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Vibration isolating plate with quasi-zero effect*

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Abstract

The Paper is devoted to vibrating isolating plate with quasi-zero stiffness. It based on dome type cells with quasi-zero stiffness, that provide low natural frequency about 1 Hz. The general scheme of the plate is presented. Dimension, efficiency and other parameters of the plate were discussed. The effect of plate's application has been estimated. The plate allows to reduce vibration level. It also allows to reduce size of foundation of machines almost two times.

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Keywords: vibration, vibration isolation, vibration isolating plate, quasi-zero stiffness

1. Introduction

Vibration is very important problem in industry. Equipment with rotating element always produce vibration. Moreover, huge machines produce high level vibration with level 5 mm/s and more. High level of vibration reduces reliability and lifetime of equipment that causes economic losses and even failure. Vibration also frequently emanate from nearby railway lines, roads or adjacent industrial complexes. Without vibration these buildings are defenseless against the structure-borne noise generated in their immediate environments: unwanted and occasionally even unacceptably severe vibrations are the result.

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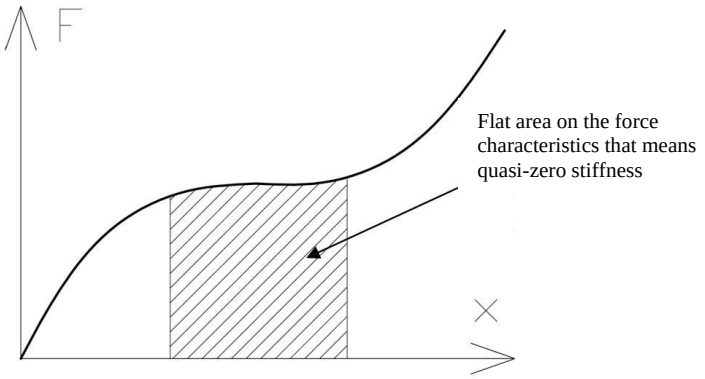
It should be highlighted that vibration can also harmfully influence on human health [1, 2]; and high-level vibration produces noise that also has harmful effect [3]. External factors such as these have an unfailingly adverse effect on the living and working environment inside the building.

For vibration isolation different vibration isolators or vibration isolating plates can be used. Note, that many of this plates presents just monolithic rubber plates and their efficiency is rather low. Many modern companies offer their vibration isolation plates with complex structure, but usually the idea is similar - the plate works like a spring with liner force characteristic. This approach doesn't allow to achieve high vibration isolating parameters.

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" [4, 5]. 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.



F – force (load); x - deformation

Fig. 1: Typical force characteristic of systems with quasi-zero stiffness

Systems with quasi-zero stiffness have great potential in vibration isolation but practical realization of this effect usually causes problems [6]. The few available prototypes are unstable due to large number of elements and that result in exceeding levels of friction in the vibration isolator that ultimately degrades the system performance.

Thus, effective systems with quasi-zero stiffness should be very reliable, easy in application. It was decided to design vibration isolating plate with quasi-zero effect.

2. Structure of vibration isolating plate with quasi-zero effect

Structure of the plate is based on vibration isolators of the dome type. Such a vibration isolator is being researching by the author and represented in the article [7, 8]. This vibration isolator presents one cell on the plate. This cell is shown on the Fig. 2.

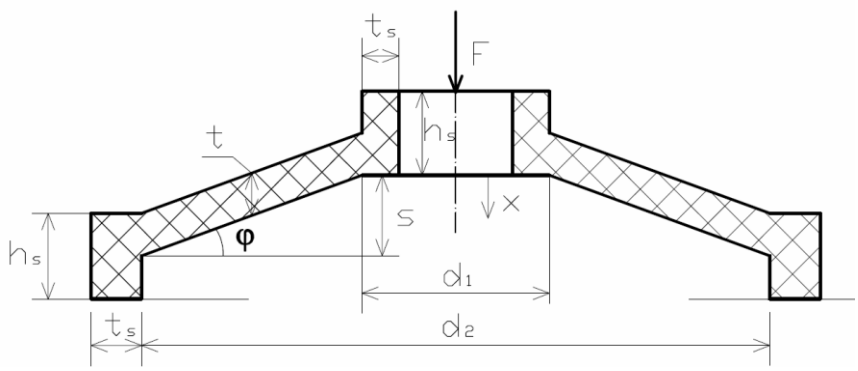


Fig. 2. The scheme of one cell of vibration isolating plate with quasi-zero stiffness

Scheme of the plate is shown on the Fig.3 The plate consists of upper and lower bases 1 and 2. Single isolating cell with quasi-zero stiffness is 3. General model is the isolating plate with quasi-zero stiffness is shown on the Fig. 4.

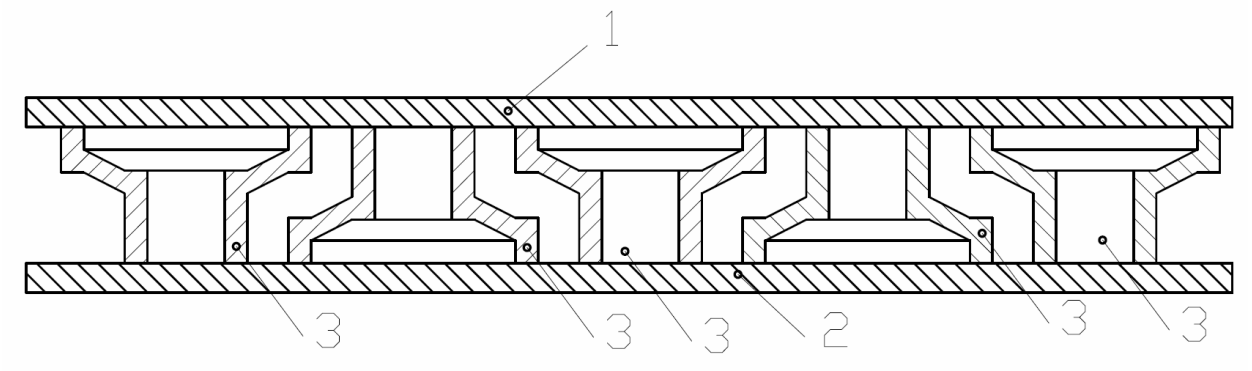


Fig. 3. The scheme of developed vibration isolating plate with quasi-zero

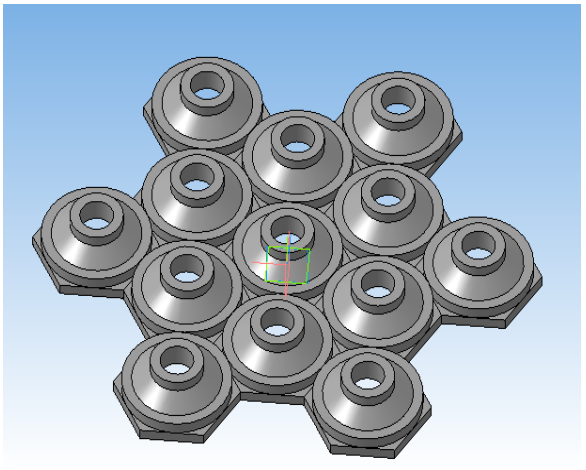


Fig. 4. 3D model of developed vibration isolating plate with quasi-zero

The principle of operating of developed plate is following.

Under load of equipment, plate is compressed and the inclined wall of each single isolating element (Fig. 2) experiences two types of deformation: bending and compression in the radial direction. Deformation by bending of the inclined wall excluding compression deformation has a linear force characteristic. As plate compresses, radial compression of the inclined wall increases. So, the inclined wall tends to return to its initial position, compensating a deformation by bending. This circumstance gives the force characteristics of a given structure non-linearity. At a higher compression radial compression of the inclined wall is at its maximum. Dimensions of elements are selected so that the quasi-zero stiffness observed in this position. A load at this position is noted as the nominal.

The material of developed vibration isolator 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, as well as other materials having a small Young's modulus (up to about 100 MPa).

3. Application of vibration isolating plate with quasi-zero effect

Material for manufacturing vibration isolating plate should have a sufficiently high relative deformation limit to reach a deformation level where the effect of quasi-zero stiffness is achievable. Different elastomers, rubbers and polyurethanes can be used.

For technical rubbers MBS (oil and petrol resistant rubbers), AMS (atmosphere oil resistant rubber) may be utilized [9] parameters single isolating cell were calculated. The results are combined in Table 1. Natural frequency of the system is approximately 0.5-1 Hz. It allows very efficiently reduces high level vibration.

According to Fig. 4 an isolating cell takes place on an hexagon with length one diameter of the cell. So, a nominal pressure on the plate can be calculated. The results are presented in Table 2.

Table 1. Dimensions of isolating cells

	MBS rubber (soft)	AMS rubber (soft)	MBS rubber (tough)
Ultimate relative deformation (Considering the safety margin)	0,1 (10%)	0,14 (14%)	0,07 (7%)
Young's Modulus, MPa	6	9	30
Work load, kg	outer radius, mm		
1	6,0	1,7	1,9
1,6	7,6	2,1	2,4
2,5	9,5	2,7	3,0
4	12,0	3,4	3,8
6,2	14,9	4,2	4,7
10	19,0	5,3	5,9
16	24,0	6,7	7,5
25	30,0	8,4	9,4
40	37,9	10,6	11,9
62	47,2	13,2	14,8
100	59,9	16,8	18,8
160	75,8	21,2	23,8
250	94,8	26,5	29,7
400	119,9	33,5	37,6
620	149,3	41,7	46,8
1000	189,6	53,0	59,4

Table 2. Optimum pressure on the plate

	MBS rubber (soft)	AMS rubber (soft)	MBS rubber (tough)
Ultimate relative deformation (Considering the safety margin)	0,1 (10%)	0,14 (14%)	0,07 (7%)
Young's Modulus, MPa	6	9	30
Optimum load, kg/m^2	$35.4 \cdot 10^3$	$45.4 \cdot 10^3$	$36.1 \cdot 10^3$
Optimum pressure, Pa	$348 \cdot 10^3$	$449 \cdot 10^3$	$354 \cdot 10^3$

So, load on the maximum value of optimal pressure on the plate can be rather big. I.e. load bearing capacity of the vibration isolating plate is not less than for traditional isolating plate.

Moreover, natural frequency of the plate can be up to 0.5-1 Hz as it was shown in the Paper [8]. It allows very efficiently reduces high level vibration.

4. Benefits of vibration isolating plate with quasi-zero effect

The vibrating isolating plate with quasi-zero stiffness allows to avoid damage of equipment or building. The plate can be designed so that none of natural frequencies of the foundation coincide with any exciting oscillation of the equipment. Machine installed on the plate oscillates, but vibration is almost not transmitted to the building. Low natural frequency (about 1 Hz) allow to have low internal stress in a machine that provides high reliability and durability. [11]

Application of the vibration isolating plate helps to reduce weight of foundation due to decrease of dynamic load (and hence total load) acting on the foundation. For example, lets consider an oil pumping units, consisting of pump NM 10000-210 and electric drive STDP-6300-2B with total weight 34850 kg. According to [12] and [13] the minimum amount of concrete under the pump unit equals V=60.9 m^3.

Application of vibrating isolating plate with quasi-zero stiffness decreases the dynamic load on the foundation and hence minimum amount of concrete under the machine can be reduced. The minimum volume of foundation can be reduced by about 60%.

5. Conclusion

The idea of vibration isolating plate with quasi-zero stiffness is presented. The plate is based on cells similar to vibration isolators with quasi-zero stiffness with quasi-zero stiffness earlier developed by the author. The cells has shown high efficiency. So, it is expected that the plate will be very effective to. The plate has high load bearing capacity - approximately 30 tons per m^2.

The plate doesn't requires difficult manufacturing technology. So mass production of the vibration isolator can be established at almost any plant of rubber products. The use of vibration isolating plate with quasi-zero stiffness allows to reduce depth of foundation, its mass, construction duration, overall costs and also reduce negative effect on human.

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