Vibration Isolating Metamaterial With Arc-Structure

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Abstract: The Paper is devoted to vibration isolating metamaterial. The internal structure is made of a special shape that provide quasi-zero stiffness. Computer modeling was made and parameters providing quasi-zero stiffness have been obtained. Structure with quasi-zero stiffness was analyzed and optimal load was considered. The metamaterial has very promising parameters for vibration isolation.

Keywords: metamaterial, quasi-zero stiffness, vibration, vibration isolation.

1. INTRODUCTION

Due to development of machines, equipment and its components, there is increase of their power with decreasing size is observed. Such a phenomenon leads to the fact that in machines and equipment relatively high dynamic loads are concentrated. Often it causes high vibration. Vibration reduces the reliability and durability of machines and units. It also accelerates wear of equipment and components, which leads to additional costs for planned and emergency repairs. In addition the vibration is transmitted to the surrounding objects, in particular on the foundation. High vibration causes excessive noise, adversely affecting the staff. Excessive vibration can cause accidents, environmental and machine damage. So, it is required to have a number of operational and maintenance personnel and support services. The annual cost of maintenance is increased. Thus, vibration isolation is very actual.

2. VIBRATION REDUCTION MEANS

It is known that the intensity of the vibrations can be reduced by the following ways:

1) reduction of vibration activity, i.e., reduction of mechanical stress levels excited by the source. We assume that the vibration occurs during operation of the equipment, and it is impossible to change it;

2) internal vibration protection, i.e., changes in the structure of the object at which the specified mechanical impacts will cause less intense vibrations of the unit or parts of it. But this method is applicable only on the design stage, it is important to protect equipment against vibration that has been already installed;

3) joining an additional mechanical system that reduces oscillations (dynamic damper). This idea may also be available only on the design stage of new equipment;

4) vibration isolation, i.e. installation between the source of vibrations and other equipment ancillary system, that protects the object from mechanical influences of excited source.
The last way is the most promising in practice. At this moment in mechanical engineering a lot of experience of rubber and spring shock absorbers has been accumulated. However, in the case of linear elastic material (spring, rubber) vibration isolation is not enough good. For quality vibration isolation low natural frequency is required. But according to technology of rubber and spring shock absorbers they requires big dimensions for low natural frequency (as they introduce linear mechanical systems).

High parameters of vibration isolators can be achieved by quasi-zero stiffness effect. Mechanical systems with this effect is also called as "systems with low stiffness" or "systems with high-static-low-dynamic-stiffness" [1, 2]. Generally, a system with quasi-zero stiffness is an elastic system with a flat area on its force characteristic, i.e. an area with stiffness close to zero. Force characteristic of system with quasi-zero stiffness is illustrated on the Fig. 1.

![Fig. 1 Force characteristic of mechanical system with quasi-zero stiffness](image)

**3. ABOUT QUASI-ZERO STIFFNESS EFFECT**

Systems with quasi-zero stiffness are still a relatively new trend in mechanical engineering, so relevant work on their theoretical and practical research is very actual. The systems are very prospective in the vibration isolations in various fields, for example: industrial machines and equipment, workstation hand-held machines, ships, precision equipment, aerospace equipment, etc. System with quasi-zero stiffness has a number of advantages compared with conventional vibration isolators: higher degree of reduction of dynamic forces transmitted due to the low rigidity, stiffness independence from the static load. The disadvantages are the complexity of the design, setting requirements. It should be noted that the creation of simple and efficient designs with quasi-zero stiffness is actual and requires further development of the engineering areas.

Many scientists study systems with quasi-zero stiffness, for example Alabuzhev [1], Carrella [2], the author [3, 4, 5], etc. Different active methods of vibration isolation can also be used to create a system quasi-zero stiffness. It is possible to use pneumatic active elements as reported in [6] and [7] or by means of electromagnetic systems [8]. Installation of the machine rotor on an elastic suspension with quasi-zero stiffness is also promising as it is mentioned in [9].

Many systems with quasi-zero stiffness are characterized by many elements. Various
elements lead to design complexity, increase in size and, high friction. High friction significantly decreases quality of the vibration isolation system. Often practical implementation of systems with quasi-zero stiffness causes problems. Despite this, systems with quasi-zero stiffness have great potential in vibration isolation.

4. Metamaterial for Vibration Isolation

Nowadays 3d-additive technologies give an opportunity to create new types of metamaterial, i.e. material with complex fine internal structure. It allows to make special form of internal structure of material that may provide quasi-zero effect. So, this metamaterial can be used as vibration isolator. Width of the metamaterial can be very small. One layer of material can be less than several millimeters. Moreover, creating metamaterial with different layers allows to get metamaterial with very interesting properties.

In the Paper there is a presentation of metamaterial with quasi-zero stiffness. General view of the internal structure is given on the Fig. 2

![General view of the internal structure of metamaterial with quasi-zero stiffness](image)

Fig. 2 General view of the internal structure of metamaterial with quasi-zero stiffness

There are many ways how we can provide quasi-zero stiffness in the metamaterial. This Paper is devoted to structure with arcs.

Analytical study and computer modeling were made for this metamaterial. The goal was to calculate geometrical parameters that provide quasi-zero stiffness. A sequence of computer modeling was made. For each experiment minimum stiffness was calculated. Length of the arc was taken 1 mm. Width of the arc is also 1 mm. Young's modulus is taken 74 MPa according to 3d-printing plastic of the type "Flex". Height of the arc $h$ and thickness $t$ were variable. The results of calculation is presented on the Fig. 2.
Table 1. Minimum stiffness (N/mm) relative to thickness and height of the arc

| Thickness $t$, mm | Height of the arc $h$, mm |
|------------------|--------------------------|
|                  | 0.1          | 0.2          | 0.3          | 0.5          |
| 0.05             | -8.724       | -23.392      | -24.522      | -22.119      |
| 0.1              | 87.36        | -79.98       | -144.5       | -154.57      |
| 0.2              | 1046.8       | 352.4        | -310.4       | -838.6       |
| 0.3              | 3118.8       | 1049.928     | -924.795     | -2498.5      |

According to interpolation of the results it was considered that quasi-zero is provided with parameters $t=0.15$ mm and $h=0.2$ mm. The modeling results of this arc is presented on the Fig. 3 and 4. On the Fig. 3 mesh is introduced, and on the Fig. 4 mechanical stress is shown.

Fig. 3 Modeling an arc of metamaterial with quasi-zero stiffness

Fig. 4 Stresses in the arc of metamaterial with quasi-zero stiffness

It is important to study force characteristic to be sure that quasi-zero stiffness effect is observed. Restoring force of the structure was calculated, also projections of this force in $x$- and $y$-direction have been obtained (Fig. 5).
As we can see from Fig. 5 graph of force in y-direction has an area with quasi-zero stiffness. Point with minimum stiffness (14 N/mm) correspond to force 121 N. It is very good values for such a small arc. So, this idea of the metamaterial is very promising. As arc has a square of 1 mm$^2$, so maximum optimal load can be up to 121 N/mm$^2$. It should be noted that at this moment no other system with quasi-zero stiffness has such a promising optimal load. Height of one layer without hardening layers is approximately 1 mm.

The basic material for metamaterial can be any elastic material, permitting a large elastic deformation, such as rubber, polyurethanes, other elastic polymeric material, metals and alloys with a high maximum relative deformation.

**5. CONCLUSION**

There is a presentation of metamaterial with quasi-zero stiffness. The internal structure is made of small arcs. Analytical and computer studies were made. Parameters of the arc-structure were calculated that provide quasi-zero effect. It is established that for this metamaterial maximum optimal load can be up to 121 N/mm$^2$ and height one layer without hardening layers is approximately 1 mm. So, such a metamaterial is very promising for vibration isolation.

**REFERENCES**

[1] Alabuzhev, P.A., Gritch, L., Kim, L., Migirenko, G., Chon, V. and Stepanov, P., Vibration Protecting and Measuring Systems with Quasi-Zero Stiffness, Hemisphere Publishing, New York, (1989).

[2] Carrella, A., Passive vibration isolators with high-static-low-dynamic-stiffness, Ph.D. Thesis, University of Southampton, UK, (2008).
[3] Valeev A.R. and Kharisov Sh. Application of Vibration Isolators with a Low Stiffness for the Strongly Vibrating Equipment, Procedia Engineering, Proceedings of the 2nd International Conference on Industrial Engineering (ICIE-2016), 150, (641-646), 2016.

[4] Valeev, A.R., Zotov, A.N., Kharisov, Sh. A. Designing of compact low frequency vibration isolator with quasi-zero stiffness. Journal of low frequency noise, vibration and active control. 34 (4), 459-474, (2015).

[5] Valeev, A.R., Zotov, A.N., Kharisov, Sh. A. Application of Disk Springs for Manufacturing Vibration Isolators with Quasi-Zero Stiffness. Chemical and Petroleum Engineering. 51 (3-4), 194-200, (2015).

[6] Le, T.D. and Ahn, K.K., Fuzzy sliding mode controller of a pneumatic active isolating system using negative stiffness structure, Journal of Mechanical Science and Technology, 26 (12), 3873-3884, (2012).

[7] Sun, X., Xu, J., Jing, X. and Cheng, L., Beneficial performance of a quasi-zero-stiffness vibration isolator with time-delayed active control, International Journal of Mechanical Sciences, 82, 32–40, (2014).

[8] Robertson, W., Wood, R., Cazzolato, B. and Zander, A., Zero-stiffness magnetic springs for active vibration isolation, Proceedings of the 6th International Symposium on Active Noise and Vibration Control, Cairns, Australia, 9-12 July, (2007).

[9] Valeev, A.R., Zotov, A.N. and Tikhonov, A.Yu., Vibration isolating shafts suspension with quasi-zero stiffness, Problems of gathering, treatment and transportation of oil and oil products, 3, 68-77, (2010).

**Personal profile**

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