Results of vibroisolator test with tuning magnet stiffness compensator

E G Gurova, N V Pustovoy, M G Gurov

Novosibirsk State Technical University, 20, Karka Marksa Ave., Novosibirsk, 630073, Russia

E-mail: lena@mail.ru

Abstract. In this paper the results of the research of the vibroisolation device (Patent № 170759 of 05.05.2017), which has been carried out in the laboratories of the FSUE “Sever” and Novosibirsk state technical university, are described. Research & Development was performed under the scholarship of the President of the Russian Federation, order № 231 of April 3, 2018.

1. Introduction
Nowadays the best way to suppress the common ship vibration is the installation of the vibrating object (in particular, ICE) on metallic-rubber isolators. Despite the wide use of this way of the vibroprotection, it can not be considered efficient enough. It can be described by the fact that the suspensions vibroisolation device must meet two contradictory requirements. Firstly, the vibroisolators must have the smallest stiffness coefficient to reduce the transmitted dynamic forces caused by oscillations of the ICE [1, 5, 16]. Secondly, to obtain alignment of the engine with equipment under the changing of the static components of the external forces (e.g., motion or maneuvering), the stiffness coefficients of the isolators must be as large as possible.

2. Calculation and simulations
The inconsistent requirements are reducing the stiffness of the suspension to suppress the vibration levels and necessity to increase its stiffness to reduce the relative movement under the action of the forces static components with the tuning correctors of the stiffness. In such suspensions, the stiffness correctors are connected in parallel to the elastic elements. The elastic elements are devices with the falling power characteristics, i.e. the negative coefficient of the stiffness [1, 2-4, 9-12].

The vibroisolators with the floating segment of the zero stiffness meet such contradictory requirements. The power characteristic of such device (shown in Figure 1) is the infinite set of straight segments parallel to the axis of the displacement $x$ located at their midpoints on the inclined line $ab$. 
Figure 1. The power characteristics of the vibroisolator with the floating segments of the zero stiffness.

The length of these segments equals the magnitude of the oscillation $2A$ of the vibroisolation object. So the tilt coefficient of these segments (i.e. the stiffness coefficient of the vibroisolator) is equal to zero, i.e. the transfer of dynamic forces caused by vibrations of the vibrating object to the protected base, which is theoretically excluded (assuming that the forces of the internal friction and the inertia forces of the intermediate elements are reduced to zero). Under the changing of the static forces acting between the vibrating and protected objects, from $P_{\text{min}}$ to $P_{\text{max}}$, the special tuning system provides the "floating" of the zero stiffness segment according to the characteristic, which provides the vibration isolator with the very definite stiffness for the slowly varying external forces [2, 7, 8, 13-15].

The vibroisolators with the stiffness compensators are connected in parallel to the resilient elements, have these power characteristics. The stiffness compensators are devices with the falling power characteristic, i.e. with the negative stiffness coefficient. The vibroisolator will have zero summary stiffness with equalized rigidities of the element and the compensator that except for transmission of the dynamic forces is caused by oscillations of the vibration elements. As has been noted, the tuning of the compensators to the changing load (floating of the zero stiffness segment) is provided by the special tuning system, which is tracking the mutual displacement of the vibrating and protected objects.

In the period from 2016 to 2017 on FSUE PO "Sever", the experimental model of the vibration isolator with the magnetic stiffness compensator was made and tested (Figure 2). The model was made according with the technical documentation [6, 7] developed by Novosibirsk state technical university (NSTU) within the framework of the research of the creation of the vibration isolating suspension of the marine diesel generator DGA 25-9M.
Figure 2. Vibroisolator with supermagnet compensator of stiffness.

The tests have been performed in the technical testing laboratory provided for:
- the measurement of the vibration acceleration of the protected object at different amplitudes of the displacement of the vibration table when installing the vibroisolator without the stiffness compensator;
- the measurement of the vibration acceleration of the protected object at various amplitudes of the displacement of the vibration table of the installation of the vibroisolator with the supermagnetic compensator of the stiffness;
- the checking of the efficiency of the vibration protection device with the magnetic stiffness compensator.

Measurements of the vibration acceleration were performed in the frequency range from 4 to 128 Hz. In this range the first harmonic of the induced forces of the elements of the ship power installations (main engines and diesel generators) is located. The voltage on the compensator electro magnets was connected either from the direct current source directly to the coils (the vibration isolator without the tuning system), or via the controlled voltage regulator (the vibroisolator with the tuning system).

Measurements of the vibration acceleration were performed with the protected mass of 5 kg for the displacement amplitude of the vibrating table - 0.5 mm and 2 mm. The test results (dependence vibration acceleration - frequency) are shown in Figures 3 and 4.
Figure 3. Characteristics of the vibroisolator with the displacements amplitude of the vibromounting 0.5 mm.

Figure 4. Characteristics of the vibroisolator with the displacements amplitude of the vibromounting 2.0 mm.

The test shows that the vibroprotection device with the tunable magnetic stiffness compensator in the frequency range from 4 to 128 Hz supresses the vibration acceleration levels by (20-55) dB. With the frequencies, where the usual vibroisolator has the resonance, the vibration acceleration is suppressed almost to zero. The test shows that the lower vibration frequency is more effective during the operation of the vibroisolator with the magnetic stiffness compensator.

3. Results
The experimental research of the vibroisolation device (Patent №170759 of 05.05.2017) shows the effectiveness of the suppression of the vibrations in the frequency range from 0.5 to 32 Hz and confirms the using of such devices in engineering, in vehicles to achieve the ideal vibroisolation.

4. Acknowledgments
The research «Vibration isolation devices with the stiffness compensators based on electromagnets
and neodymium magnets» was performed under the scholarship of the President of the Russian Federation for young scientists, order № 231 of April 3, 2018.

References

[1] Alabuzhev P M, Gritchin A A, Stepanov P T, Khon V F 1977 Some results of an investigation of a vibration protection system with stiffness correction Soviet mining science USSR 13 № 3 338-341

[2] Bartel T, Gaisbauer S, Stohr P, Herold S and Melz T 2014 Development of functionally integrated mounts for three- and six-axial vibration isolation of sensitive equipment Proceedings of international conference on noise and vibration engineering (ISMA2014) and international conference on uncertainty in structural dynamics (USD2014) 119-130

[3] Bonisoli E, Vigliani A 2007 Identification techniques applied to a passive elasto-magnetic suspension Mechanical systems and signal processing 21 № 3 1479-1488

[4] Carrella A, Brennan M J and Waters T P 2007 Static analysis of a passive vibration isolator with quasi-zero-stiffness characteristic Journal of sound and vibration 301 № 3-5 678-689

[5] Gurova E G 2015 Improving of the operation efficiency of the vehicle due to using of the neodymium magnets inside the vibration isolation devices Conf. Series-Materials Science and Engineering 91 012091

[6] Gurova E G, Gurov M G and Panchenko Y V 2016 Simulation of the Magnetic Characteristics and Properties of the Neodymium Compensator of the Stiffness IOP Conference Series: Materials Science and Engineering 142 № 1 123667

[7] Gurova E G, Gross V Y, Kurbatov V S, Makarov S V, Sergeev A A and Shchurov N I 2013 Development of spatial vibration protection devices World Applied Sciences Journal 22 44-48

[8] Ishida S, Suzuki K and Shimosaka H Design and experimental analysis of origami-inspired vibration isolations with quasi-zero-stiffness characteristic Proceedings of the asme international design engineering technical conferences and computers and information in engineering conference 5B V05BT07A015

[9] Koyacic I, Brennan M J, Waters T P 2008 A study of a nonlinear vibration isolator with a quasi-zero stiffness characteristic Journal of sound and vibration 315 № 3 700-711

[10] Lin S Y, Xu J and Cao H 2016 Analysis on the ring-type piezoelectric ceramic transformer in radial vibration IEEE Transactions on power electronics 31 № 7 5079-5088

[11] Lee C M, Goverdovskiy V N and Temnikov A I 2007 Design of springs with «negative» stiffness to improve vehicle driver vibration isolation Journal of sound and vibration 302 № 4-5 865-874

[12] Lee J, Ghasemi A H, Okwudire, C E and Scruggs J 2017 A linear feedback control framework for optimally locating passive vibration isolators with known stiffness and damping parameters Journal of vibration and acoustics-transactions of the asme 139 № 1 011006

[13] Prisekin V L, Pustovoi N V and Rastorguev G I 2014 Algorithms for controlling fatigue tests of airplanes Journal of Applied Mechanics and Technical Physics 55 № 1 164-171

[14] Rivin E I 1995 Vibration isolation of precision equipment Precision engineering – journal of the american society for precision engineering 17 № 1 41-56

[15] Subrahmanyan P K, Trumper D L 2000 Synthesis of passive vibration isolation mounts for machine tools - A control systems paradigm Proceedings of the 2000 American control conference 1-6 2886 – 2891

[16] Spiewak S, Karpachevsky T and Zaiss C 2014 High performance isolation and excitation of vibration for enhanced identification of inertial sensors Proceedings of the asme international mechanical engineering congress and exposition 4B V04BT04A061