

# Estimation of power losses because of viscous friction in vibroisolation devices with electromagnetic stiffness compensators

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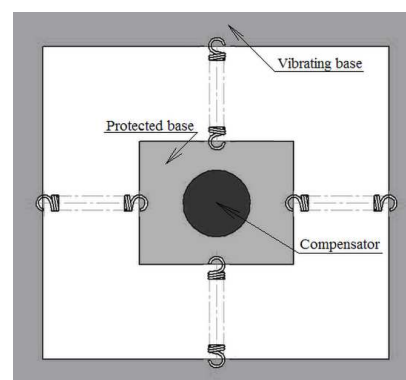
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**Abstract.** In this research the method of the calculation of the power losses in DC electromagnet through eddy currents, which are analog of the viscous friction, is presented. The influence of these currents on the operation of the vibroisolator with the electromagnetic stiffness compensator is estimated. The losses of the power by eddy currents are less than 1 per cent of the electromagnet power itself and the compensator totally. The example of the calculation of the losses for eddy currents in steel conductor is also shown.

## 1. Introduction

Nowadays a sufficiently large number of research teams are developing the antivibration and vibroisolation devices to reduce the vibration levels on vehicles in the production industry. In [1-3, 5], the assembly of the 3D electromagnetic stiffness was designed to install in parallel the resilient elements of the vibroisolation suspensions with the purpose of the correction of its stiffness coefficient. The 3D compensator is two rigidly connected electromagnets of the DC current with separate magnetic conductors relatively each space axis. In figure 1, the design of the vibroisolator with the 3D electromagnetic stiffness compensator is shown.



**Figure 1.** Vibroisolator with 3D electromagnetic compensator of stiffness

The operation of such devices is based on the methods [5, 12, 13], which contain the ideal vibroisolation of the absolutely solid body due to the random space oscillations which will be provided at any moment if the sum of the projections of all applied forces on random coordinate axis and the sum of its moments relatively to this coordinate axis are zero.

The method also implies that all forces, acting in real vibroisolation systems (the nature of their causes can be divided as follows), are the forces transmitted through the protected object vibrating (inertial forces); forces of resilient interaction of the vibrating and protected objects; dissipative interaction forces of the vibrating and protected objects (friction force); inertial forces intermediaries connecting the vibrating and protected objects.

## 2. Materials and methods

The most efficient and compatible with the requirements device of the vibroisolation is one with an electromagnetic compensator of the stiffness, shown in research [2-4, 8]. Such compensator has no interacting parts, and consequently, it is almost deprived of the friction force and parts wearing. There is no intermediate corrector moving mass; therefore, the inertia is excluded. Such compensator has a fast response tuning system, which distributes the voltage on electromagnets with variation of the load. Such property allows one to form the working stiffness compensator characteristics and, consequently, the complete vibroisolation system. It eliminates the resonant mode transients caused by the load variation, provides a zero stiffness and expands the range of the vibration system operation frequencies. It allows one to exclude the resonant regimes during the transition processes specified by the variation of the load, to provide a zero stiffness and to expand the range of the working frequencies of the systems with vibrations. However due to work in the vibroisolation system with electromagnetic stiffness compensators, there is an analog of the viscous friction in eddy currents, arising in the interaction joints between the anchor and the core; the core and the rod are joining the anchor of the stiffness compensator with the protected object. In researches [6, 10, 14, 15] devoted to the development of the vibroisolator with the 1D electromagnetic stiffness compensator, the rough calculation of the eddy currents was made. These eddy currents, in principle, influence the characteristics of the vibroisolators with the stiffness compensator. The action of these currents is analogue to the action of the viscous friction in the oscillatory system.

If this action is sufficient, it is necessary to take into account the influence of these currents with calculations on the dynamic properties of the vibroisolators with the electromagnet stiffness compensator, and consequently on the simulation of such vibroisolators with the correctors.

For the design of the spatial vibroisolators and taking into account the mutual influence of the electromagnets coils on the axis of the space, the more precise estimation and the calculation of the power losses are needed. The estimation of the eddy currents is possible with power losses in the steel conductor of the DC electromagnet. The method of the eddy current estimation is based on [8-10, 13-15] the following assumptions:

1. a magnetic induction remains approximately constant from the surface to specific depth and also decreases sharply to zero after some depth;
2. a density of the eddy flow decreases at the same area according to the linear law and remains zero on the depth, where the magnetic induction disappears;
3. a magnetic permeability is supposed to be constant;
4. a shift of the phases between the currents and magnetic induction after the penetration into the material is ignored.

The losses for the unit of surface square are determined from the formula:

$$P = \frac{4 \cdot H_0^2 \cdot S}{2 \cdot a \cdot \gamma}, \quad (1)$$

where  $H_0$  is a magnetic-field strength;

$S$  is a surface area;

$a$  is a penetration depth;

$\gamma$  is conductivity.

The dependency of the magnetic-field strength on the width of the working gap is calculated by the following formula:

$$H_0 = \frac{IW}{\delta \cdot \mu}, \quad (2)$$

where  $IW$  is an increase of the magnetize force;

$\delta$  is a working gap;

$\mu$  is magnetic conductivity of the steel.

As it was shown in [7-11, 15], the dependency of the magnetized force on the working gap is:

$$IW = \frac{B_0 \cdot \Delta\delta}{\mu_0}, \quad (3)$$

where  $B_0$  is magnetic induction;

$\mu_0$  is vacuum permeability;

$\Delta\delta$  is amplitude.

Accordingly to [10], the depth of the penetration is calculated by the formula:

$$a = 5000 \cdot \sqrt{\frac{\rho \cdot H_{0g}}{f \cdot B_0}}, \quad (4)$$

where  $\rho$  is steel resistivity;

$H_{0g}$  is an active value of the magnetizing force;

$B_0$  is magnetic induction;

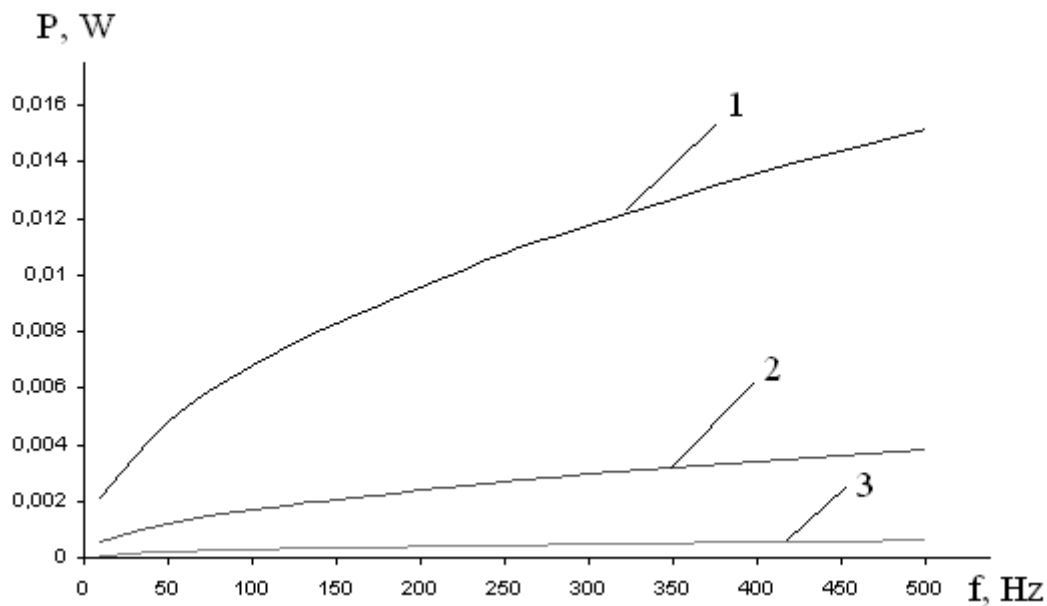
$f$  is a frequency.

The active value of the magnetizing force is calculated by the formula:

$$H_{0g} = \frac{H_0}{\sqrt{2}}. \quad (5)$$

The area is calculated according to the shape of the cross section of the conductor.

As it was mentioned above, the calculation of the losses due to eddy currents for the electromagnets of the constant current with steel round core (traction force 50 N) in the range from 10 to 500 Hz with the help of this method was done. Figure 2 shows the dependency of the power losses by eddy currents on the frequency under different values of the working gap, between the anchor and core of the DC electromagnet. It can be seen that the losses through eddy currents increase with the increasing of the frequency; but with the increase of the working gap, the power losses value in DC electromagnet is significantly reduced.



**Figure 2.** The dependency of the eddy currents power losses on the frequency: 1 – a working gap of 0.1 cm; 2 – a working gap of 0.3 cm; 3 – a working gap of 1,0 cm

The suggested method of the calculation allows one to estimate the value of the lost power of the electromagnet under the operation of the vibroisolator with the electromagnet stiffness compensator both relatively one axis and relatively 3 axes. On the basis of the given method, the estimation of the percentage ratio of the lost power due to operation from calculated power of DC electromagnet itself was obtained:

$$K = \frac{P_{cons.}}{P_{el.}} \cdot 100\%, \quad (6)$$

where  $P_{cons.}$  – losses of the power for eddy currents;  
 $P_{el.}$  – calculated power of the DC electromagnet.

As to the calculations obtained, the losses through eddy currents in the range from 10 to 500 Hz are very small and not higher than 1 percent of the electromagnet power consumption in the range from 10 to 650 W. The results of the calculations are shown in table 1.

**Table 1.** The dependency of the eddy currents power losses on the frequency

Frequency. Hz Gap. cm	10	50	100	150	250	300	350	400	450	500
<b>0.1</b>	0.08490	0.18984	0.26848	0.32882	0.42450	0.46502	0.50228	0.53696	0.56953	0.60034
<b>0.2</b>	0.00531	0.01187	0.01678	0.02055	0.02653	0.02906	0.03139	0.03356	0.03560	0.03752
<b>0.3</b>	0.00105	0.00234	0.00331	0.00406	0.00524	0.00574	0.00620	0.00663	0.00703	0.00741
<b>0.5</b>	0.00014	0.00030	0.00043	0.00053	0.00068	0.00074	0.00080	0.00086	0.00091	0.00096
<b>0.7</b>	0.00003	0.00006	0.00009	0.00010	0.00014	0.00015	0.00016	0.00017	0.00018	0.00019
<b>1</b>	0.00001	0.00002	0.00003	0.00003	0.00004	0.00005	0.00005	0.00005	0.00006	0.00006

### Conclusion

Therefore, the eddy currents, which are analogue of the viscous friction, have no sufficient impact on the dynamic properties of the electromagnetic stiffness compensators, so when designing the vibration isolators with uniaxial and 3-axial stiffness compensators, the latter could be ignored.

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