Comparison of mechanical characteristics of vibration isolators made of wire pressed materials

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Abstract: All-metal vibration isolators are widely used in vibration isolation systems due to its high strength, long service life, considerable energy dissipation coefficient. The elastic-damping elements of these vibration isolators are made of pressed wire materials, such as MR (Russia) and Spring Cushion (Germany). The comparison of the load carrying capacity, energy and life-time, the dimensional, mass and amplitude-frequency characteristics of vibration isolators made from these two materials. It is established that the isolator made of MR material compared with the isolator made of Spring Cushion material with similar life-time has a greater load-bearing capacity (it is 3-4 times greater) and damping properties (it is 1.5-2 times greater). The vibration isolators made of MR material of VVM-70 and DKU-90 types compared with the vibration isolator made of Spring Cushion material produced by STOP-CHOC company provide lower (1.5-2 times lower, respectively) transfer and frequency ratios within the resonant mode of vibration, which leads to higher vibration isolation properties of vibration isolators produced of MR material.

Key words: MR material, Spring Cushion, vibration isolator, elastic-damping characteristics, energy dissipation coefficient, amplitude-frequency characteristics, life-time.

1. INTRODUCTION

The protection against vibration and shock, the increase of power plants, on-board equipment, and other products capacity used in the conditions of intense dynamic loads in a wide temperature range is provided in many cases by the use of all-metal vibration isolators. These vibration isolators have high strength, long life, high coefficient of energy dissipation. They are able to operate in harsh environments and in vacuum. Their elastic-damping elements (EDE) are made of pressed wire materials: in Russia and in China they are made of nonwoven MR (metal rubber) material [1 - 5], in Europe they are made of woven fabric Spring Cushion [6 - 10]. These damping materials may be also used in combination with a hydrodynamic damper [11]. Currently, however, there are no studies comparing elastic-damping, dynamic, and other characteristics of vibration isolators made of different wire materials, allowing the assessment of their performance and competitiveness within the same operating conditions.

2. RESEARCHED VIBRATION ISOLATORS

MR material is a porous structure obtained by cold pressing of coiled wire into the final parts according to its shape and size [1]. The stainless metal wire is applied as the original material for MR manufacture. The technological processes of MR material production [1] are based on wire coiling into a spiral (turn to turn tightly), the spiral dosing and stretching to the step equal to the helix diameter, shaping the spiral into a preliminary half-finished tape, folding it into a roll-workpiece, which is placed in a press-form and undergoes the compaction according to the finished product form. This technology is the most common one to manufacture EDE types such as cylinders, bushings, blocks, washers, membranes and so on. To increase the static strength and the damping capacity of vibration isolators of DKU type (see Fig. 1) their EDE is reinforced with special wire harness formed into a reinforcing element (RE) [1]. Spring Cushion material has an ordered structure by applying a woven wire tape sock in a certain way, unlike the coiled wire used to manufacture MR material. The schematic diagram of EDE production of a sleeve or cone type from Spring Cushion material is similar to the mentioned above for UDE made of MR.

The elastic-damping elements (EDE) of pressed wire used for vibration isolators, have a bell shape (DKU-90-150/7 vibration isolator, Russia, Fig. 1) or sleeves, cylindrical (VVM-70 isolator, Russia, Fig. 2) or conical (STOP-CHOC V118D-GS isolator, Germany, Fig. 3). An unload spring may be applied.

The following EDE were applied for material comparison: sleeve EDE made of MR and Spring Cushion material, produced of the same wire with the diameter of 0.2 mm, with the same external diameter of 39 mm and the internal diameter of 15 mm, with the height of 20 mm and the same weight of 48 grams, with the same relative density $\overline{\rho} = 0.3$ ($\overline{\rho} = \rho_{MR} / \rho_S$, where ρ_{MR} - wire material density, ρ_S - steel density), the same preliminary static deformation of 1.5 mm.

The isolators with the same nominal (mass) load of 700 N were chosen in accordance with the data of the catalog [12] and the work [1] for the study of static, dynamic, overall and mass characteristics of the vibration isolators made of different materials: DKU-90-150/7 (Russia) (see Fig. 1) VVM-70 (Russia) (see Fig. 2) made on the basis of MR material and STOP-CHOC V118D-GS (Germany) made of Spring Cushion material (Fig. 3), (hereinafter referred to as DKU-90, VVM-70 and DBM-STOP-CHOC respectively). Table 1 shows the mass and dimensional characteristics of compared isolators.

Table 1. Mass and dimensional characteristics of vibration isolators

Vibration isolator type	Weight, kg	Length, mm	Width, mm	Height, mm
DKU-90-150/7	1.6	102	102	112
STOP-CHOC V118D-GS	2.4	130	130	98
VVM-70	0.4	64	64	51

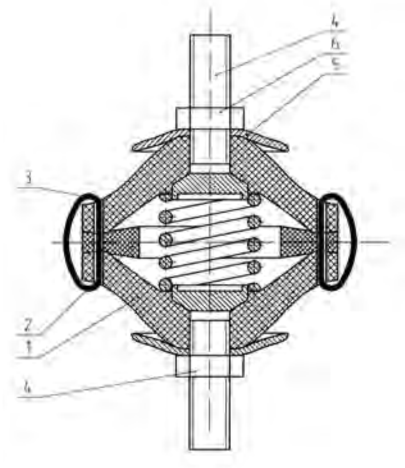


Fig. 1. Vibration isolator DKU-90. 1- EDE;

2 - spacer; 3 - stitched wire;
4- fastening bolts; 5 – fixation washer; 6- nut

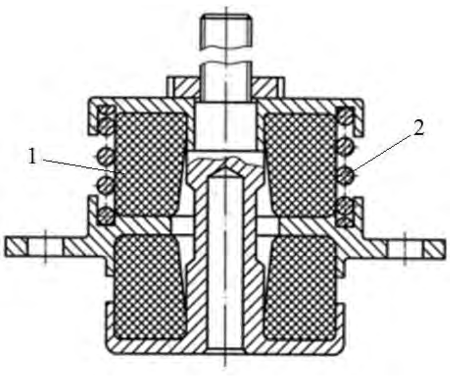


Fig. 2. Vibration isolator BBM-70. 1- EDE,

2 – unload spring

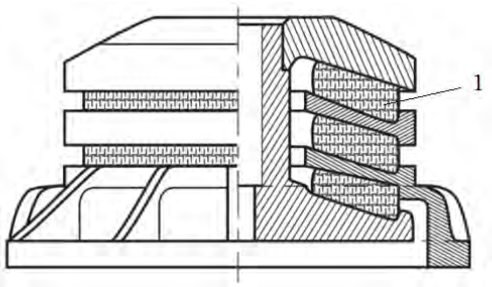


Fig. 3. Vibration isolator STOP-CHOC. 1- EDE

MR material consists of compacted wire coils, rather than just wire as Spring Cushion. Due to the additional elasticity of helices it should be expected that the load carrying capacity of MR material will be greater.

3. STATIC CHARACTERISTICS RESEARCH

The static characteristics representing the elastic-damping characteristics of vibration isolators, were determined according to the GALDABINI Quasar 25 device as a group of hysteresis loops within the coordinates of "load F - displacement x" relative to the center of static balance and the loads changing the span Fm (Fig. 4 a, b, c, d). During the static tests the samples were stabilized initially by a 5-6 fold compressive loading of 2100 N, and then were completely unloaded. Then the center of the static equilibrium was measured by gradually reducing the F load from the maximum value of 2100 N to the value of F_p = 700 N, corresponding to the static equilibrium center. At that the span load F_m of the sample deformation during each cycle i made:

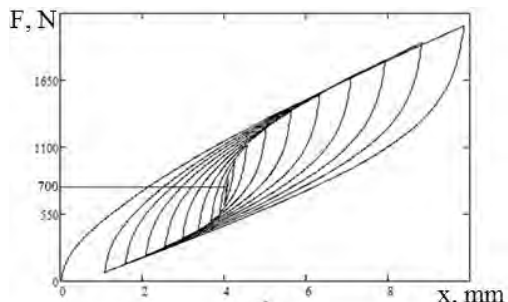
$$F_m = F_{\max,i} - F_{\min,i}\,, \qquad (1)$$

where $F_{max,i}$ and $F_{min,i}$ - is the maximum and the minimum load on sample respectively:

$$F_{\max,i} = 2100 - 0.2 \cdot F_p \cdot i\,;\ [\mathrm{N}]\,; \qquad F_{\min,i} = 700 + 0.1 \cdot F_p \cdot i\,;\ [\mathrm{N}]\,.$$

According to the obtained hysteresis loops the damping ability of vibration isolators was determined as the energy dissipation dependences of ψ from cyclically varying loads F_m. In this case, the value equal to 8 from the ratio of value of hysteresis loop ΔW to the curvilinear triangle area below the median line of the hysteresis loop W (Fig. 6d).

$$\psi = 8\Delta\mathrm{W} / (\mathrm{W})\,. \qquad (2)$$



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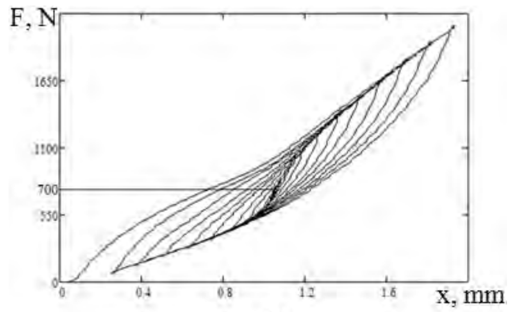

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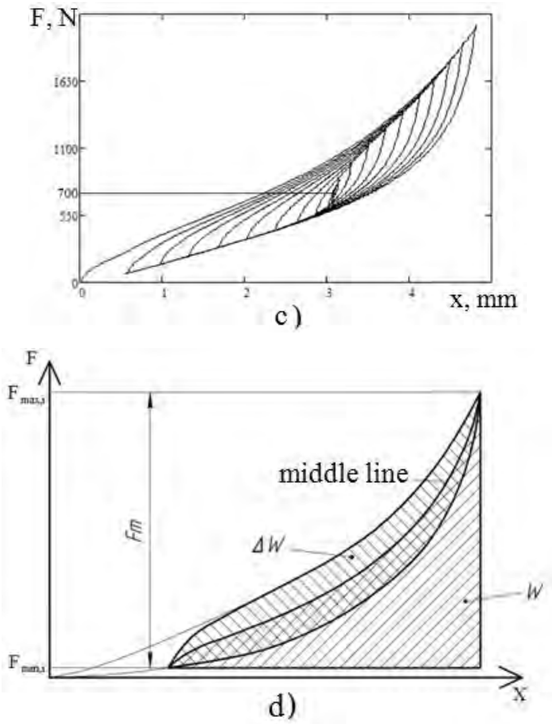


Fig. 4. Deformation processes for vibration isolators: a - DKU-90; b - STOP-CHOC; c - VVM-70; d - for ψ determination.

ψ values for different F_m, values determined according to the formulae (1) and (2) respectively, are presented by Fig. 5.

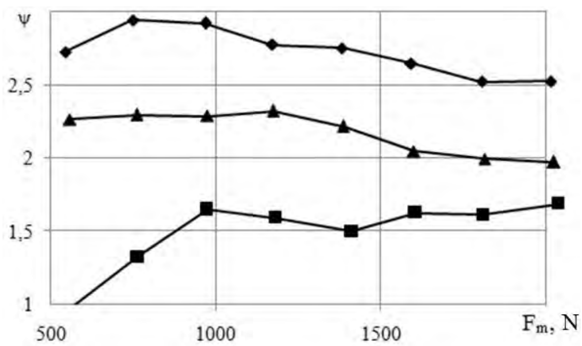


Fig. 5. Energy dissipation coefficient ψ dependence on load span. DKU-90; STOP-CHOC; BBM-70

Fig. 5 shows that DKU-90 has the highest energy dissipation coefficient, surpassing the same coefficient for the STOP-CHOC vibration isolator almost twice, and for 70 DBM - one and a half times.

Pressed wire materials are essentially anisotropic ones [13, 14]. The static characteristics of sleeves made of MR and Spring Cushion materials in the pressing direction (axis X) (Fig. 6) and perpendicular to the pressing direction (along the sleeve radius, axis Y) (Fig. 7) were identified. It is interesting that the performance ratio in these directions is similar for both materials. Thus, the ratio of the hysteresis loop half-width (characterizing the dissipative properties) in the direction of X and Y axes makes $80N/100N = 0.8$ for MR material and $40N/50N = 0.8$ for Spring Cushion. The static stiffness ratio calculated according to the midline of the hysteresis loop in the direction of X and Y axes makes $(410N/mm)/(215N/mm) = 1.91$ for MR material and $(203N/mm)/(102N/mm) = 1.99$ for Spring Cushion.

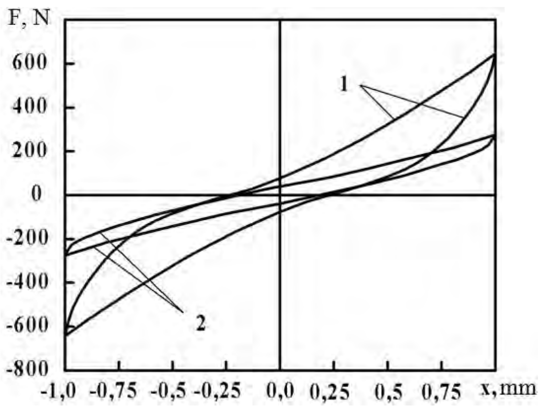


Fig.6. Static characteristics of sleeves in axial direction. 1 – MR material, 2 – Spring Cushion

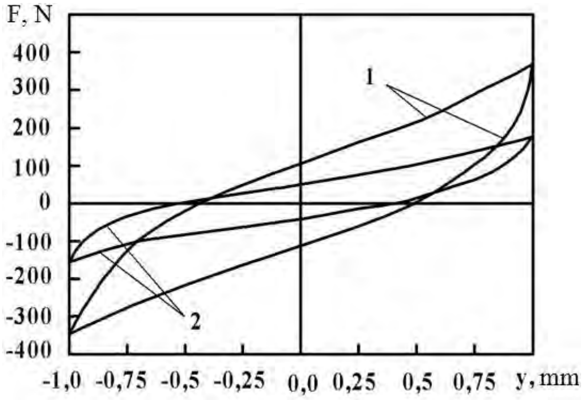


Fig. 7. Static characteristics of sleeves in radial direction. 1 – MR material, 2 – Spring Cushion

As the technologies of material production are significantly different, in this case we may talk about the relationships inherent in any damping wire materials. However, as expected, the MR material stiffness is significantly higher.

4. STUDY OF DYNAMIC CHARACTERISTICS

The vibration stand VEDS-1500 was used for vibration tests. The results for the same bushings made of MR and Spring Cushion materials are shown in Table 2. As the elastic-damping elements have nonlinear characteristics depending on the amplitude, the comparative experiments were carried out at different values of the input vibration acceleration W_v. The resonance frequency f_p and the amplitude of the vibration isolator deformation *A* were determined. The energy dissipation coefficient ψ value was checked according to the transfer ratio μ_p at resonance. $\psi \approx 2\pi / \mu_p$ was accepted.

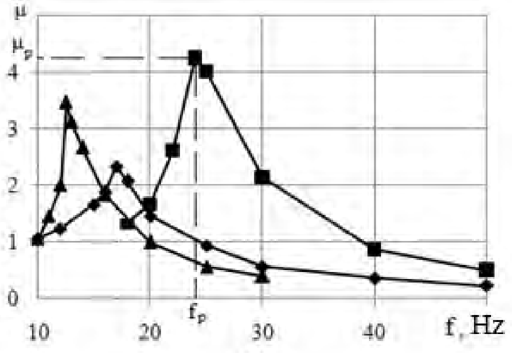
It is obvious that the MR material has a significantly higher load capacity. A similar resonance frequency (about 60 Hz) is obtained when the vibration isolator made of MR has a load of 15 kg, and the vibration isolator made of Spring Cushion has the load of only 3.6 kg, i.e. 4 times less. The dynamic experiment confirms that the material has a higher MR energy dissipation coefficient (at the amplitude of 0.4 mm $\psi = 2.24$ compared to $\psi = 1.74$ at Spring Cushion). Moreover, at the increase of strain amplitude ψ value of MP material is increased and the Spring Cushion value is reduced.

Because of the random spiral stacking the MR material structure is more uniform, which leads to less change of the vibration isolator properties at the external impact change. When the amplitude of the operational acceleration is increased twice the resonant frequency of the vibration isolator made of MR is changed by 6...20%, whereas the vibration isolator made of Spring Cushion is changed by 20...30% (see. Table 2).

Table 2. Dynamic characteristics of bushings

Material	Load, kg	Load direction	W_v, m/s^2	f_p, Hz	ψ	A, mm
MR	5	Axial	10	50	1.34	0.053
			20	24	1.70	0.122
		Radial	10	101	1.57	0.10
			20	95	2.02	0.17
	15	Axial	10	60	1.69	0.26
			20	57	2.24	0.43
Spring Cushion	5	Axial	10	48	1.74	0.4
			20	40	1.34	1.4
		Radial	10	36	1.74	0.70
			20	28	1.85	2.2
	3.6	Axial	10	67	1.74	0.20
			20	53	1.57	0.73

The tests of vibration isolators were carried out with the same mass of 70 kg per vibration isolator. The amplitude-frequency characteristics (AFC) of vibration isolators were determined according to the kinematic method of oscillation harmonic excitation (see Fig. 8) as the transfer ratio $\mu = A/A_0$ dependence on the excitation frequency f, where A_0 is the exciting vibration amplitude, measured on vibration stand table; A - amplitude of load mass vibration displacement. Also the area was determined where the transfer ratio μ became less than 1.



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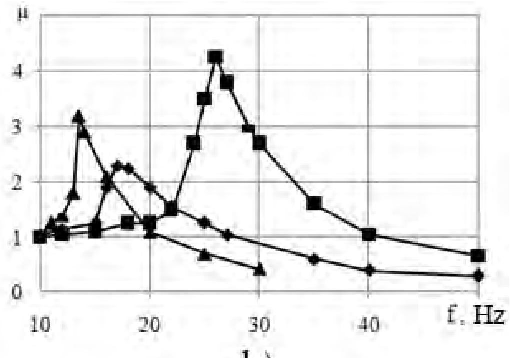

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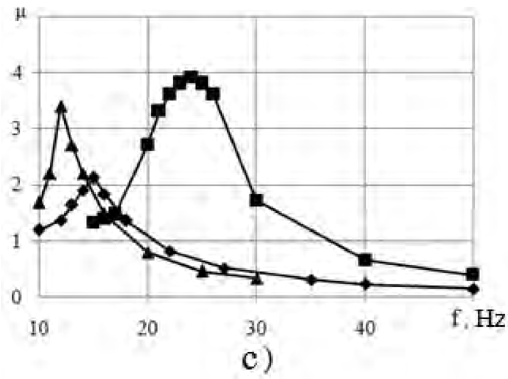

Fig. 8. AFC of vibration isolators for different amplitudes of the kinematic harmonic excitation: a - A_0=0.2 mm; b - A_0=0.3 mm; c - A_0=0.5 mm; DKU-90; STOP-CHOC; VVM-70

According to the AFC dependencies showed by Fig.8 the STOP-CHOC isolator has the worst transfer ratio μ_p (see fig. 8a) at resonance (about 4) compared with the Russian counterparts (2.5 for DKU-90; 3.5 for VVM-70). Besides, the area of vibration isolation for STOP-CHOC vibration isolator starts at around 40 Hz and higher, while the area of vibration isolation for DKU-90 and VVM 70 starts at 20 ... 30 Hz, depending on the excitation amplitude. The latter is determined mainly by higher resonance frequencies f_p for German STOP-CHOC (23...28 Hz), compared with Russian ones: 12…18 Hz for VVM-70 and DKU-90 respectively (see fig. 8 a, b, c).

5. LIFE-TIME CHARACTERISTICS STUDY

The static and dynamic properties of MR and Spring Cushion bushings under similar parameters of wire materials are too different to compare the resources. The elastic-damping elements made of MR material equivalent to the elements of Spring Cushion were produced according to the carrying capacity (the resonant frequency of the vibration isolator made 39 Hz at the object weight protected from vibration of 5.8 kg and the amplitude of the input vibration acceleration of 20 m/s^2). To ensure such parameters the MR material had a relative density of $\overline{\rho} = 0.22$ and the weight of elastic-damping elements and weight of only 35 grams compared to 48 grams of Spring Cushion. The energy dissipation coefficient ψ of the equivalent vibration isolator made of MR makes 2.3 at the amplitude of the input vibration acceleration of 20 m/s^2 and 1.8 for the amplitude of the input vibration acceleration of 10 m/s^2. For the vibration isolator made of Spring Cushion these values make 1.3 and 1.8 respectively.

The life-time experiment was carried for sleeve-type vibration isolators made of MR and Spring Cushion at the frequency of 35 Hz at the vibration deformation amplitude of 2.5 mm and at the weight load of 5.8 kg. After *N* cycles of loading the resonant frequency f_p and ψ values were controlled at the vibration acceleration amplitude of 20 and 10 m/s^2 (as the wire damping materials are non-linear ones the variation of the resonance frequency at different amplitudes could be different). The value ψ was calculated according to the transfer ratio at the resonance frequency μ_p using the approximate linear equation $\psi \approx 2\pi / \mu_p$. The parametric fault served as the criterion of resource exhaustion - the deviation of at least one of the parameters f_p or ψ by more than 20% of the initial value. The experiment results are shown by table 3.

It is evident that the vibration isolator life-time made of MR and Spring Cushion materials are approximately equal. Both vibration isolators at the input acceleration of 20 m/s^2 have the resonance frequency and the deviation of more than 20% from the initial value occurred at 189000 cycles of loading. However, the vibration isolator made of Spring Cushion has the deviation value ψ of more than 20% from the original one occurred even at 147000 cycles of operation, while at the vibration isolator of MR material within the whole service life has the corresponding changes by 11% maximum. The Spring Cushion isolator has a resonant frequency change at greater (more than 1.5 mm) strain amplitudes during all operation time by 4% only, ψ value was increased by 15%. However, at small strain amplitudes (0.4 ... 0.8 mm) the reduction of the resonance frequency made 27%, and the ψ value was decreased by 31%. Probably the wear of wires made of MR and Spring Cushion materials occurs in different ways. This issue is related to the structure of Spring Cushion regularity and requires further study.

The service life of the vibration isolators made of MR (DKU type), ceteris paribus, has a ten-fold resource compared with sleeve-types due to reinforcement [1].

Table 3. Sleeve-type vibration isolator life-time

Material	W_v, m/s^2	N	0	21000	42000	63000	105000	147000	189000
Spring Cushion	20	f_p, Hz	38.5	37	37	37	37.5	37	37
	10	f_p, Hz	46	47	43	40	39	37	36
	20	ψ	1.33	1.43	1.43	1.45	1.45	1.48	1.52
	10	ψ	1.80	1.59	1.50	1.50	1.43	1.39	1.36
MR	20	f_p, Hz	39	38	38	37	35	34	32
	10	f_p, Hz	47	45	44	43	41	39	36
	20	ψ	1.30	1.26	1.30	1.32	1.30	1.30	1.26
	10	ψ	1.80	1.80	1.83	1.87	1.90	1.93	2.00

6. CONCLUSIONS

According to the studies of vibration isolators made of wire pressed materials MR and Spring Cushion performed in this paper one may draw the following conclusions. The manufacturing technology of MR material includes more manual labor than the manufacturing technology of Spring Cushion. However, non-woven MR material (Russia), as compared with the Spring Cushion material (Germany) has a higher load-bearing capacity (3-4 times higher) and higher damping properties (1.5 - 2 higher) with a similar service life. The vibration isolators made of MR material like VVM-70 and DKU-90 compared with STOP-CHOC vibration isolators provide lower (1.5-2 times, respectively) gain and frequency ratios of the resonant vibration modes, which lead to higher MR vibration isolator protective properties. This means that MR material has an absolute advantage over Spring Cushion at high requirements for dimensions, weight and vibration isolation properties of vibration isolation systems, although it is desirable to increase the automation level of its production.

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