

## Mechanical Characteristics of Vibration Isolators Made of Various Wire Materials

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**Abstract:** The comparison was performed concerning the load carrying capacity, the energy dissipation coefficient, life-time, dimensional, mass and amplitude-frequency characteristics of vibration isolators made of pressed wire materials MR (Russia) and Spring Cushion (Germany). The vibration isolators made of MR material have a higher load-bearing capacity (3-4 times) and damping properties (1.5-2 times) at original resource, provide lower (1.5-2 times, respectively) gain and frequency ratios within the resonant oscillation modes.

**Key words:** MR material, spring cushion, vibration isolator, elastic-damping characteristics, amplitude frequency characteristics

### INTRODUCTION

All-metal vibration isolators have a high strength, long life-time, high energy dissipation coefficient, 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 China they are made of nonwoven MR (Metal Rubber) (Lazutkin, 2010; Zhu *et al.*, 2011) in Europe they are made of woven Spring Cushion material (Gildas, 1989; Kozian and Schmoll, 1998). These damping materials may also be used in combination with a hydrodynamic damper (Jiang *et al.*, 2005). Currently, however, there are no studies compared to the characteristics of vibration insulators made of different wire materials, allowing estimating the effectiveness of their application.

### STUDIED MATERIALS AND VIBRATION ISOLATORS

MR material is made by cold pressing of coiled wires into the final shape parts (Lazutkin, 2010). The technological processes of MR material production (Lazutkin, 2010) are based on wire coiling into a spiral, the spiral dosing and stretching to the step equal to the spiral diameter, the spiral shaping into preliminary taped workpiece, its folding into a rolled workpiece which is placed in a mold and subjected to pressing according to the finished product form. In order to increase the static strength and the damping capacity of vibration isolators

of DKU type (Fig. 1a) their EDE is reinforced with special wire harness (Lazutkin, 2010). The spring cushion material has an ordered structure due to the application of a wire woven ribbon, unlike the wire spirals used to manufacture MR material. The schematic diagram of the EDE production of a sleeve or a cone type of spring cushion material is identical to that considered above for EDE made of MR.

For the comparison of materials the sleeve EDE were used made of MR and Spring Cushion materials, 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, the same height of 20 mm, the same weight of 48 g and the same pre-static deformation of 1.5 mm. In order to study the static, dynamic and overall mass characteristics of the vibration insulators made of different materials the vibration insulators with the same nominal (mass) load of 700 N were chosen in accordance with the catalog data (STOP-CHOC) and (Lazutkin, 2010): DKU-90-150/7 (Russia) (Fig. 1a), BBM-70 (Russia) (Fig. 1b) made on the basis of MR material and STOP-CHOC V118D-GS (Germany) made of Spring Cushion material (Fig. 1c). Table 1 demonstrates its mass and dimensional characteristics.

Table 1: Mass and dimensional characteristics of vibration isolators

Vibration isolator type	Mass (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
BBM-70	0.4	64	64	51

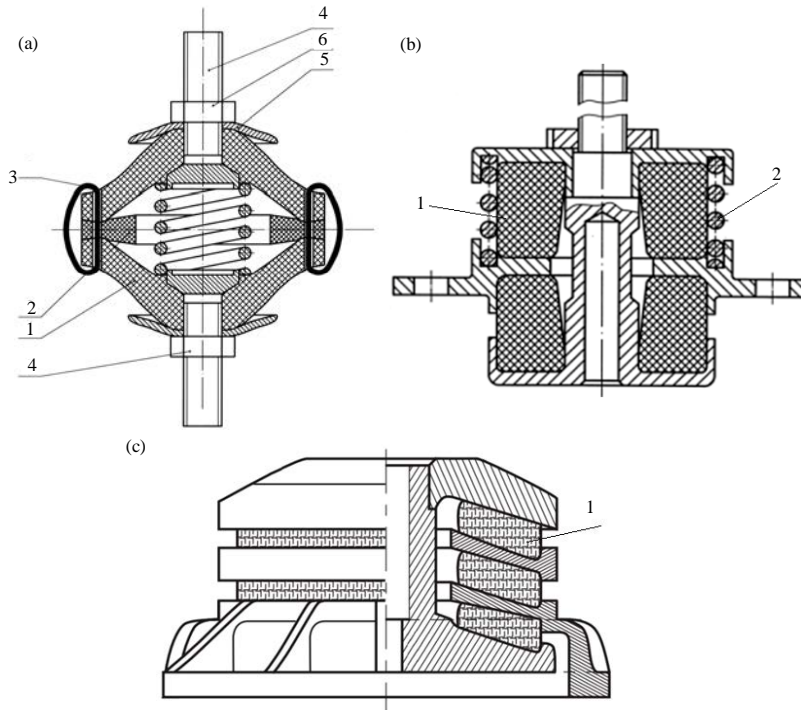


Fig. 1: Vibration isolators made of wire molded materials; a) DKU-90: 1 = EDE; 2 = spacer; 3 = stitched wire; 4 = mounting studs; 5 = limiting washer; 6 = nut; b) BBM-70: 1 = EDE; 2 = unload spring; c) STOP-CHOC: 1 = EDE

### STATIC CHARACTERISTIC EXPLORATION

The static characteristics were defined as a group of hysteresis loops in terms of “F load-displacement x” to the center of static balance and changing spans of  $F_m$  loads. During the static tests the samples were stabilized initially by 5-6 times of compressive loading of 2100 N and then were completely unloaded. Then the center of the static equilibrium was obtained by the gradual reduction of F load from the maximum value of 2100 N to the value of  $F_p = 700$  N to the static equilibrium center. At that each  $i$  deformation cycle of the span sample along  $F_m$  load made:

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

Where:

$F_{max,i}$  = The maximum load on the sample

$F_{min,i}$  = The minimum load on the sample, respectively:

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

According to the obtained hysteresis loops the damping ability of vibration isolators was determined as the dependences of the energy dissipation coefficient  $\psi$  on the load spans  $F_m$ . At that the value equal to 0.125 from

the ratio of the hysteresis loop area  $\Delta W$  was taken as  $\psi$  value to the area of the curvilinear triangle below the median line of the hysteresis loop  $W$  (Fig. 2a).

$$\psi = \frac{\Delta W}{(8W)} \quad (2)$$

The  $\psi$  values for different  $F_m$  values obtained according to Eq. 1 and 2 are presented on Fig. 2b. The largest energy dissipation coefficient has DKU-90 isolator, surpassing the same coefficient for the vibration isolator STOP-CHOC almost two times and one and a half times for BBM-70.

The wire pressed materials are anisotropic ones (Ao *et al.*, 2005). The static characteristics of the MR sleeves and Spring Cushion sleeves in the pressing direction (along the sleeve axis, axis X) (Fig. 3a) and in the perpendicular direction (along the sleeve radius, axis Y) (Fig. 3b) were obtained. It is interesting that the performance ratio in these areas is similar for both materials. The ratio of the hysteresis loop half-width (describing the dissipative properties) in the direction of X and Y axis makes  $80 \text{ N}/100 \text{ N} = 0.8$  for MR and  $40 \text{ N}/50 \text{ N} = 0.8$  for Spring Cushion. The static stiffness ratio calculated by the midline of the hysteresis loop in the direction of axes X and Y axis makes  $(410 \text{ N/mm})/$

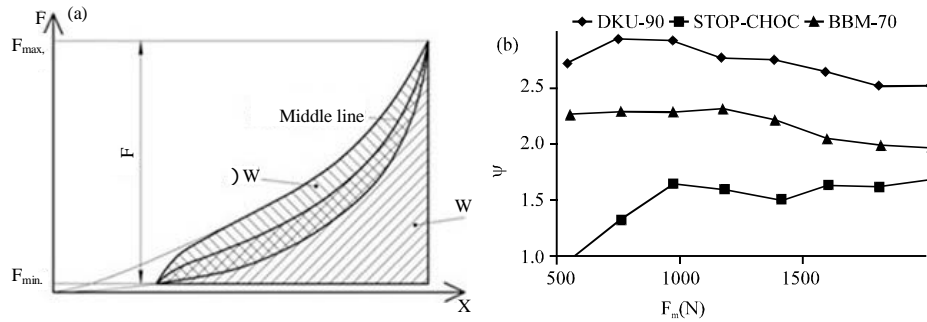


Fig. 2: Energy dissipation coefficient. a) determination; b) dependence on load spans

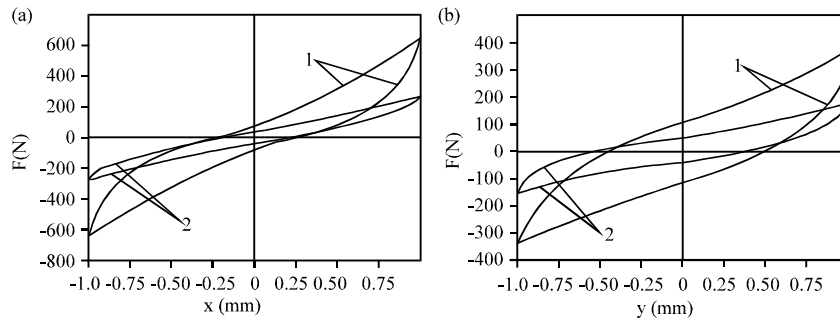


Fig. 3: Static characteristics of sleeves 1: MR material, 2: Spring Cushion; a) axial direction and b) radial direction

(215 N/mm) = 1.91 for RM and (203 N/mm)/(102 N/mm) for Spring Cushion. As the material production technologies differ in this case, we may talk about the relationships inherent to any wire damping materials. However, the MR material stiffness is substantially higher.

### DYNAMIC CHARACTERISTICS EXPLORATION

Since, EDE have nonlinear characteristics depending on the amplitude, the experiments were performed at different values of the input vibration acceleration  $W_v$ . The resonant frequency  $f_p$  and the vibration isolator deformation amplitude  $A$  was determined (Table 2). The value of the energy dissipation coefficient  $\psi$  was obtained by the energy transfer on resonance  $\mu_p$ . The following dependency was taken:  $\psi \approx 2\pi/\mu_p$ .

With the additional elasticity of its wire spirals, MR material has a higher load carrying capacity. A similar resonance frequency (about 60 Hz) is obtained when the MR vibration isolator has a load of 15 kg and the Spring Cushion vibration isolator load is only 3.6 kg. The dynamic experiment confirms that the MR material has a higher ratio of energy dissipation (at the amplitude of 0.4 mm  $\psi = 2.24$  compared to  $\psi = 1.74$  for Spring Cushion). At that when the deformation amplitude increase,  $\psi$  value of MR material increases and the similar value of Spring Cushion material decreases.

Table 2: Dynamic characteristics of sleeves

Material	Load (kg)	Direction	$W_v$ (m/sec <sup>2</sup> )	$f_p$ (Hz)	$\psi$	A (mm)
MR	5	Axial	10	50	1.34	0.053
			20	24	1.70	0.122
		Radial	10	101	1.57	0.100
			20	95	2.02	0.170
Spring Cushion	5	Axial	10	60	1.69	0.260
			20	57	2.24	0.430
		Radial	10	48	1.74	0.400
			20	40	1.34	1.400
	3.6	Axial	10	28	1.74	0.700
			20	67	1.85	2.200
			10	67	1.74	0.200
			20	53	1.57	0.730

Because of the spiral random placing the MR material structure is more uniform which leads to the less change of the vibration isolator properties when at the external load change. When  $W_v$  doubles, the resonant frequency of the MR vibration isolator changes for 6-20% while the similar change of Spring Cushion vibration isolator is 20- 30% (Table 2).

The tests of vibration isolators were carried out with the same mass value of 70 kg per isolator. At the kinematic method of oscillation harmonic excitation the amplitude-frequency characteristics of vibration isolators were determined (Fig. 4) as the dependence of transfer ratio  $\mu = A/A_0$  on the excitation frequency  $f$  where  $A_0$  is the amplitude of the exciting vibration displacement;  $A$  is the amplitude of load mass vibration displacement.

Table 3: Vibration isolator characteristics change during the operation process

Material	$W_v$ (m/sec <sup>2</sup> )	N	0	21000	63000	105000	147000	189000
Spring Cushion	20	$f_p$ (Hz)	38.50	37.00	37.00	37.50	37.00	37.00
	10	$f_p$ (Hz)	46.00	47.00	40.00	39.00	37.00	36.00
	20	$\psi$	1.33	1.43	1.45	1.45	1.48	1.52
	10	$\psi$	1.80	1.59	1.50	1.43	1.39	1.36
MR	20	$f_p$ (Hz)	39.00	38.00	37.00	37.00	34.00	32.00
	10	$f_p$ (Hz)	47.00	45.00	43.00	41.00	39.00	36.00
	20	$\psi$	1.30	1.26	1.32	1.30	1.30	1.26
	10	$\psi$	1.80	1.80	1.87	1.90	1.93	2.00

STOP-CHOC vibration isolator has the worst transfer ratio  $\mu_p$  on the resonance (about 4) compared to the Russian ones (2.5 for DKU-90; 3.5 for BBM-70). The area of vibration isolation for the vibration isolator STOP-CHOC begins at around 40 Hz and higher while for DKU-90 and BBM-70 it starts from 20-30 Hz, depending on the excitation amplitude. The reason for this is the higher resonance frequencies  $f_p$  of the German STOP-CHOC (23-28 Hz) compared to the Russian ones, 12-18 Hz for BBM-70 and DKU-90.

### LIFE-TIME CHARACTERISTICS EXPLORATION

Since, the static and dynamic properties of MR and Spring Cushion sleeves under similar parameters of wire materials were too different for the life-time comparison experiment the EDE of MR material were made equivalent to EDE Spring Cushion by the carrying capacity (the resonant frequency of 39 Hz at the mass of 5.8 kg for the object to be protected from vibration and the amplitude of  $W_v = 20$  m/sec<sup>2</sup>). To ensure such parameters MR material had the EDE weight of only 35 g against 48 g of Spring Cushion. The value  $\psi$  at the equivalent MR vibration isolator is 2.3 for the amplitude of  $W_v = 10$  M/c<sup>2</sup>, the Spring Cushion isolator has these values of 1.3 and 1.8, respectively.

The life-time experiment was carried out for sleeve-type MR and Spring Cushion vibration isolators at the frequency of 35 Hz at  $A = 2.5$  mm and the mass load of 5.8 kg. After N cycles of load the resonance frequency  $f_p$  and the value  $\psi$  was controlled at the amplitude  $W_v$  equal to 20 and 10 m/c<sup>2</sup> (as wire damping materials are non-linear, the variation of the resonance frequency could be different at different amplitudes). The value  $\psi$  was calculated according to the transfer ratio at the resonant frequency  $\mu_p$  by the approximate linear equation  $\psi = \approx \pi/\mu_p$ . The parametric fault served as the criterion of life-time exhaustion the deviation of at least one of the parameters  $f_p$  or  $\psi$  makes >20% of the initial value. The experiment results are shown in Table 3.

It is evident that the life-time of vibration isolators made of MR and Spring Cushion material is approximately equal. Both vibration isolators at  $W_v = 20$  M/c<sup>2</sup> have the

deviation  $f_p$  of >20% of the initial value which took place at 189000 load cycles. However, the Spring Cushion vibration isolator has the deviation value  $\psi$  of >20% from the baseline one. It took place already at 147000 cycles while the vibration isolator made of MR material has the maximum change of 11% throughout the whole resource. For the Spring Cushion vibration isolator at higher A (>1.5 mm) the value of  $f_p$  decreased by only 4% during the whole operation time,  $\psi$  value increased by 15%. However, at the values of  $A = 0.4-0.8$  mm  $f_p$  decreasing is 27% and  $\psi$  value decreased by 31%. Probably, the wear of wires in MR and Spring Cushion material happens in different ways. This issue is related to the Spring Cushion structure regularity and requires further study. The life-time of MR vibration isolators (DKU type) is ten times higher than sleeve-type isolators due to the reinforcement (Lazutkin, 2010).

### CONCLUSION

The manufacturing technology of MR material includes more manual labor than the Spring Cushion manufacturing technology. However, the non-woven MR material (Russia) as compared with the Spring Cushion material (Germany) has a higher load-bearing capacity (3-4 times) and damping properties (1.5-2 times) at similar life-time. The vibration isolators made of MR material (BBM-70 and DKU-90 types) compared with the vibration isolators of STOP-CHOC company provide lower (1.5-2 times, respectively) transfer ratio at the resonant modes of vibration which lead to higher vibration isolator properties of MR material. This means that at high requirements for dimensional, weight and vibration isolation characteristics of vibration isolation systems MR material has an advantage over Spring Cushion, although it is desirable to increase the automation share during its production.

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