Russian Federation of the 10th March 2015.

1. Introduction
In [1] the variant of the device design for decreasing a vibration level is shown. The principle of the action of this device is based on the theory of vibration isolation [2]. Such devices include a resilient element and a compensator of stiffness which are connected in parallel. The design of the proposed compensator is performed with the use of neodymium magnets (supermagnets). These magnets are composed of neodymium, iron and boron. Such magnets have big traction forces and small dimensions. The application of such supermagnets inside the vibration isolation devices simplifies their transport applications for decreasing mechanical oscillations.

2. Calculation and simulations
For designing and calculation of the compensator the vibration and resilient parameters of the whole vibration isolation device should to be taken into account. Therefore, let us calculate the traction characteristic of the stiffness compensator based on supermagnets on the assumption of the fact that the magnitude of vibration is not higher than 1 cm. In [3] the equation of the traction characteristic of the neodymium magnet of a cylindrical shape is presented in (1):

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

where \(\mu_0=4\pi \cdot 10^{-7}\) – magnetic constant, H/m;
\(M\) is the residual magnetization of the magnet, A/m;
\(R\) is the radius of the magnet, m;
\(h\) is the height of the magnet, m;
\(x\) is the displacement from the center, m.

Let us assume that there is residual magnetism in the magnet, thus we can find whether force \(F\) becomes very big for \(x\) close to zero:

\[ M = \frac{2B_0}{\mu_0}, \]

where \(B_0\) is a residual magnetic induction of the magnet, T.
In this case the equation of the force dependence on movement of the magnet takes the following view:

$$F(x) = \frac{\pi \mu_0}{4} \left( \frac{2B_0}{\mu_0} \right)^2 R^4 \left( \frac{1}{x^2} + \frac{1}{(x+2h)^2} - \frac{2}{(x+h)^2} \right), \quad (3)$$

For calculation of the traction characteristic of the cylinder-shaped neodymium magnet on the basis of equation (3) let us assume the following input data:

- Type of the magnet: N45;
- Residual magnetic induction, $B_0$: 1320-1380 mT;
- Radius of the magnet, $R$: 2.25 cm;
- Height of the magnet, $h$: 2 cm;
- Range of the travel, $x$: 0 to 10 mm.

The results of the calculation are shown in table 1:

| $x$, mm | 1   | 3   | 5   | 7   | 9   | 10  |
|---------|-----|-----|-----|-----|-----|-----|
| $F(x)$, kN | -267 | -27.4 | -8.86 | -4.02 | -2.16 | -1.65 |

According to these data we can formulate the dependence of the repulsion magnet force on movement. Its view is shown in Figure 1.

![Traction characteristic of the neodymium magnet](image)

**Figure 1.** Traction characteristic of the neodymium magnet

Compensators should have an incident force characteristic according to the operating principle of the vibration isolation devices. For this, in the compensator of stiffness based on neodymium magnets it is necessary to use the pairs of oppositely directed magnets. Such position of magnets allows having the incident force characteristic [4].

Now we can calculate the characteristic of two oppositely directed magnets as shown in Figure 2.
On the basis of equation (3) for description of the force dependence on movement of two magnets, placed oppositely and relatively each other, that is, the compensator of stiffness itself, we can obtain:

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

where \( \delta \) is a maximum distance between two magnets, m;
\( x \) is a relative movement of the center of the iron anchor with thickness of \( 2\Delta x \), m.

\[
x = x_1 - \Delta x.
\]

Considering the fact that the plate should be infinitesimal, value \( \Delta x \) in the formula (5) can be neglected.

On the basis of (4) we can calculate the dependence of the force on movement in the range from 0 to 2 cm:

**Table 2.** Dependence of the force on movement of the neodymium magnet of the stiffness compensator

| \( x \), mm | 1 | 3 | 5 | 7 | 9 |
|-------------|---|---|---|---|---|
| \( F(x) \), N | 2.65E+05 | 2.34E+04 | 0 | -2.34E+04 | -2.65E+05 |
The traction characteristic for two neodymium magnets having a common anchor

The dependence presented in Figure 3 shows that the inclusion of two oppositely directed magnets allows obtaining an incident force characteristic of preset stiffness. The inclusion of the device with a such characteristic corresponds to the operating principles of the vibration isolators.

3. Results and Discussion

However, from (4) we can clearly see that the precise calculation of the characteristic of the compensator is complicated enough and the registration in the control devices by such stiffness compensators is quite difficult either. And it is reasonable to obtain a simplified equation of dependence of the traction characteristic of two oppositely directed neodymium magnets.

For this simplification we should use a polynomial equation of the odd degree:

\[ y(x) = A_1 x + A_3 x^3 + A_5 x^5 + \ldots + A_{2n-1} x^{2n-1} \]  

(6)

where \( A_1, A_3, A_5, \ldots, A_{2n-1} \) are constant coefficients.

For the calculation of the constant coefficients we should make up a set of equations of 2n-1.

\[
\begin{align*}
A_1 x_1 + A_3 x_1^3 + A_5 x_1^5 + \ldots + A_{2n-1} x_1^{2n-1} &= y_1, \\
A_1 x_2 + A_3 x_2^3 + A_5 x_2^5 + \ldots + A_{2n-1} x_2^{2n-1} &= y_2, \\
&\vdots \\
A_1 x_{2n-1} + A_3 x_{2n-1}^3 + A_5 x_{2n-1}^5 + \ldots + A_{2n-1} x_{2n-1}^{2n-1} &= y_{2n-1},
\end{align*}
\]

(7)

Having solved this set of equations let us determine coefficients: \( A_1, A_3, A_5, \ldots, A_{2n-1} \).

The presented equation (6) allows describing the traction characteristic of two oppositely directed magnets with sufficient precision. It allows a significant simplification of the calculation methods of characteristics and their application. The examples of the accurate (4) and precision (6) equations, presented in this paper, take into account a tuning system in order to obtain the operation of the vibration isolator with the neodymium magnet’s corrector of stiffness under different loads.

4. Conclusion

Precision and simplified dependencies for the description of the traction characteristics of stiffness compensators of vibration isolators presented in this paper are a part of SIEDR with the support of the
scholarship of the president of the Russian Federation for young scientists (order №184 of the Ministry of science and education of the RF of the 10th of March, 2015), which is directed at the development of the spatial vibration isolation devices based on the theory of the spatial vibration isolation with a zero stiffness phenomenon.

References
[1] Gurova E G and Gurov M G 2014 Applied Mechanics and Materials 682 118-121
[2] Gurova E G, Gross V Y, Kurbatov V S, Makarov S V, Sergeev A A and Shchurov N I 2013 World Applied Sciences Journal 22 44-48
[3] Vokoun D, Beleggia M, Heller L and Sittner P 2009 Journal of Magnetism and Magnetic Materials 321 3758–3763
[4] Gurova E G 2015 Conf. Series-Materials Science and Engineering 91 012091